

Physik am Samstag

## Licht als Werkzeug

Wofür gab es den Physik-Nobelpreis 2018?

*Prof. Dr. Walter Pfeiffer*



# Es gibt ein Quiz mit Preisen!

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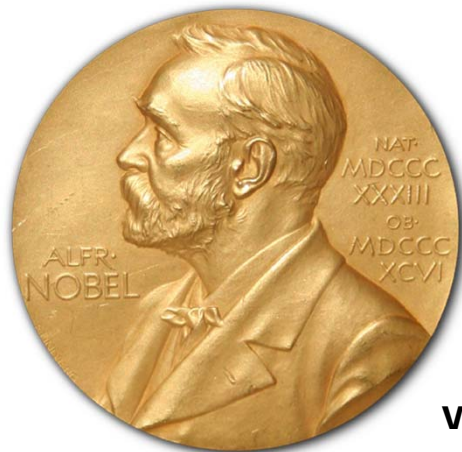


Beantworten Sie die Fragen und nehmen Sie an der Ziehung am Ende der Veranstaltung teil!

The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to **Arthur Ashkin** "for the optical tweezers and their application to biological systems",



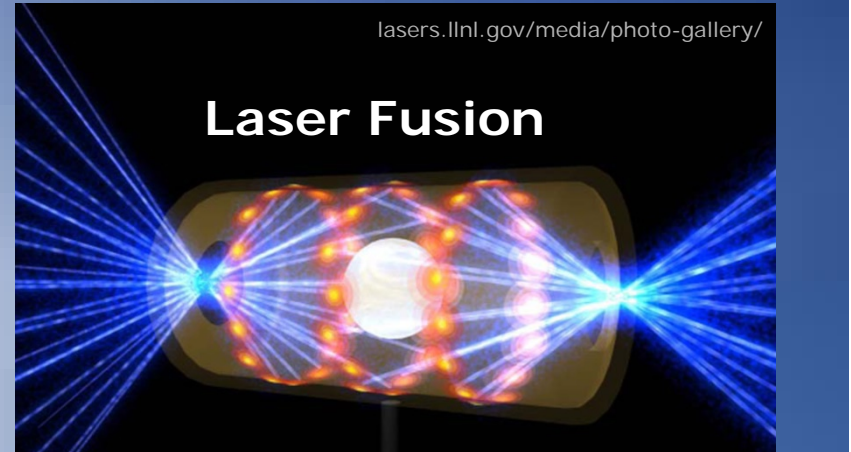
the other half jointly to **Gérard Mourou** and **Donna Strickland** "for their method of generating high-intensity, ultra-short optical pulses."



[www.nobelprize.org/prizes/physics/2018/summary/](http://www.nobelprize.org/prizes/physics/2018/summary/)



