

Max Planck,

**Kiel and recent progress in the dynamics
of correlated quantum many-body systems**

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2. Max Planck and Kiel

3. Planck and the discovery of elementary quanta

4. Quantum mechanics:

from the Big Bang to ultracold atoms

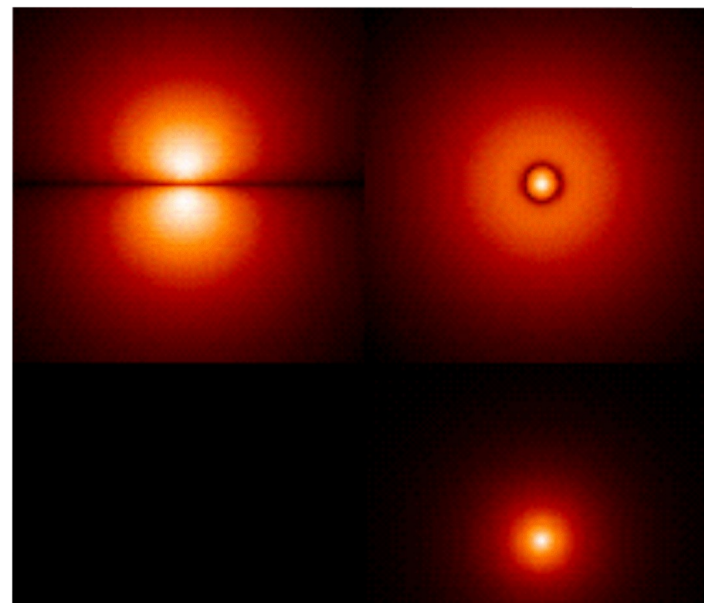
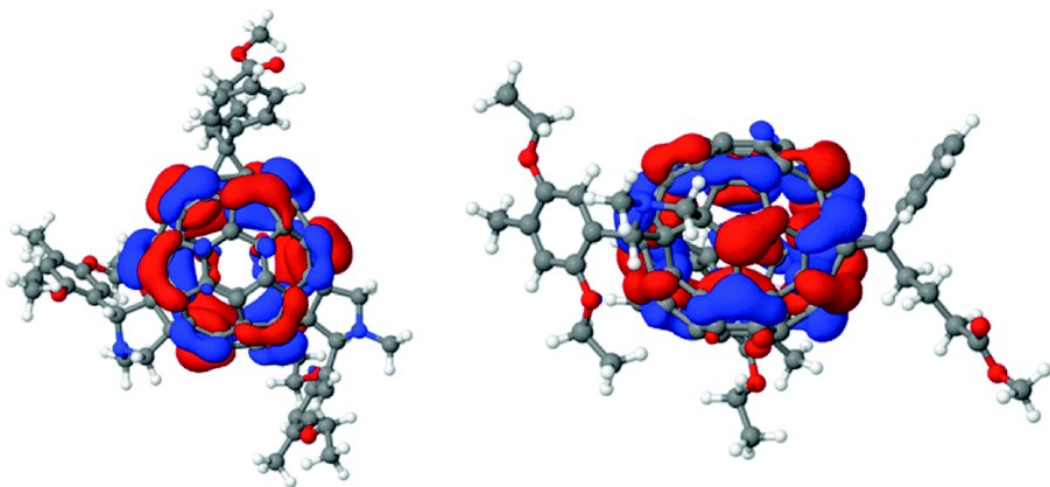
1. Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

The basis for modern (quantum) chemistry, material science

Atoms and molecules

Lowest hydrogen orbitals
(analytical results)



DFT result for 3 LUMO frontier orbitals for the most probable PPCBMB adducts, phenyl-C61-butyric acid methyl ester,

Stephen et al., Chemical Communications 2016

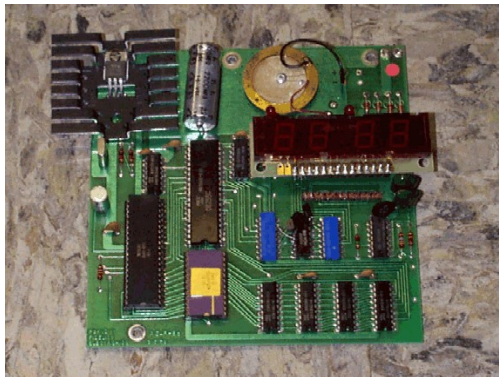
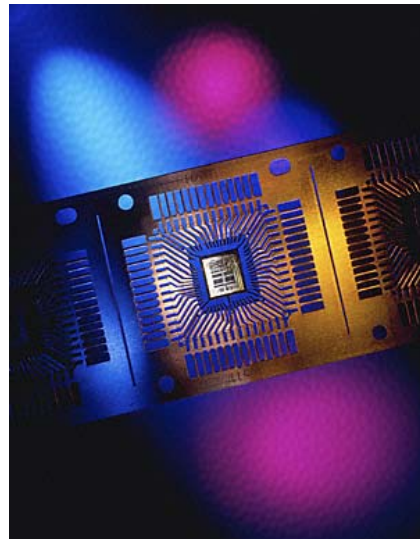
Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

The basis for modern (quantum) chemistry, material science

The basis for electronic conduction: from nanotechnology to electrical engineering