# Licht transportiert Energie

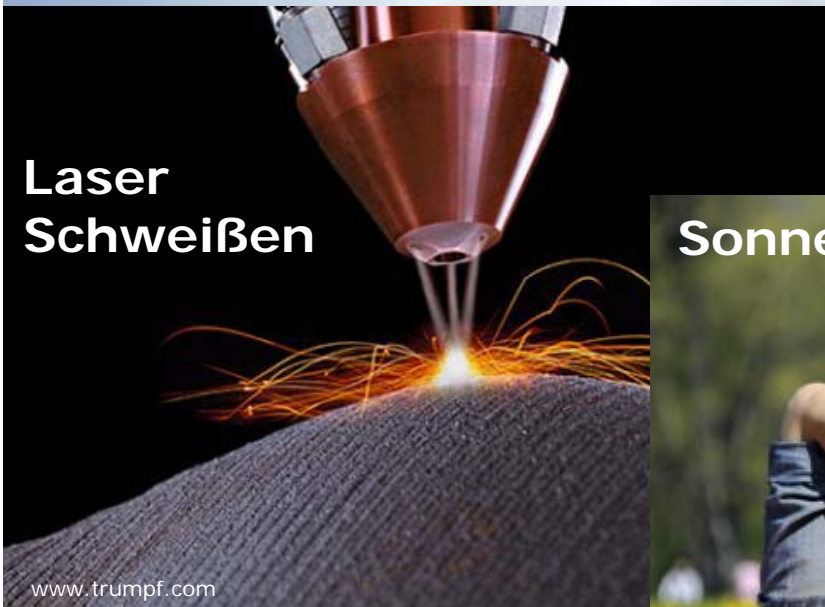


## Photovoltaik



photovoltaik-augsburg.eu

## Laser Schweißen



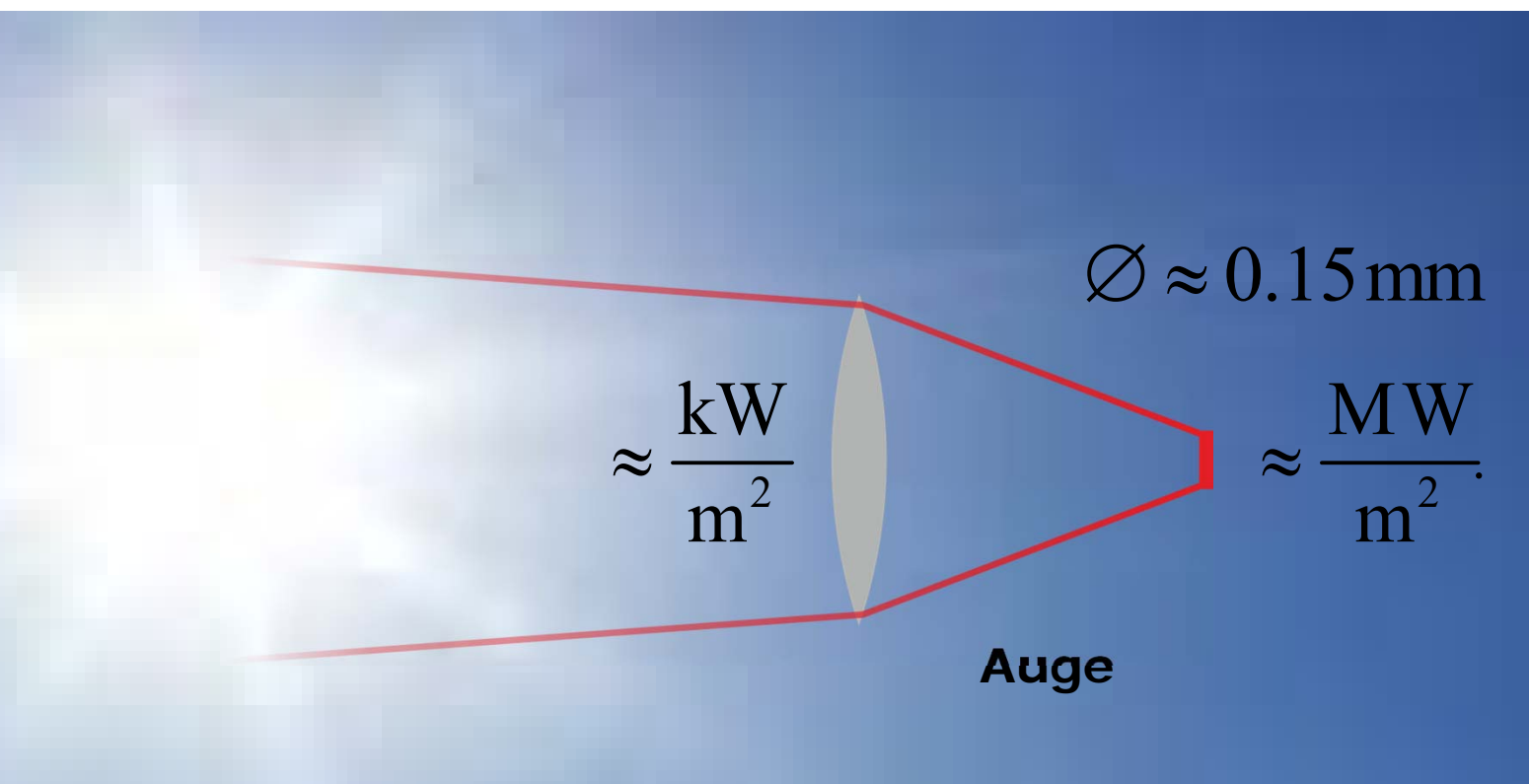
www.trumpf.com

## Sonnenbad

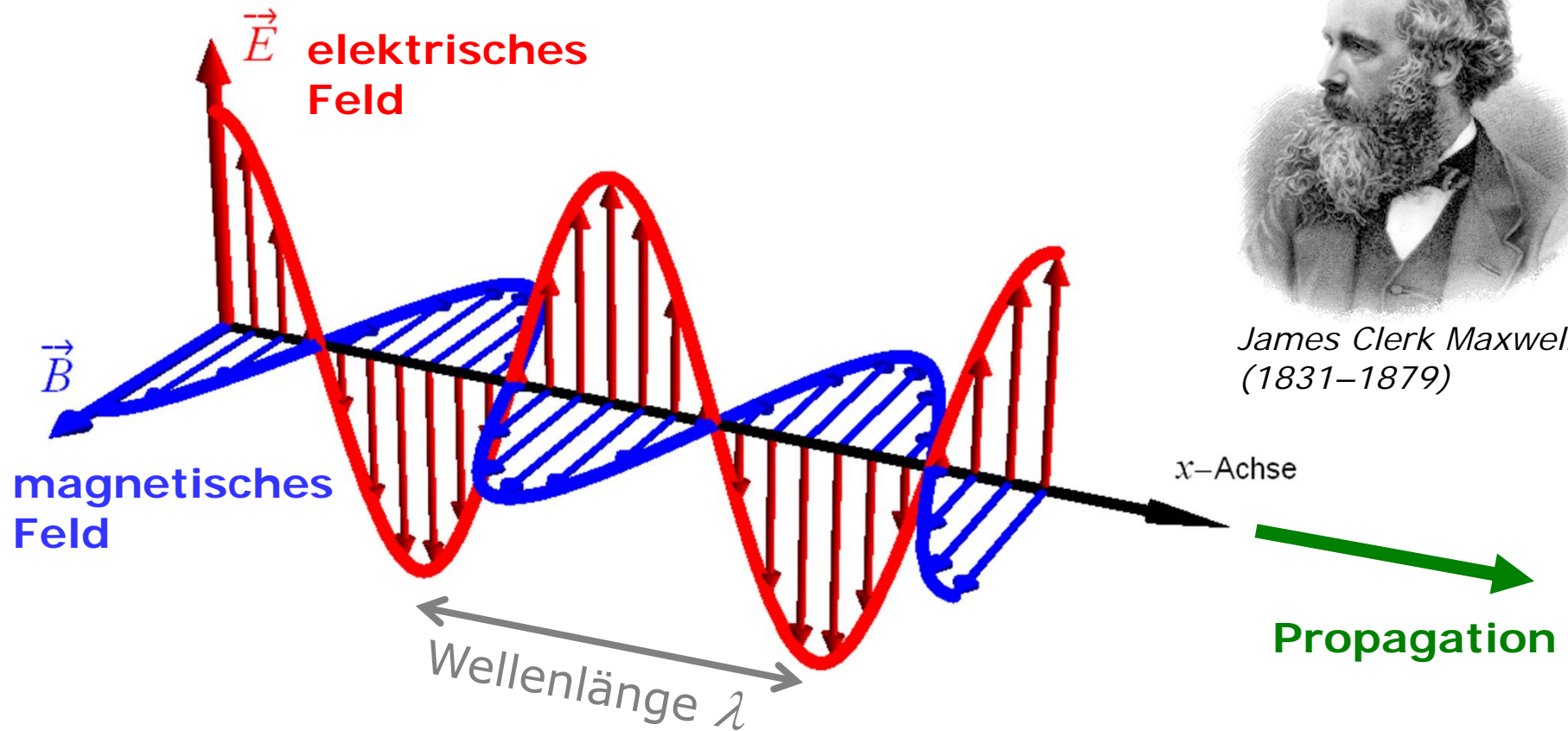


dpa 2011

umweltbundesamt



# Elektromagnetische Wellen



James Clerk Maxwell  
(1831–1879)

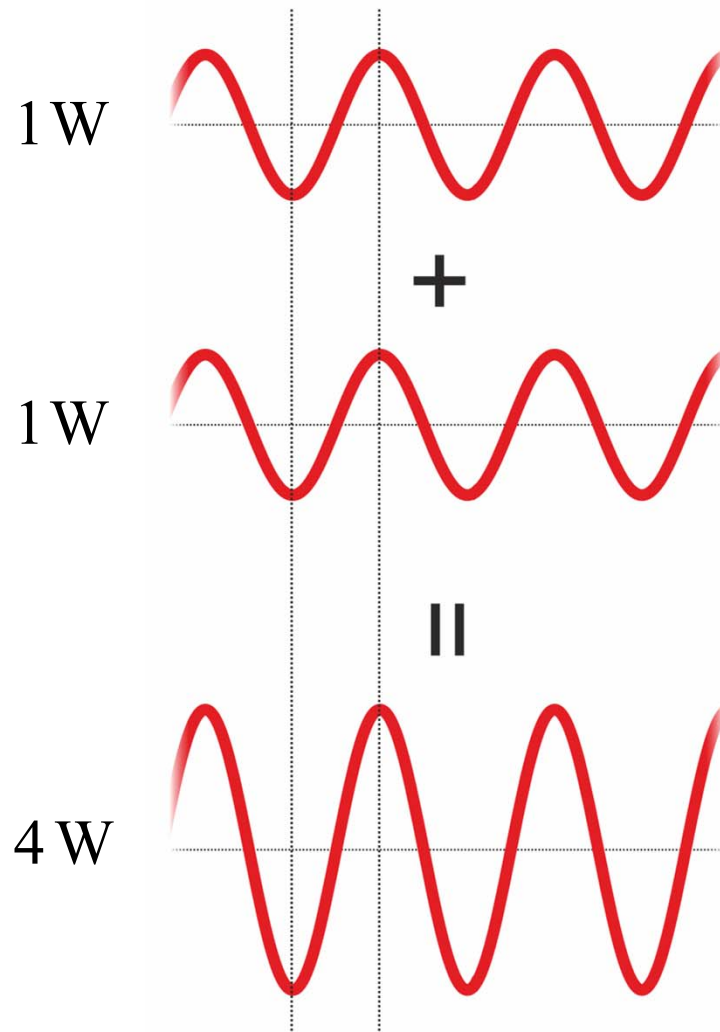
Lichtintensität  $P \propto |\vec{E}|^2$



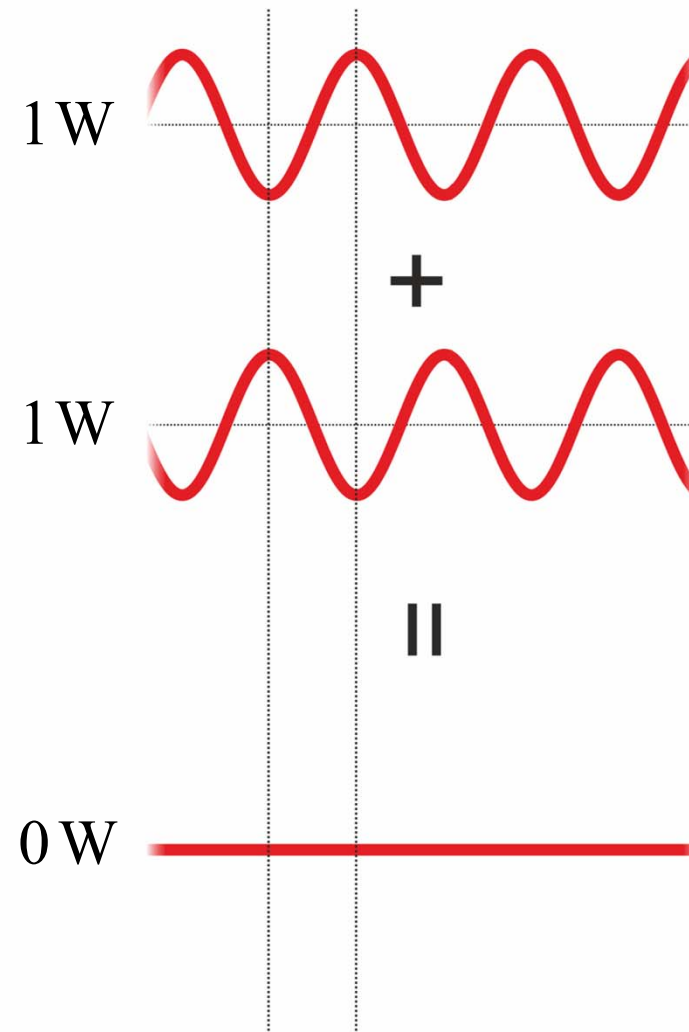


# „Addieren“ von Lichtwellen

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**Konstruktive Interferenz**

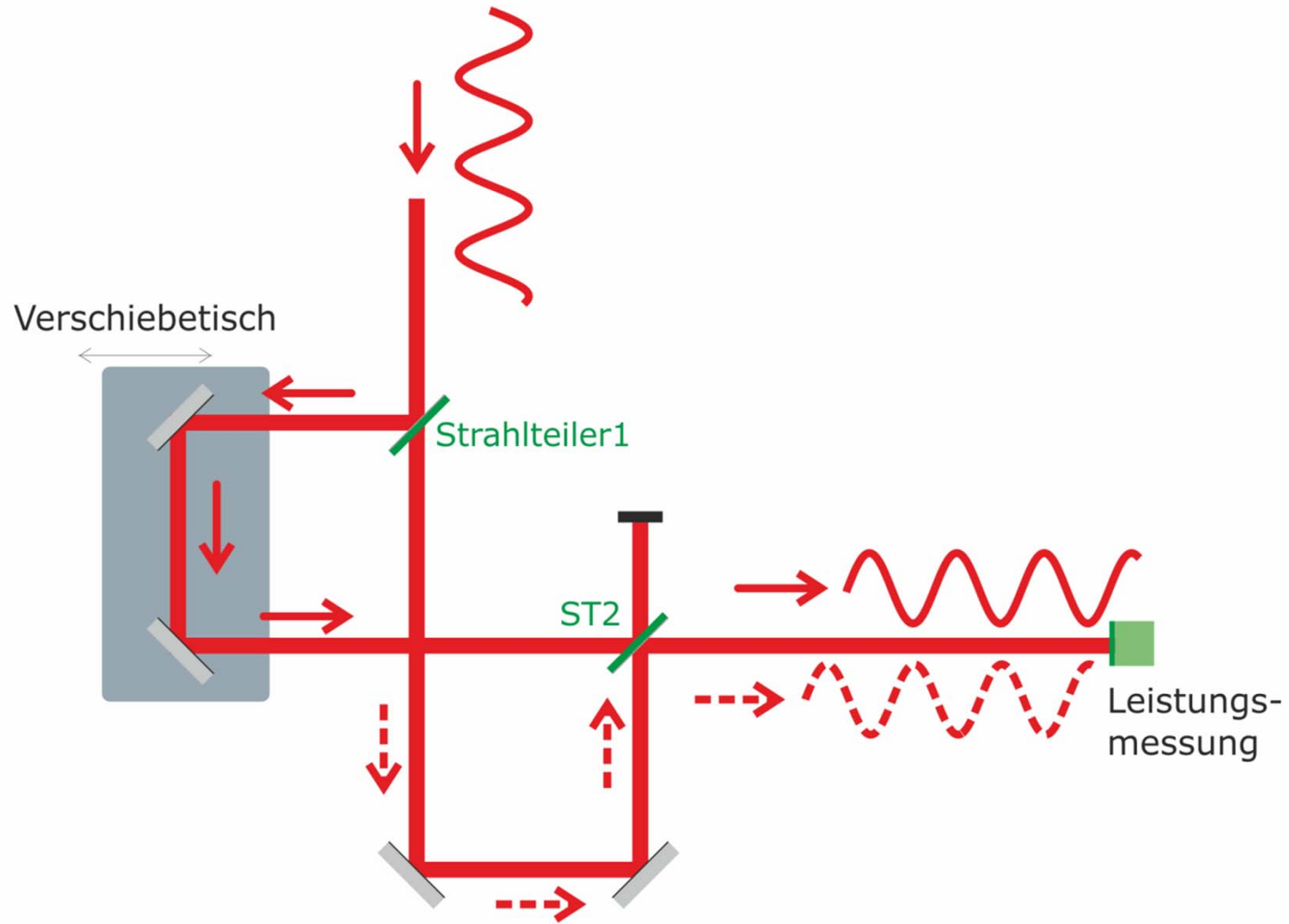


**Destruktive Interferenz**



# Licht + Licht = kein Licht

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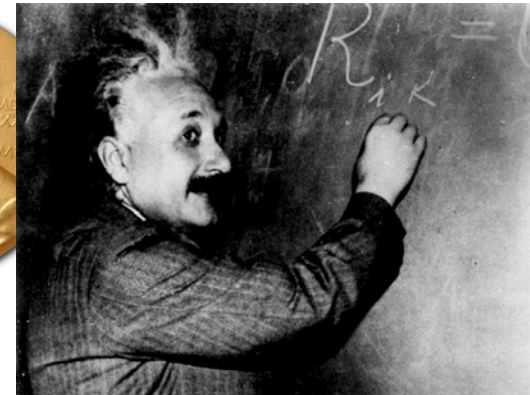
# Licht – Materie Wechselwirkung

Energieaustausch in Form von  
Energiepaketen (Lichtquanten)

$$E_{\text{Lichtquant}} = h \frac{c}{\lambda}$$
$$\approx 2.5 \cdot 10^{-19} \text{ J für } \lambda = 800 \text{ nm}$$