Nanotechnology



Quantum physics today

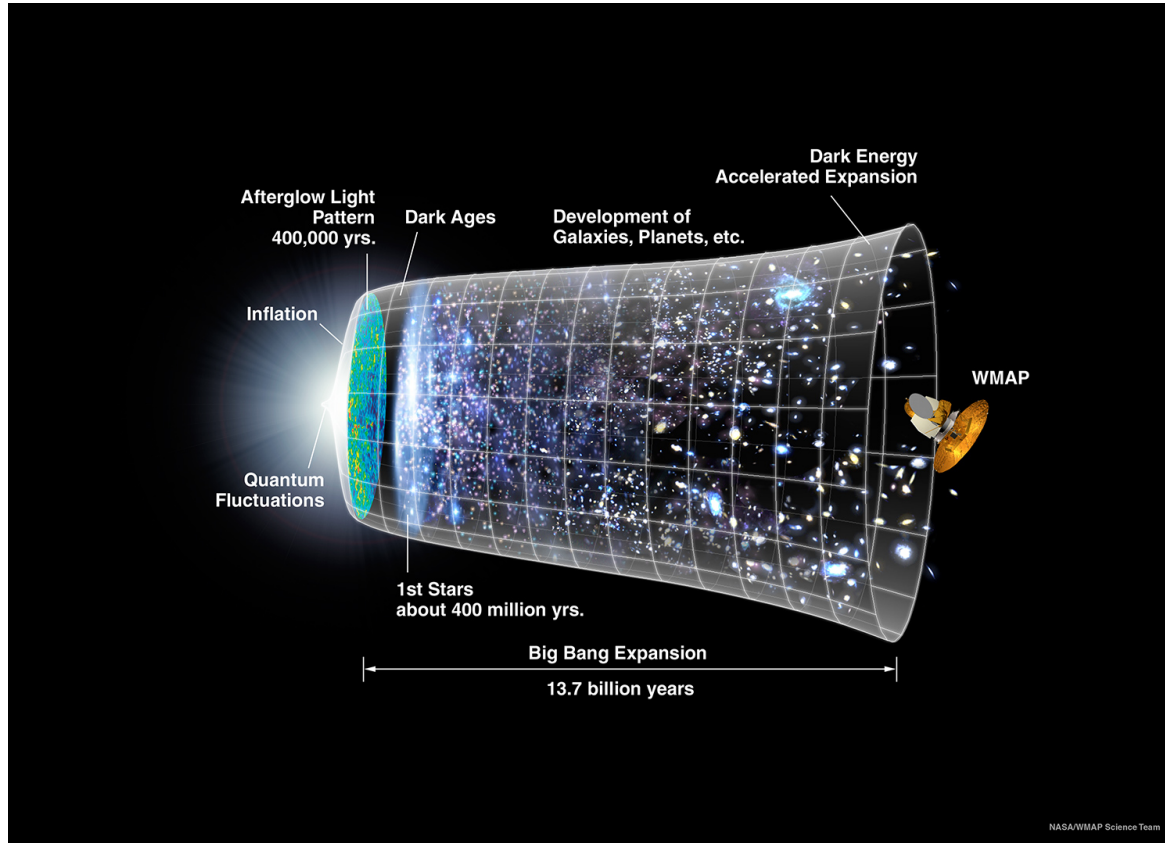
The basis for the description of atoms, molecules, nuclei, elementary particles...

The basis for modern (quantum) chemistry, material science

The basis for electronic conduction: from nanotechnology to electrical engineering

The basis for understanding the Universe and its history

Evolution of the universe



Quantum Theory provides strong evidence for the Big Bang theory

Quantum physics today

The basis for the description of atoms, molecules, nuclei, elementary particles...

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The basis for understanding the Universe and its history

It all started December 14 1900, with Max Planck's discovery

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2. Max Planck.

Childhood in Kiel, 1858-1867

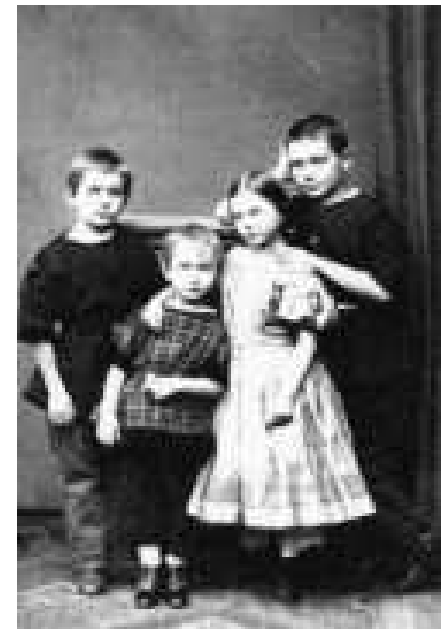
Born in Kiel, 23. April 1858

Father Julius Wilhelm Planck (1817-1900), law professor in Kiel
Mother Emma Planck, (born Patzig)

Uncle Gottlieb Planck (1824-1907), lawyer
Grandfather Gottlieb Jakob Planck (1751-1833), theologist



Parents



Max with brothers
and sister, 1862

Max Planck's family moves to Munich

German/Austrian-Danish War Februar-October 1864

for the duchies Holstein, Saxe-Lauenburg,
and Schleswig

Reason: passing of the November
Constitution, which integrated the Duchy of
Schleswig into the Danish kingdom in
violation of the London Protocol

1867: Planck's father under protest
against Prussia leaves Kiel

Planck retains ties to his hometown

Map: Maximilian Dörrbecker (Chumwa)



Max Planck studies physics

School in Munich: 1867-1874

Studies: 1874-1879, Munich and Berlin

Helmholtz, Kirchhoff, Weierstraß

Self-education: Clausius

PhD thesis 1879: on 2nd law of thermodynamics

Privatdozent: 1879-1885, Munich

Continue in Physics?