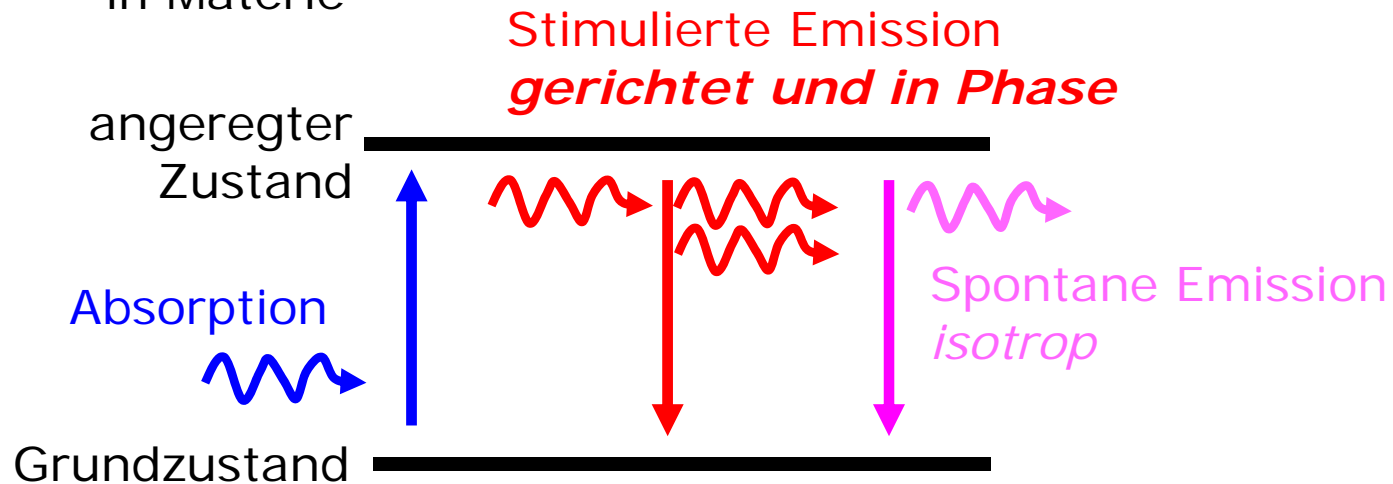


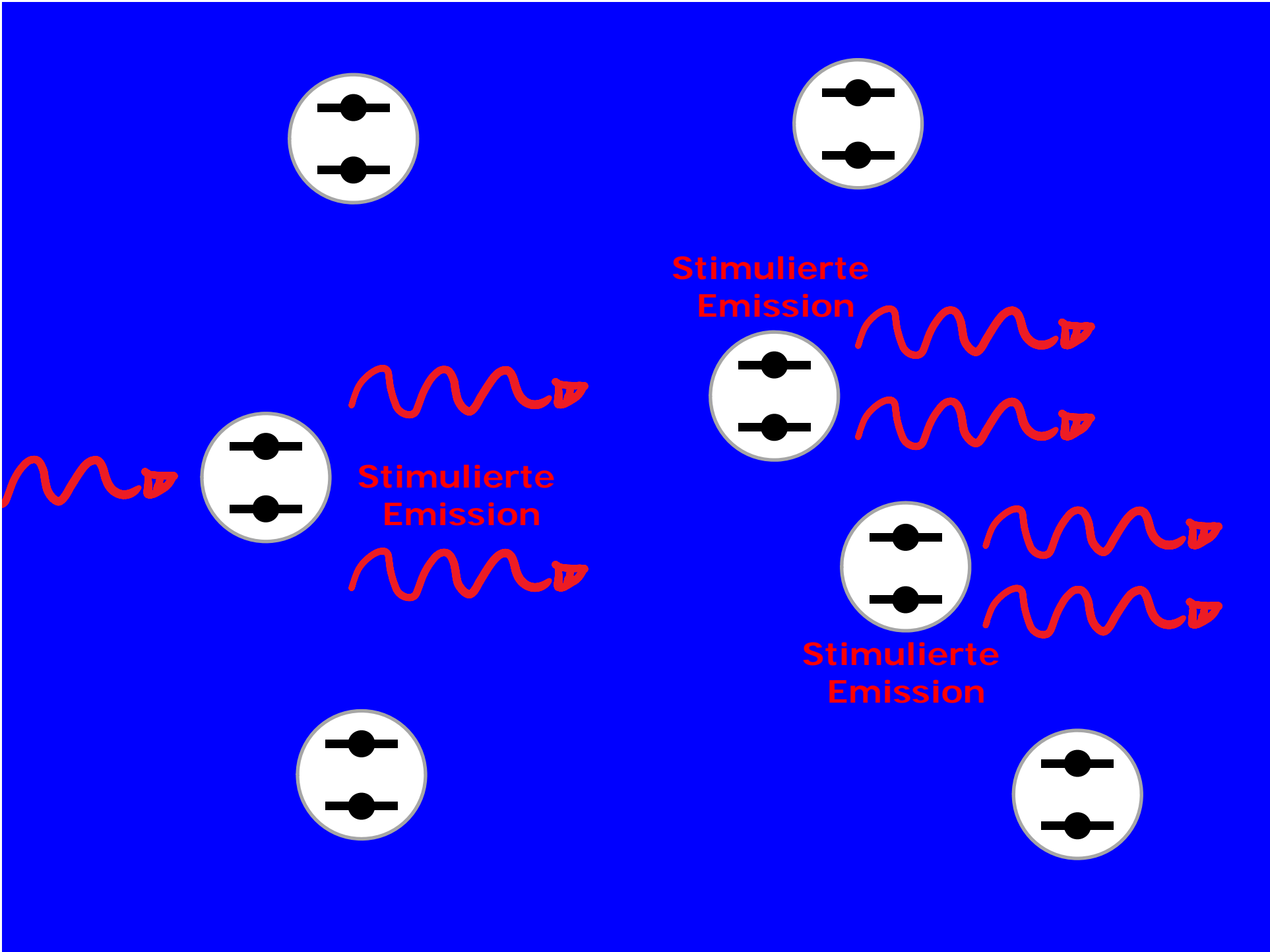
1922



Albert Einstein, 1879 -1955

quantisierte  
Energiezustände  
in Materie

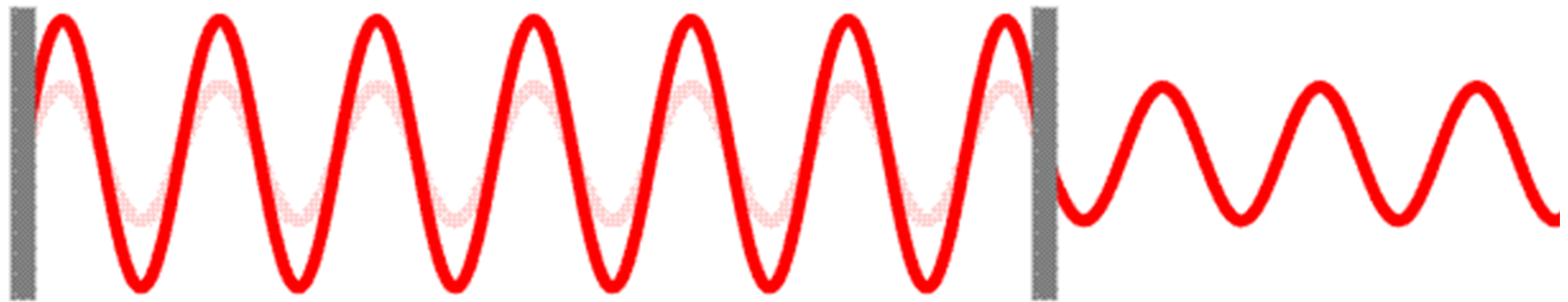
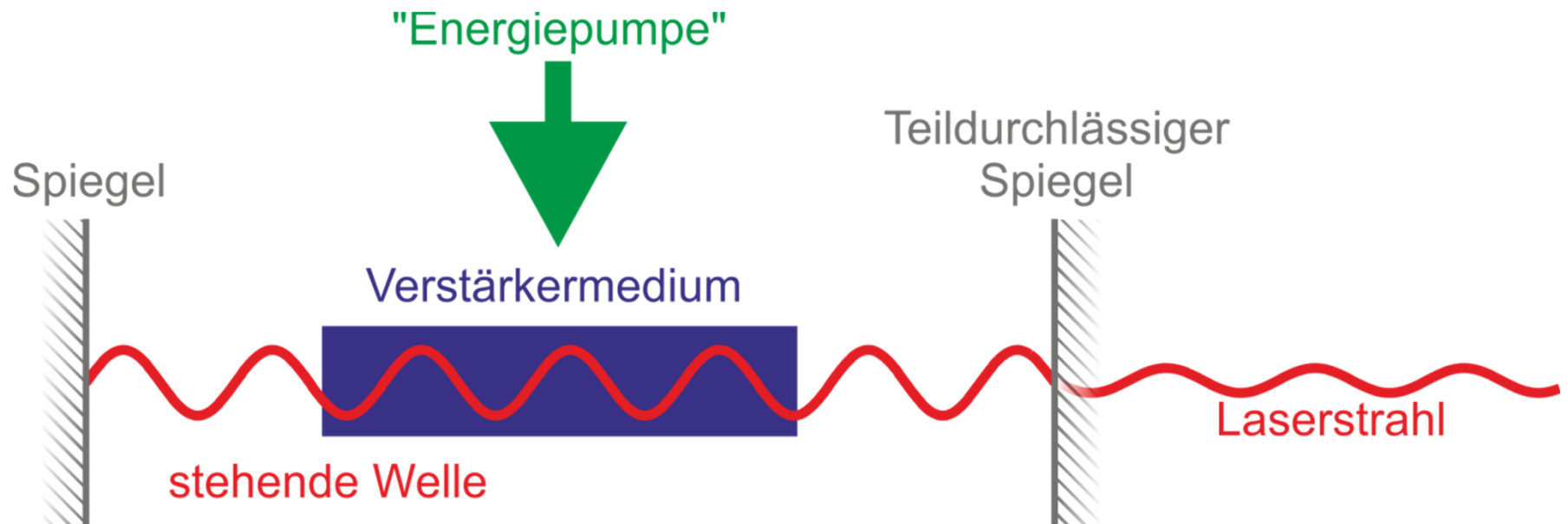




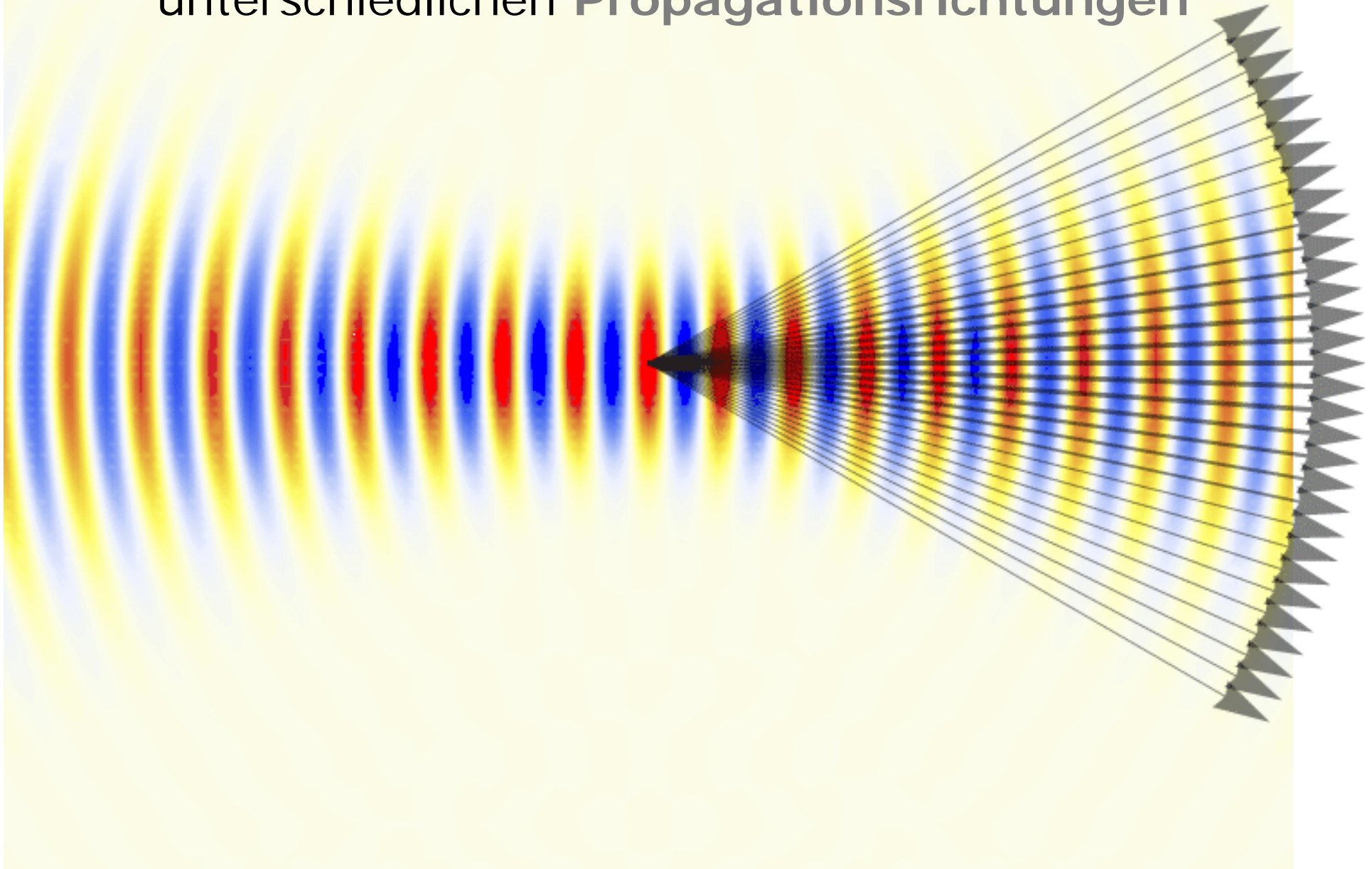


# Prinzip eines Lasers

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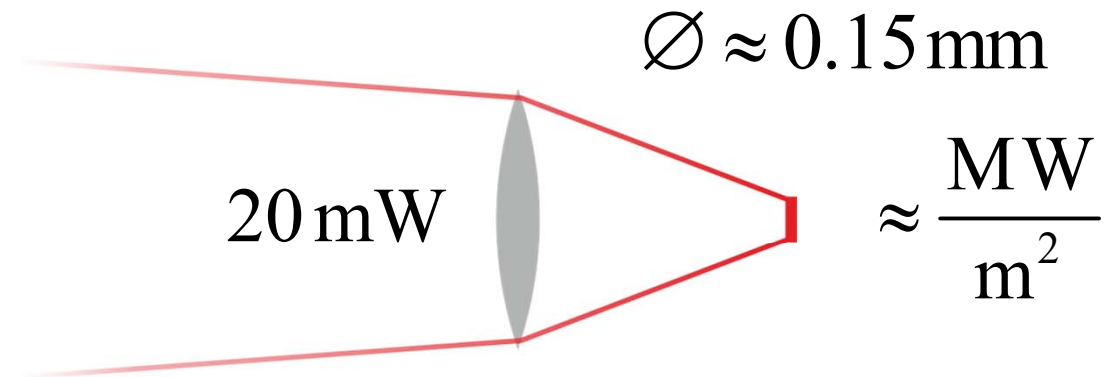
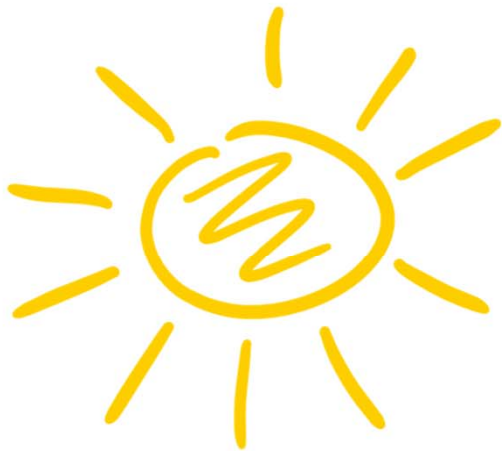
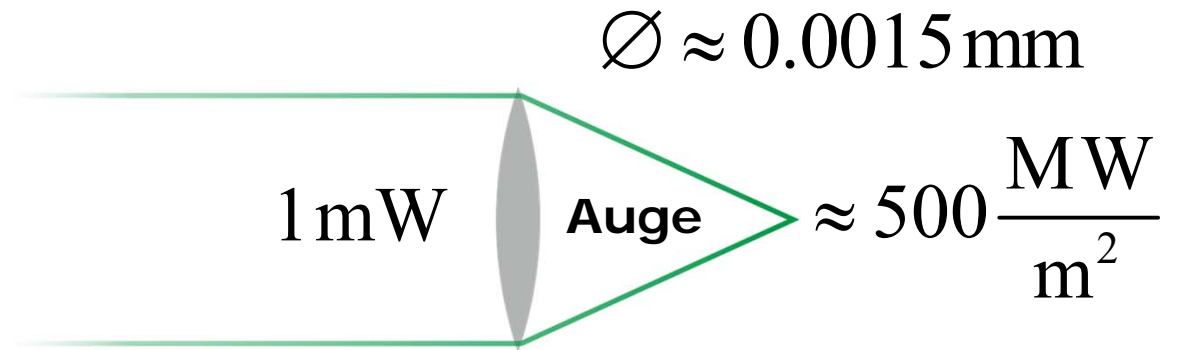


Addition von 31 ebenen Wellen mit unterschiedlichen **Propagationsrichtungen**



# Intensitäten auf der Netzhaut

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# Komet Hale-Bopp [en.wikipedia.org](http://en.wikipedia.org)

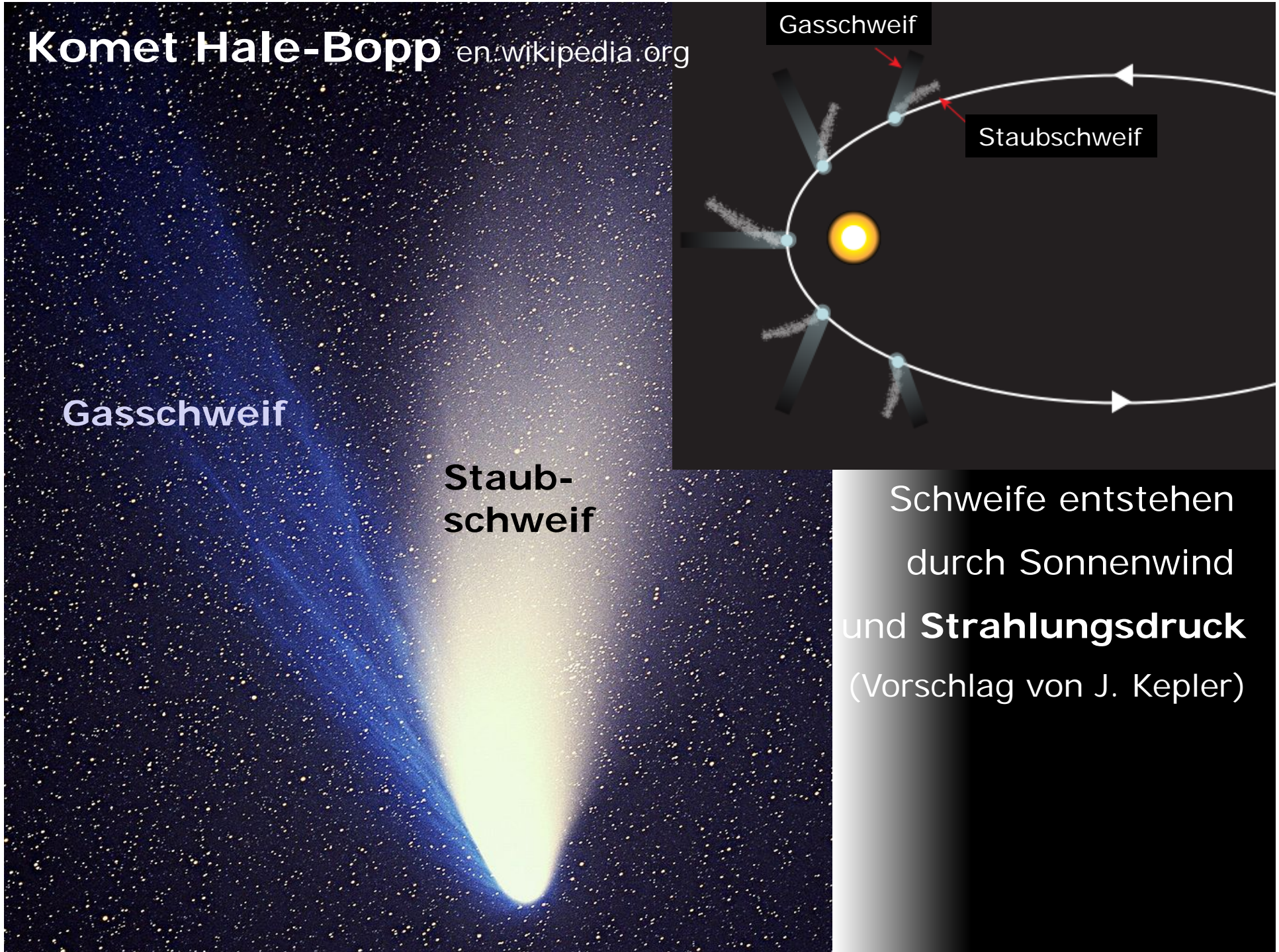
Gasschweif

Staub-  
schweif

Gasschweif

Staubschweif

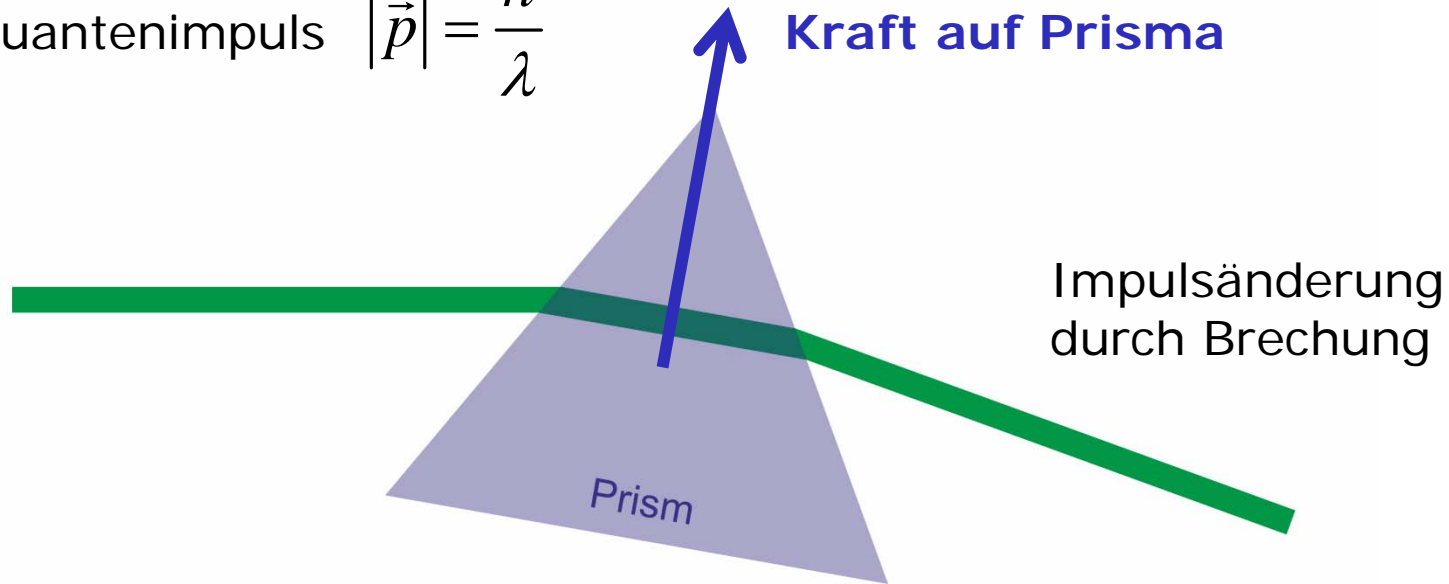
Schweife entstehen durch Sonnenwind und **Strahlungsdruck** (Vorschlag von J. Kepler)