Planck, 1874

Continue in Physics?



Advice from Prof. Jolly, in Munich, 1877

*„Theoretical Physics is close to completion,
... similar as geometry is long complete.“*

*„in some „corners“ there might be a few tiny „dust grains“
left to explore and categorize, but the system as a whole
is well founded.“*

*„I do not desire to discover new ground, but only
to understand the existing fundamentals of the physical science
and, possibly, to deepen them“*

Planck, Naturwiss. **13**, 52-59 (1925)

Finally: a position in Kiel

1885: call to Kiel University as extra-ordinarius for Theoretical Physics,
Planck: „relief“

1886 Max Planck founds a family
marries his girlfriend from childhood,
Marie Merck

the couple has 4 children:

- 1888: son Karl (–1916)
- 1889: twins Emma (–1919), Grete (–1917),
- 1893: son Erwin (–1945)



Professor in Kiel

Important papers in Kiel: on thermodynamics

- *"Über das Prinzip der Vermehrung der Entropie" (3 Arb.)*
- *"Über die molekulare Konstitution verdünnter Lösungen"*
- *"Das chemische Gleichgewicht in verdünnten Lösungen"*
- *"Über die Hypothese der Dissoziation der Salze in sehr verdünnten Lösungen"*
- *"Über die Dampfspannung verdünnter Lösungen flüchtiger Stoffe"*
- *"Zur Theorie der Thermoelektrizität in metallischen Leitern"*

1887: wins 2nd prize in Göttingen theory challenge
(supported Helmholtz' ideas against W. Weber)

1889: offer to Berlin University (successor of Kirchhoff)

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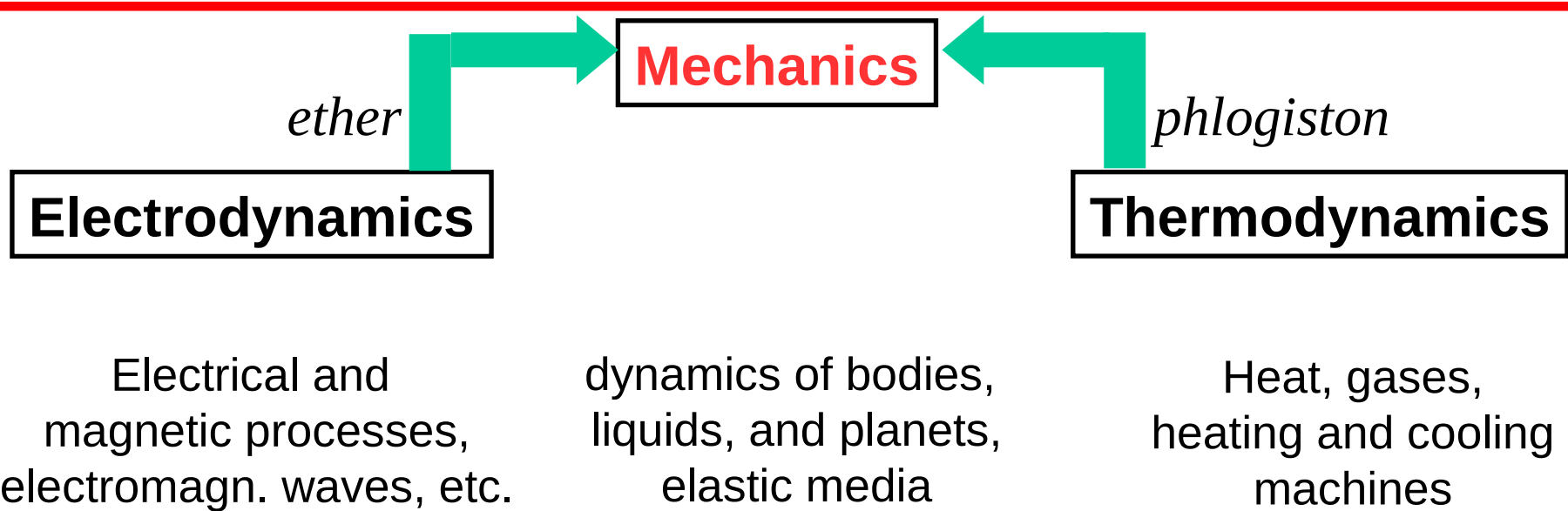
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Theoretical physics around 1875



Theoretical physics around 1875

EM wave
velocity in
moving systems



Spectrum of
black-body
radiation

ether

Mechanics

phlogiston

Electrodynamics

Thermodynamics

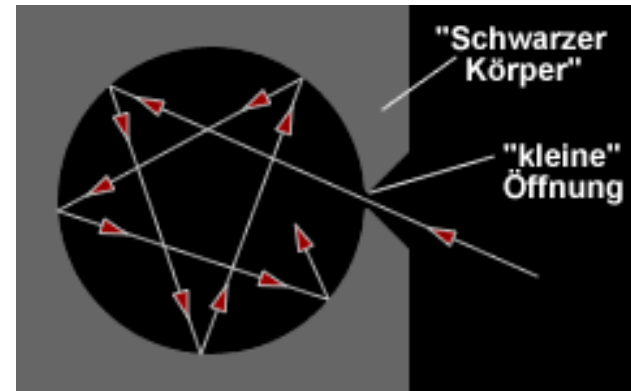
Electrical and
magnetic processes,
electromagn. waves, etc.