# Kräfte durch Licht

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Lichtquantenimpuls  $|\vec{p}| = \frac{h}{\lambda}$



Ein einzelnes 532 nm Lichtquant,  $\alpha=20^\circ$   $\rightarrow \Delta p_{prism} \approx 4 \cdot 10^{-28} \text{ N s}$

1 mW 532 nm Laserstrahl,  $\alpha=20^\circ$   $\rightarrow 2.7 \cdot 10^{15} \text{ photons s}^{-1}$

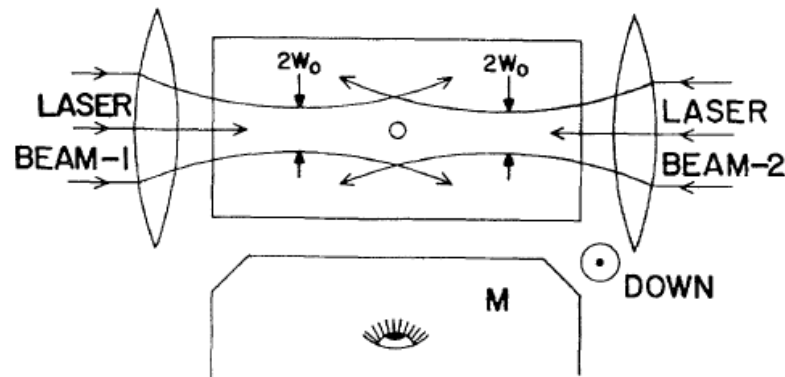
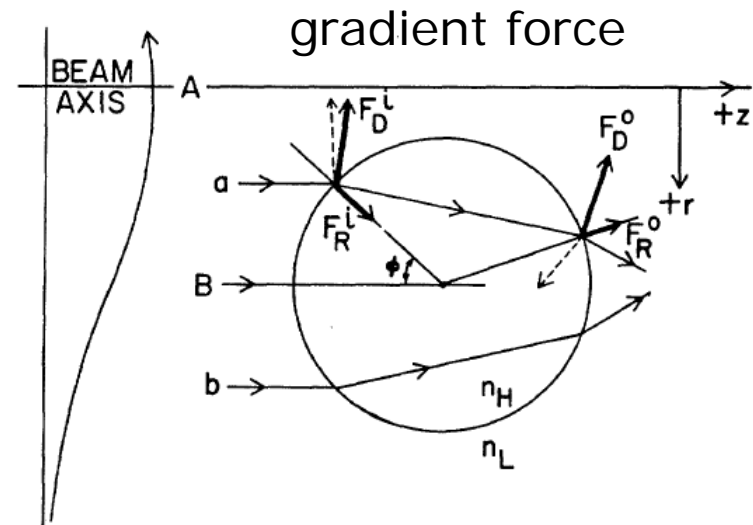
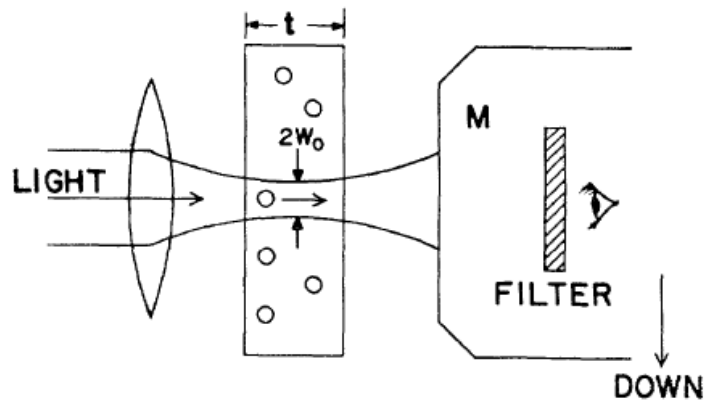
$F_{prism} \approx 1 \cdot 10^{-12} \text{ N} = 1 \text{ pN}$

ACCELERATION AND TRAPPING OF PARTICLES BY RADIATION PRESSURE

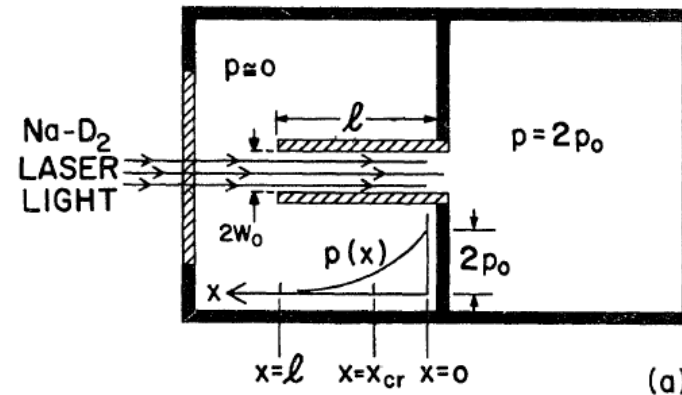
A. Ashkin

Bell Telephone Laboratories, Holmdel, New Jersey 07733

(Received 3 December 1969)



Sodium pump





# Optische Pinzette

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[www.opticaltweezers.org](http://www.opticaltweezers.org)

<http://opticaltweezers.org/videos/geometrical-optics/brownian-motion-in-an-optical-trap-medium-na-geometrical-optics/>



A. Callegari, et al., *Computational toolbox for optical tweezers in geometrical optics*, J. Opt. Soc. Am. B **32**, B11 (2015).

# Anwendungen

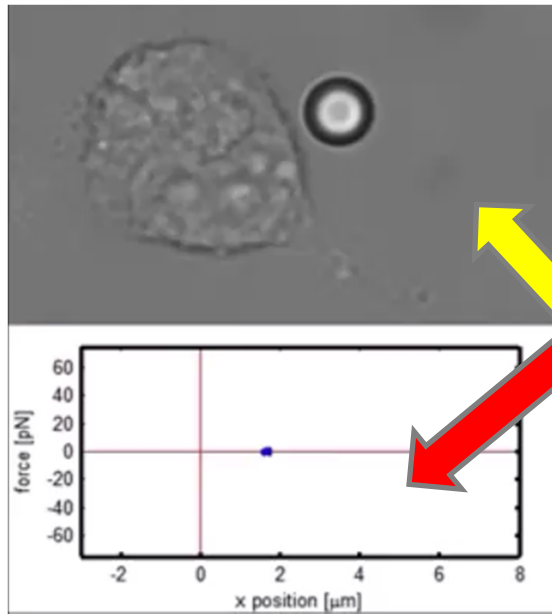
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- Einzelmoelkül Biophysik
- **Zellbiologie**
- Spektroskopie
- Optofluide und *Lab on a Chip*
- Kolloid- und Aerosole
- Mikrochemie
- Statistische Physics
- Nanothermodynamik
- Plasmonik
- **Manipulation von Nanostrukturen**
- Quanten Optomechanik
- Einfang und Kühlung von Atomen
- ...