dynamics of bodies,
liquids, and planets,
elastic media

Heat, gases,
heating and cooling
machines

Max Planck and black-body radiation

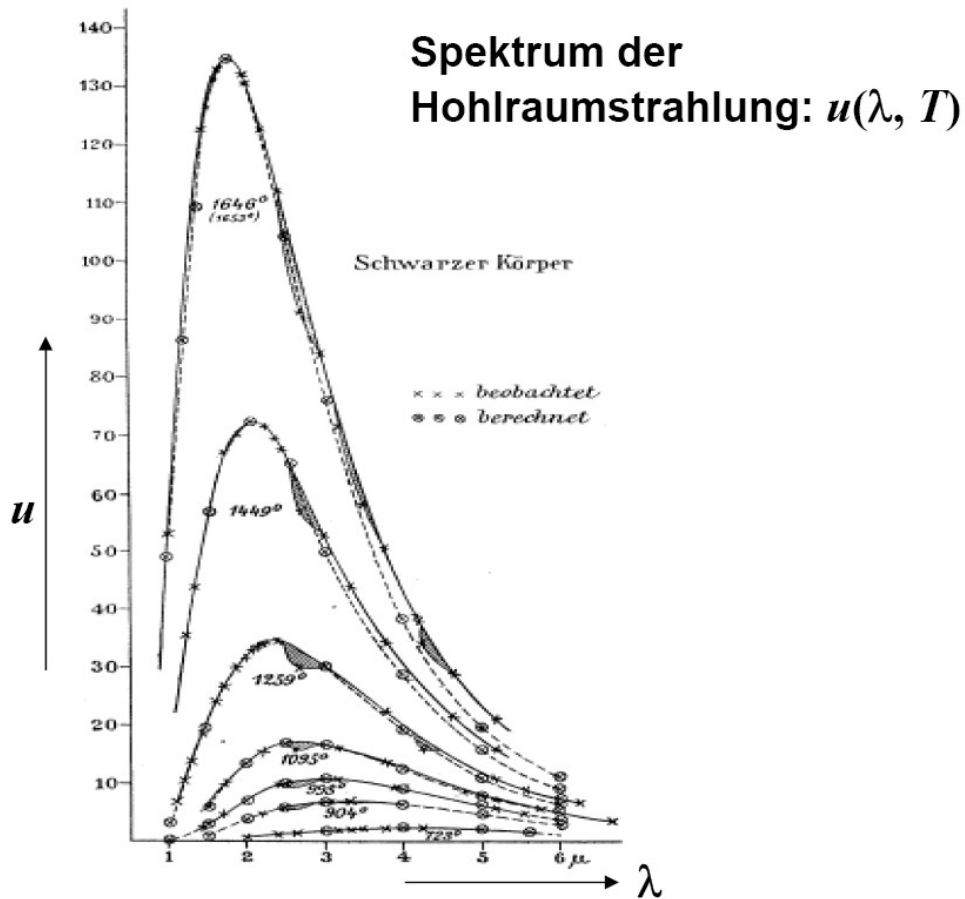
1860: Gustav Kirchhoff formulates model of „black body“:
EM waves in resonator in TD equilibrium



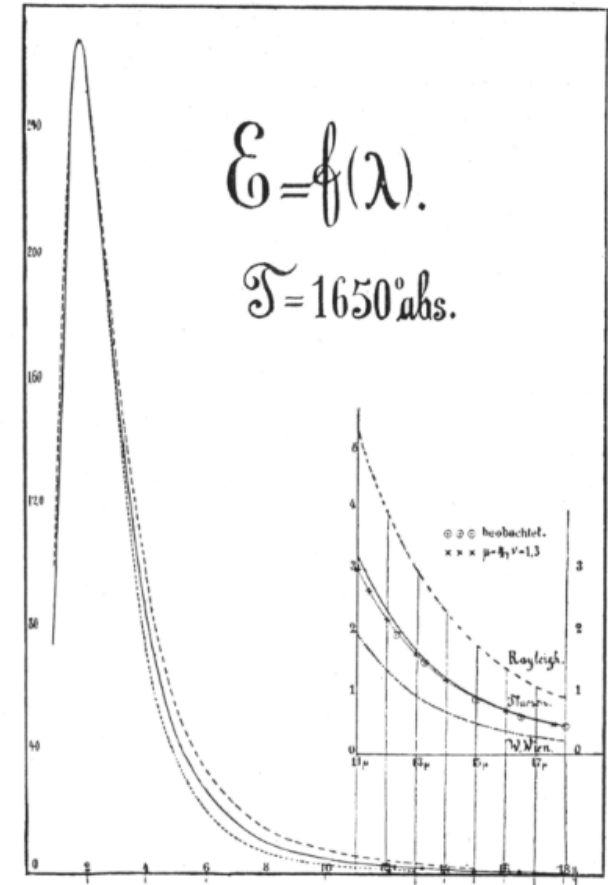
1894: Berlin – Experimentalists at PTRA show Planck
their new data
– Planck starts to look for a theory

Planck does, what he can best: he computes the
Entropy of the EM radiation (a truly „crazy idea“)

New accurate experimental data



Messung von Lummer und Pringsheim (1900)



Planck finds the radiation formula (DPG, Berlin, 19.10. 1900)

I. Wien-Formel
(große Frequenzen)

$$U(\beta) = b e^{-a\beta}$$

$$R = \left(\frac{d^2 S}{dU^2} \right)^{-1} = -aU$$

II. Rayleigh-Jeans-Gesetz
(kleine Frequenzen)

$$U(\beta) = \frac{d}{\beta}, \quad \beta = 1/kT$$

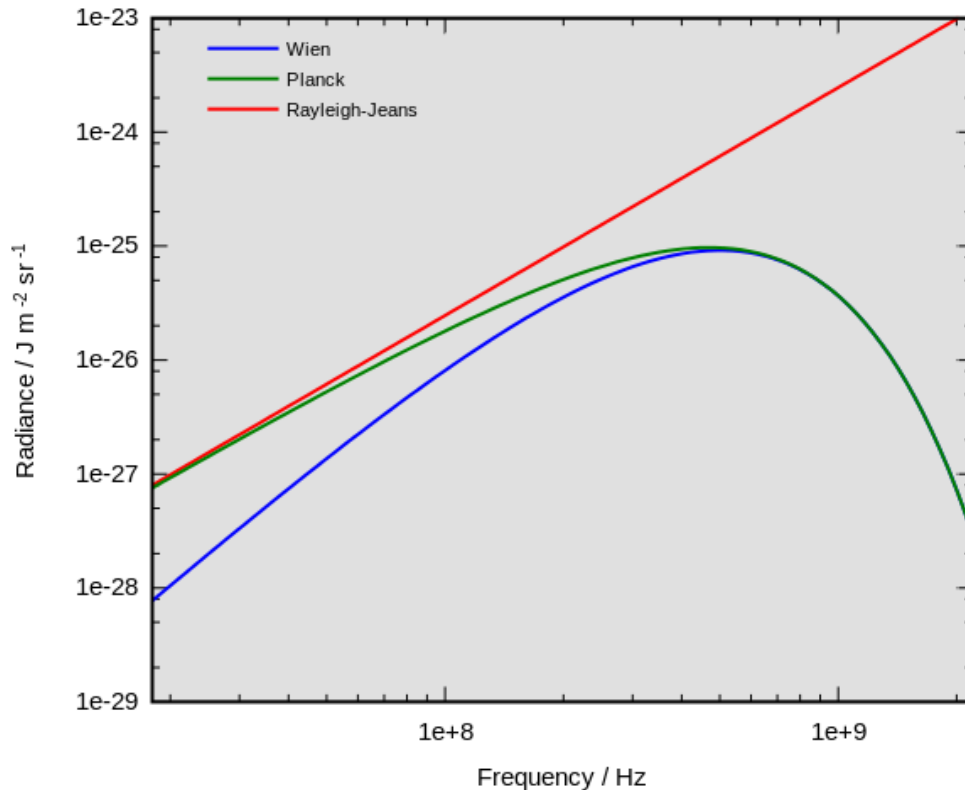
$$R = -U^2 / d$$

Kombination: $R = -aU - U^2 / d$

Integration: $\frac{dS}{dU} = \beta(U) = \frac{1}{a} \ln \left[1 + \frac{ad}{U} \right]$

Auflösen nach U: $U(\beta) = \frac{ad}{e^{a\beta} - 1}$

Planck finds the radiation formula (DPG, Berlin, 19.10. 1900)



**Planck's result „interpolates“
between the known limits**

perfect agreement with
experiment

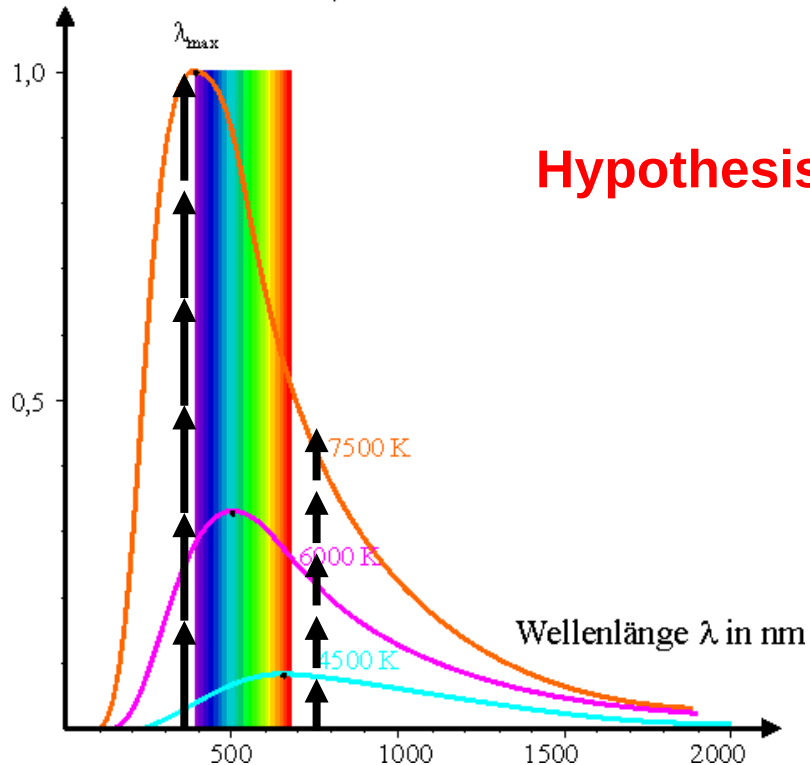
but: no physical explanation

Planck's Derivation

$$\rho(\lambda, T) = \frac{8\pi ch}{\lambda^5} \frac{1}{e^{hc/kT\lambda} - 1}$$

Planck recognizes sum of geometric progression

Strahlungsleistung $P_{\lambda, T}$ im Intervall $[\lambda; \lambda + \Delta\lambda]$