# Optischer Aufbau

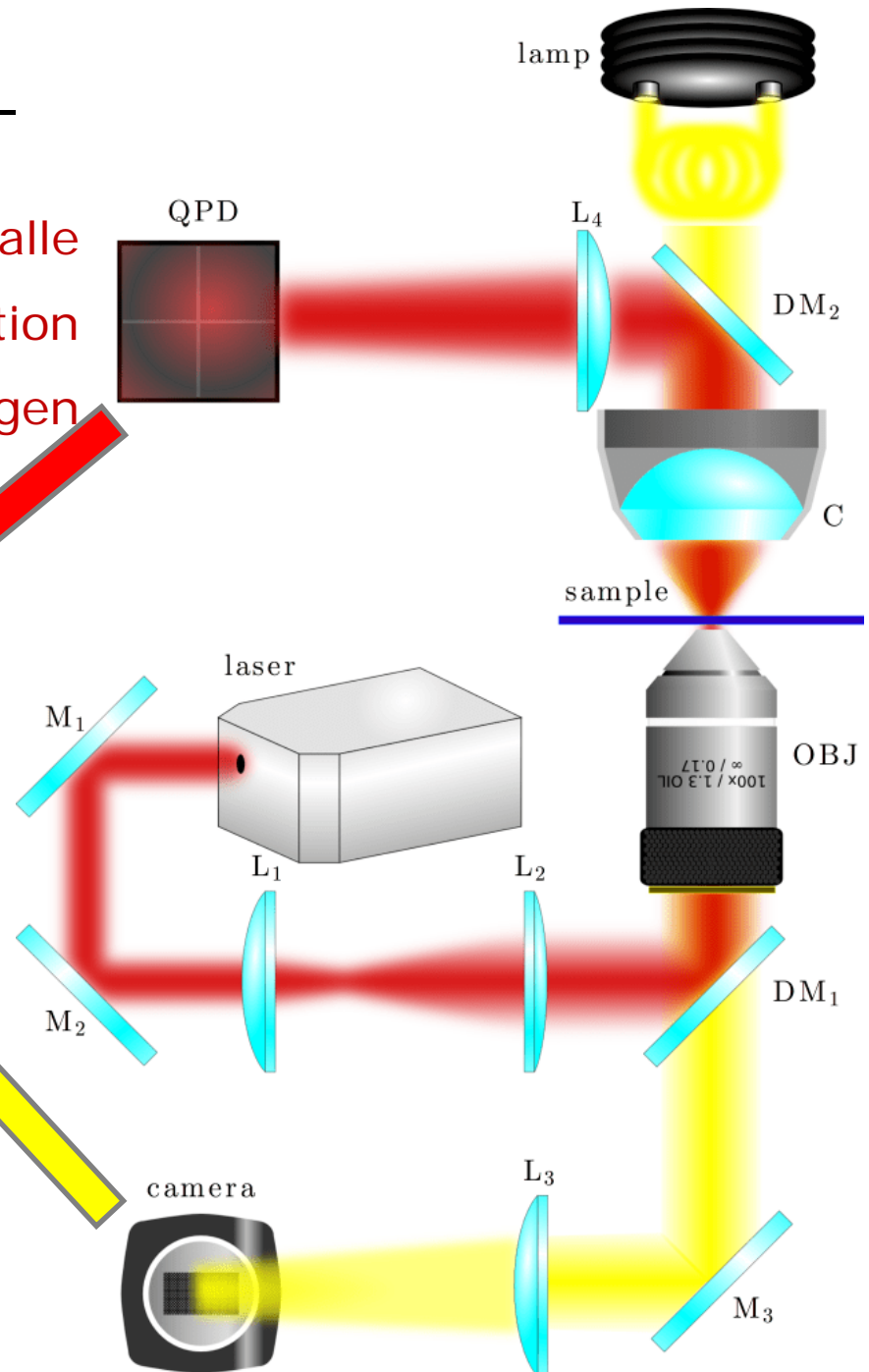
www.opticaltweezers.org

Nachweis von Streulicht aus der Falle  
sensitiv auf Partikelposition  
Kraftmessungen



<https://www.youtube.com/watch?v=Hki1a6-hCmM>

P. Jones, O. Marago, G. Volpe, *Optical Tweezers: Principles and Applications* (Cambridge University Press, 2015)

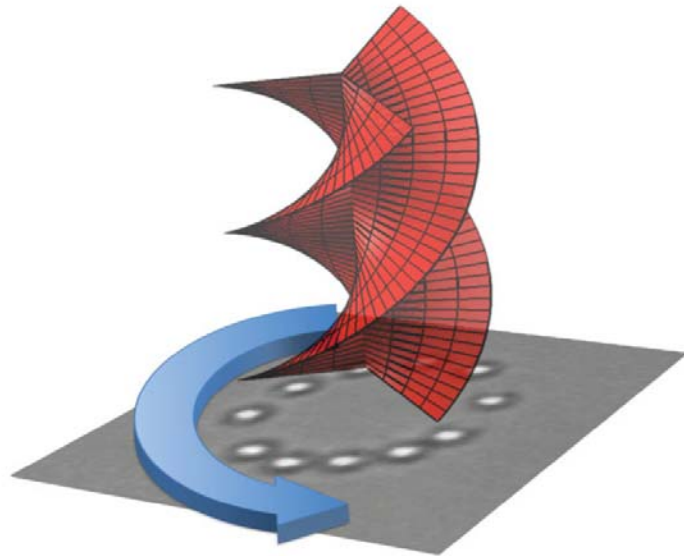




# Not Just for Fun

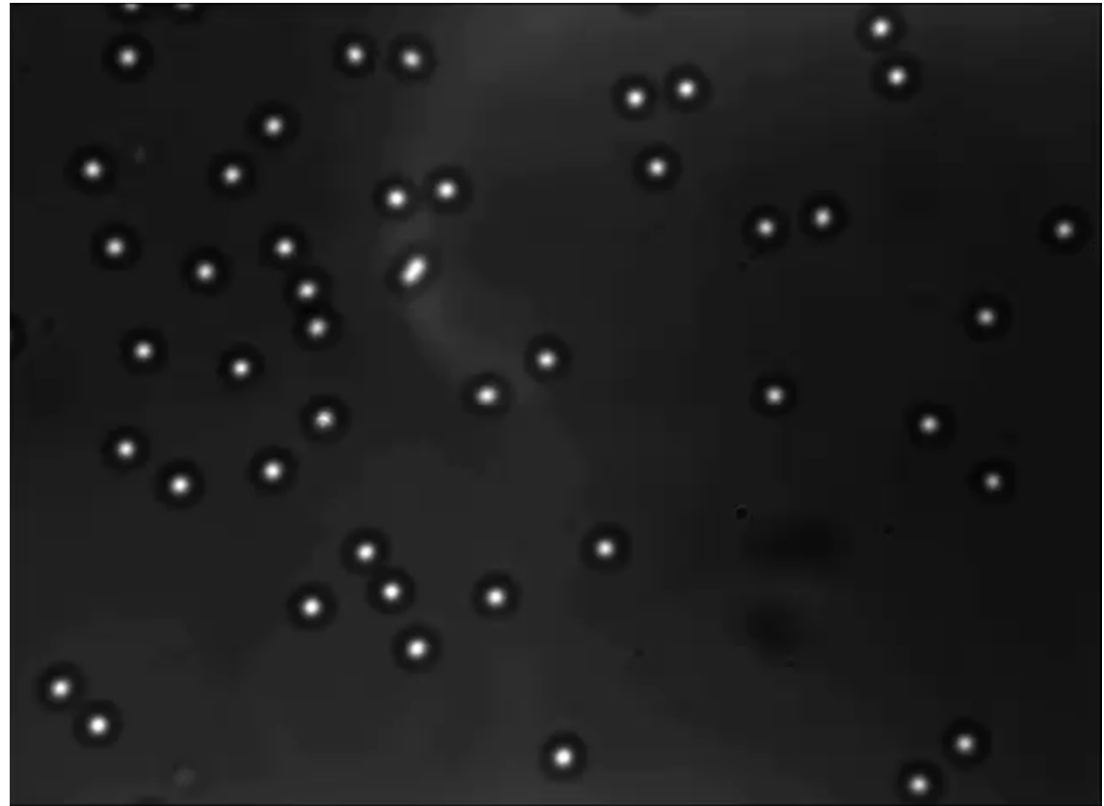
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Drehimpuls von Licht



M. Padgett, Light's twist.  
*Proc. Roy. Soc. A.* **470**,  
20140633 (2014).

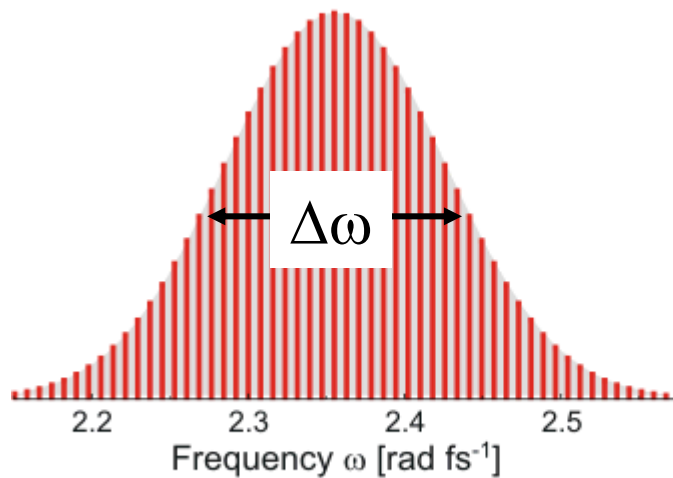
<https://www.youtube.com/watch?v=-HOWmGQhTu8>