Hypothesis: energy at each wavelength composed of N identical **finite** „energy quanta“

$$U_\nu = N_\nu \cdot \varepsilon_\nu = N_\nu \cdot h\nu$$

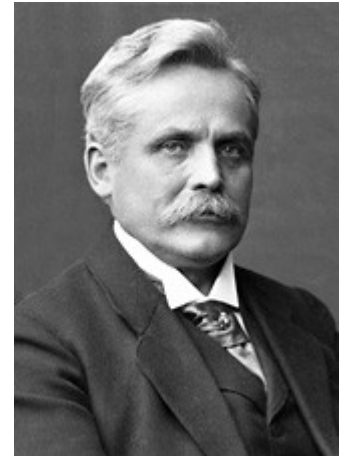
14. December 1900, DPG, Berlin
„**Birthday of quantum theory**“

Broad scepticism against Planck's discovery

- Striking contradiction to radiation laws of classical electrodynamics
- Criticism from Rayleigh, Jeans, Ehrenfest, H.A. Lorentz and many other theoreticians

1911: Nobel prize for Wilhelm Wien,

"for his discoveries regarding the laws governing the *radiation of heat*"



1918: Nobel prize for Max Planck

„for his work on the establishment and development of the theory of elementary quanta.“

Planck's „theoretical conclusion stands in very sharp opposition to our earlier concept of the radiation phenomenon. Experience had to provide powerful confirmation, therefore, before Planck's radiation theory could be accepted. In the meantime this theory has had unheard-of success.“

„Planck's radiation theory is, in truth, **the most significant lodestar** for modern physical research, and it seems that it will be **a long time before the treasures will be exhausted which have been unearthed as a result of Planck's genius.**“

A.G. Ekstrand, President of the Royal Swedish Academy of Sciences, 1. June 1920

Tragic personal life

- 1909 death of Planck's wife Marie
- 1911: Second marriage, to Marga von Hoeßlin
son Herrmann (1911-1954)
- witnesses death of all 4 children from first marriage:
 - son Karl: died 1916 in World War I
 - twins Grete and Emma: died 1917 and 1919 when giving birth

World War II: Planck stayed in Nazi Germany (conservative, loyal, patriot)

- 1943, October: during a lecture in Kassel Planck barely survived the bombing of the city
- 1944: Planck's house in Berlin was bombed, he lost everything
- 1945, 23.1.: son Erwin executed (participant in Hitler assassination attempt)

Planck stays in Germany and defends science and scientists

Planck's public activities (selection):

- many public lectures about science
- permanent Secretary of Prussian Academy of Sciences (1912/38)
- Rector of Berlin University (1913/14), supported Einstein
- several times president of German Physical Society
- President of Kaiser-Wilhelm-Society (1930/36)



- **1946**: Invited to Newton's 300th birthday celebration, London
- **1945/46** president of the Max Planck Society, laid foundation for revival of German science system after WWII

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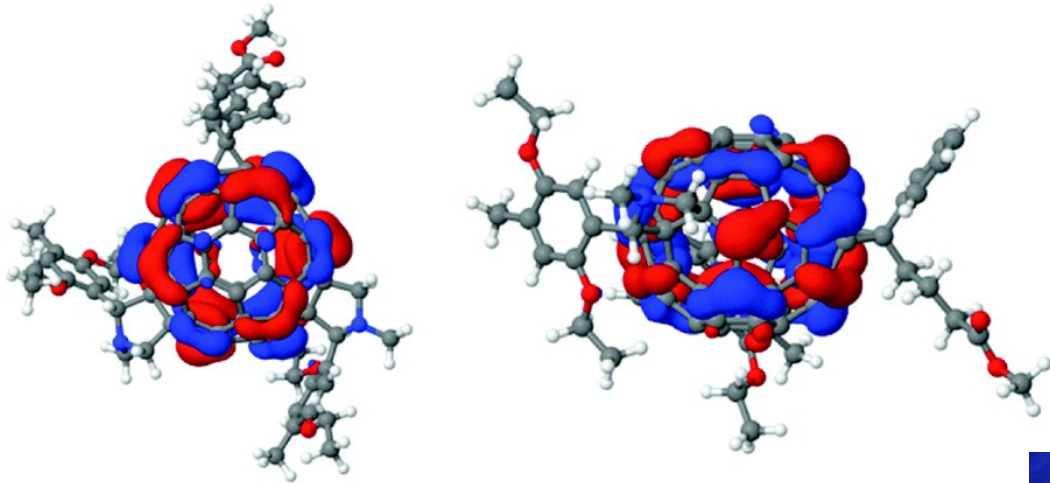
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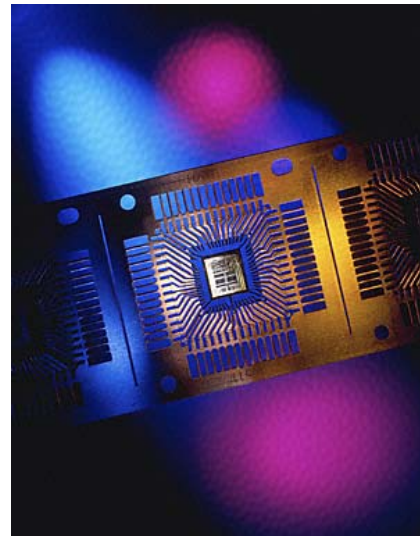
Atoms, molecules, nanotechnology



DFT result for 3 LUMO frontier orbitals for the most probable PPCBMB adducts, phenyl-C61-butrylic acid methyl ester,

Stephen et al., Chemical Communications 2016

Electrical conduction,
Optical properties,
Computer chips



Quantum effects on cosmic scales?

Big Bang

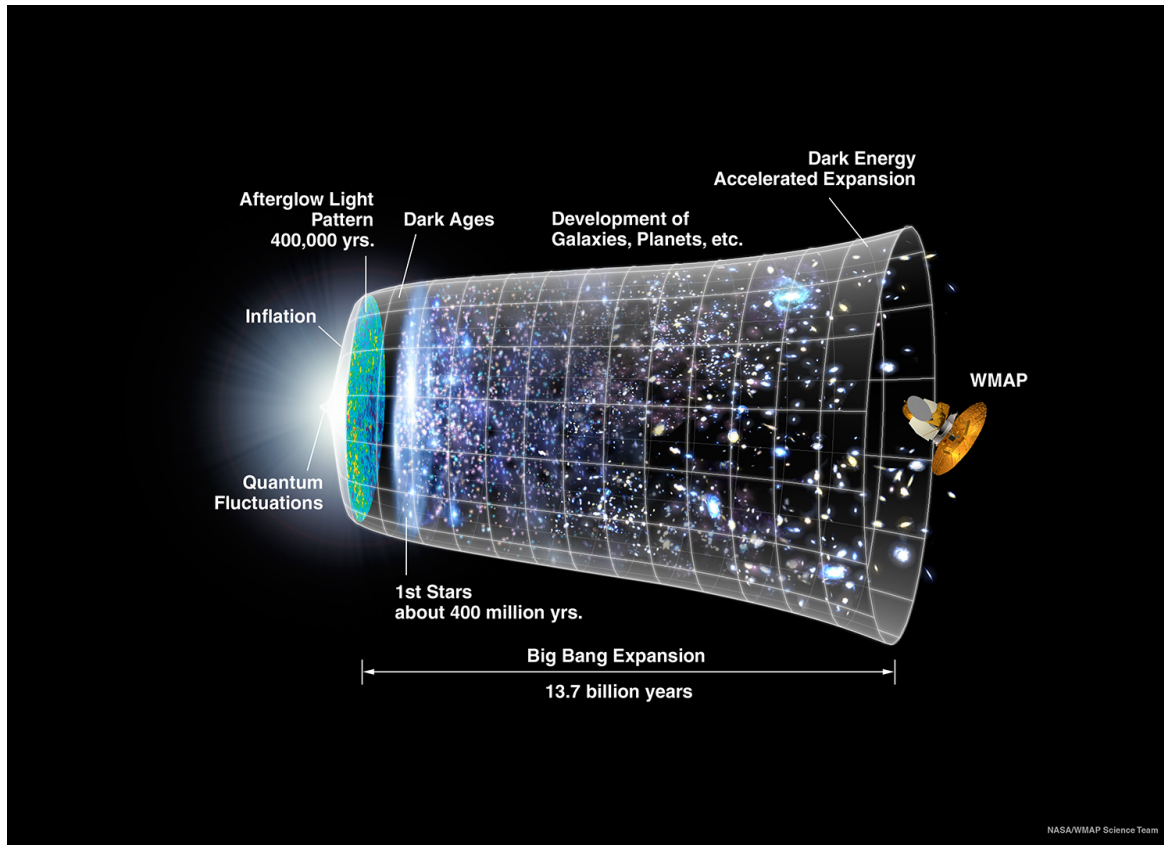
Expansion, cooling, condensation

matter today

electrons,
quarks,
photons

a few photons
should have
survived

Gamov, 1947



Discovery of the cosmic microwave background radiation

1964: Penzias, Wilson



Cosmic radio signals
annoying noise....

Expansion and cooling 3000K \rightarrow 2.73K

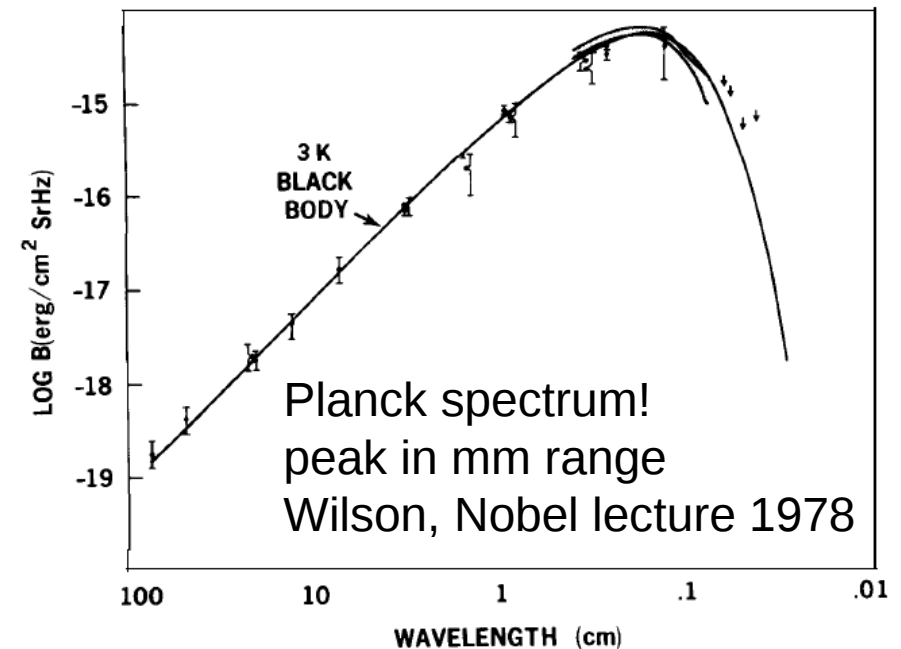
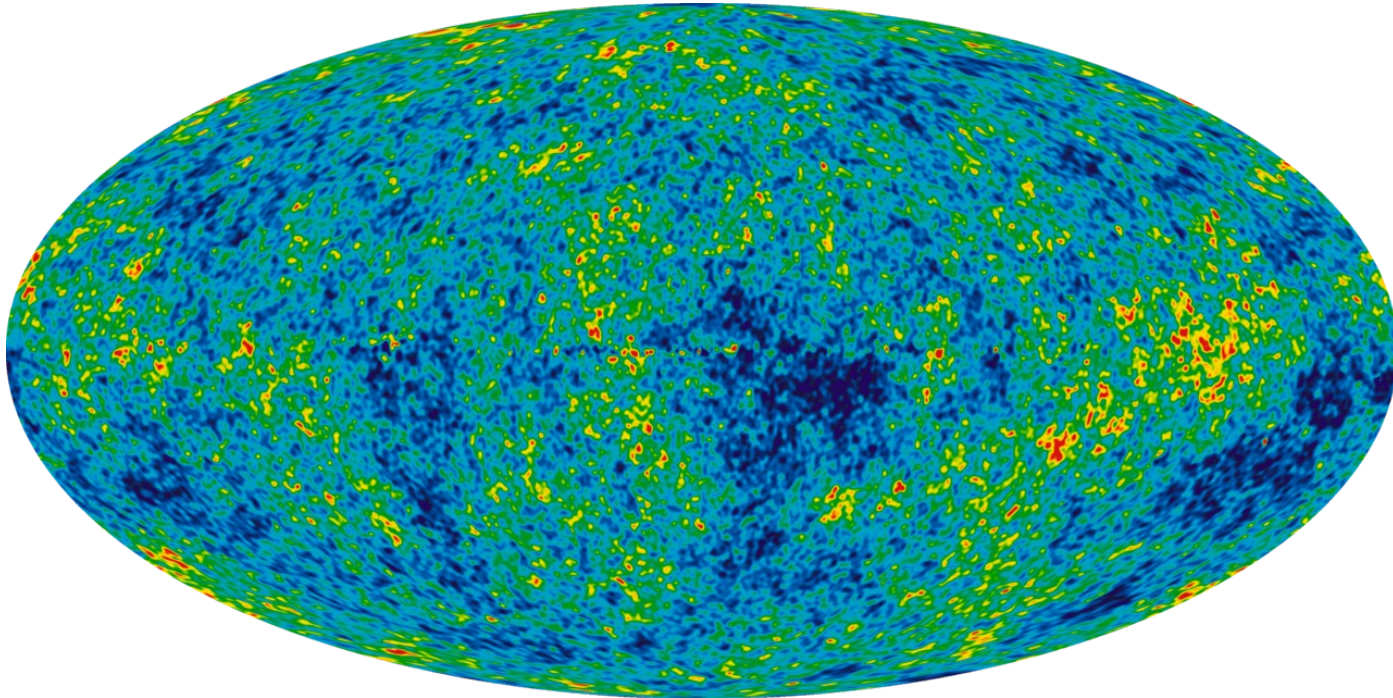


Fig. 12 Measurements of the spectrum of the cosmic microwave background radiation.

A window to the Universe 13.7 billion years ago!



2006: Physics Nobel prize for Mather and Smooth, COBE satellite (1989-93)

today: Satellites measure anisotropy, mass distribution etc.

WMAP (2001-10), Planck (2009-13)

source: Wikipedia

Summary and Outlook



„I do not desire to discover new ground, but only to understand the existing fundamentals of the physical science and, possibly, to deepen them“

„....the most significant lodestar for modern physical research, ... it will be a long time before the treasures will be exhausted which have been unearthed as a result of Planck's genius.“

Quantum mechanics: Revolution in science, technology
A unique example of scientific discovery and personal integrity
A story that should be kept and told

Planck Celebration in Kiel 2007/2008

Extensive program of city Kiel, University and Planck School celebrating Planck's 150th birthday

4. 10. 2007: Kiel commemorates the 60th anniversary of Planck's death

2008, spring: Scientific colloquium and public lectures



Planck and Quantum mechanics

Public lecture for school children



Kiel City council hall, April 2008

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First proposal of a **Max-Planck-Museum**



A Museum for Planck and Quantum mechanics



Physikzentrum der CAU Kiel, Leibnizstrasse, Opening: 14.12. 2013

www.theo-physik.uni-kiel.de/~bonitz/planck.html

M. Bonitz, "Max Planck, Kiel and correlated quantum systems", Budapest, October 2018

A Museum for Planck and Quantum mechanics

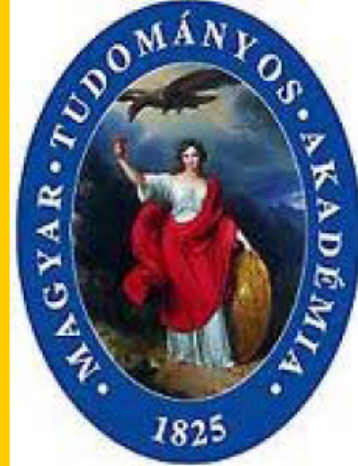


Physikzentrum der CAU Kiel, Leibnizstrasse, Opening: 14.12. 2013

www.theo-physik.uni-kiel.de/~bonitz/planck.html → s. flyer

Planck 2018

Memorial Scientific Symposium



10-11 October 2018. Széchenyi Square 9, Budapest, Hungary

Thanks to Sandor Varro
Hungarian Academy of Sciences

for a wonderful initiative!