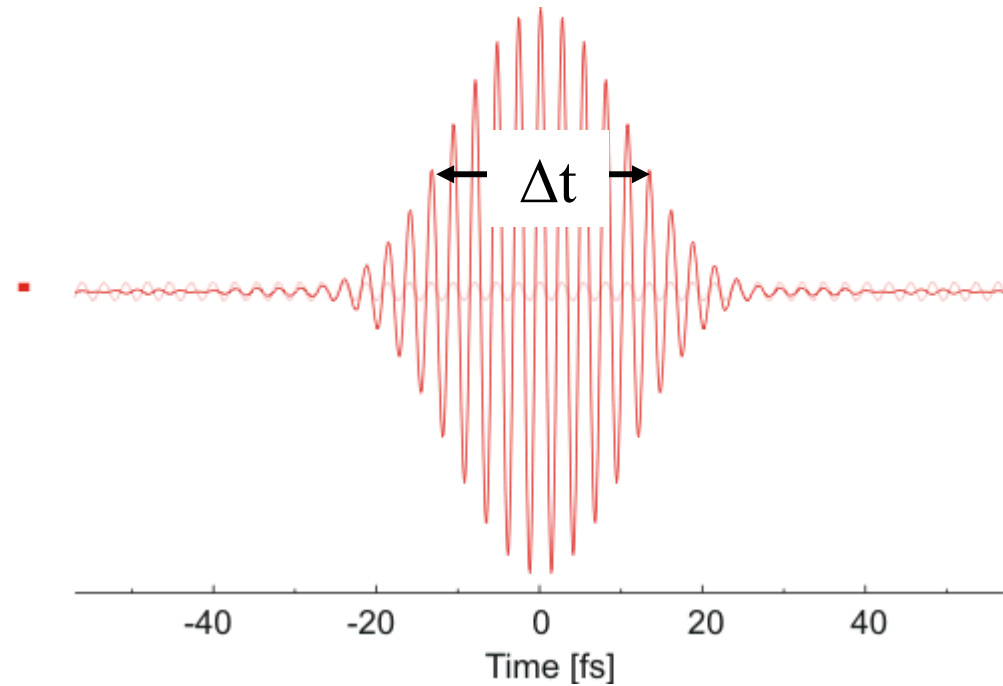
Optische Pinzette mit Drehimpulslicht

# Wir bauen einen ultrakurzen Puls

Spektrum



Elektrisches Feld



$$\Delta \omega \cdot \Delta t \geq 2 \pi$$

⇒

**Hohe Zeitauflösung**

1 mJ in 10 fs  
10 μm Ø

⇒

$10^{11}$  W

⇒

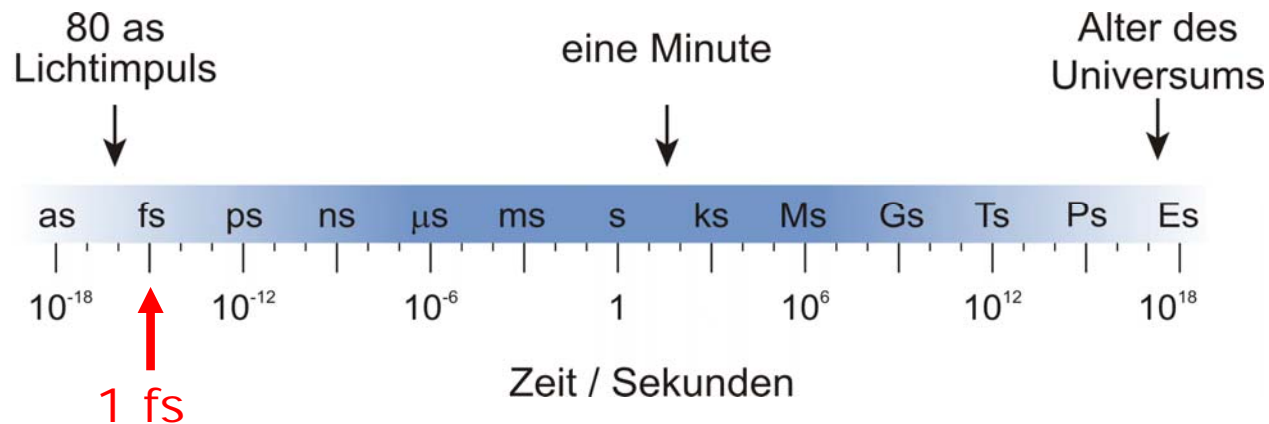
$10^{21}$  W m<sup>-2</sup>

$10^{12}$  V m<sup>-1</sup>

⇒

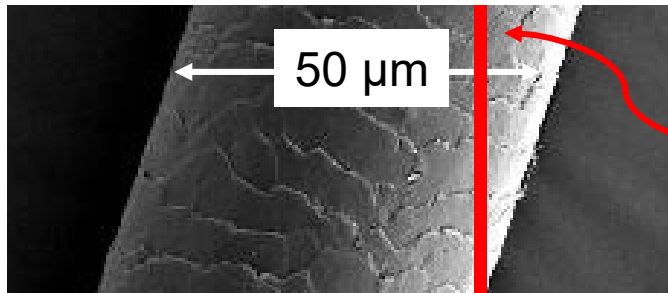
**Hohe Intensitäten**

# Wie "kurz" ist eine Femtosekunde?



← 350 000 – 400 000 km → Mond

Ein Lichtblitz von  
**1 s** Dauer ist  
**300 000 km** lang



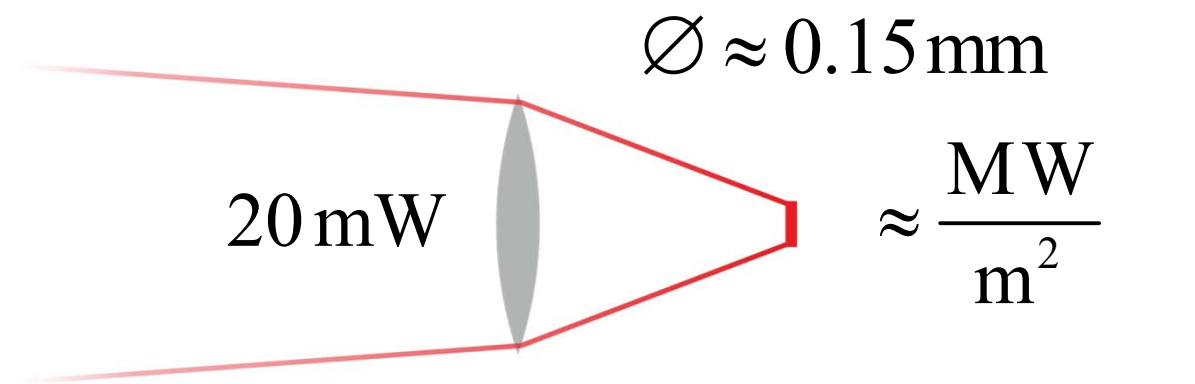
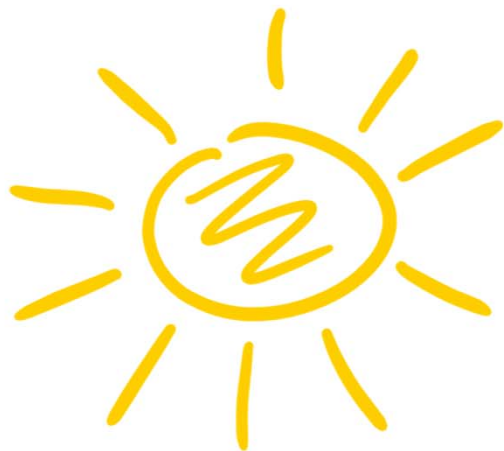
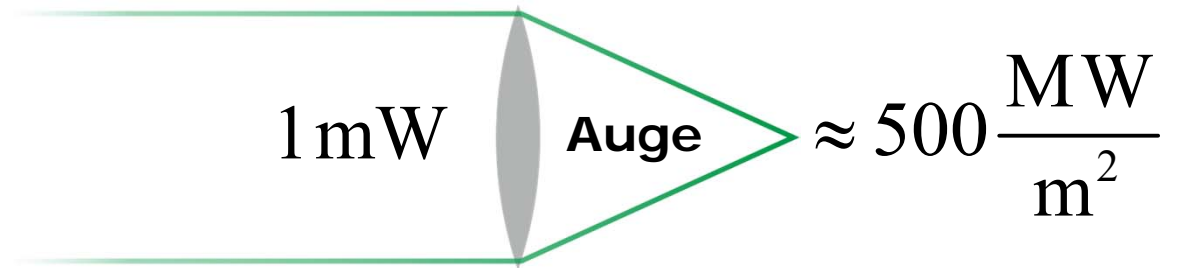
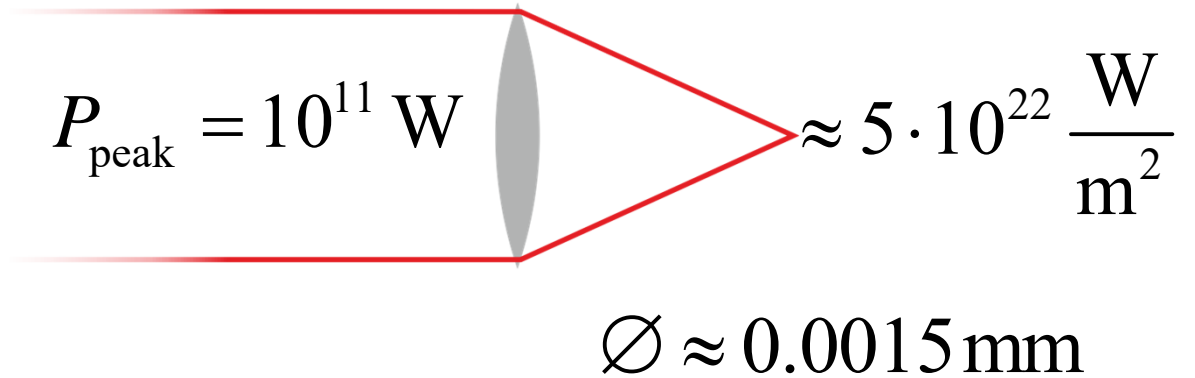
Ein Lichtblitz von  
**7 fs** Dauer ist  
**2  $\mu\text{m}$**  lang

Elektronenmikroskopie eines Haares

# Intensitäten auf der Netzhaut



1 mJ, 10 fs



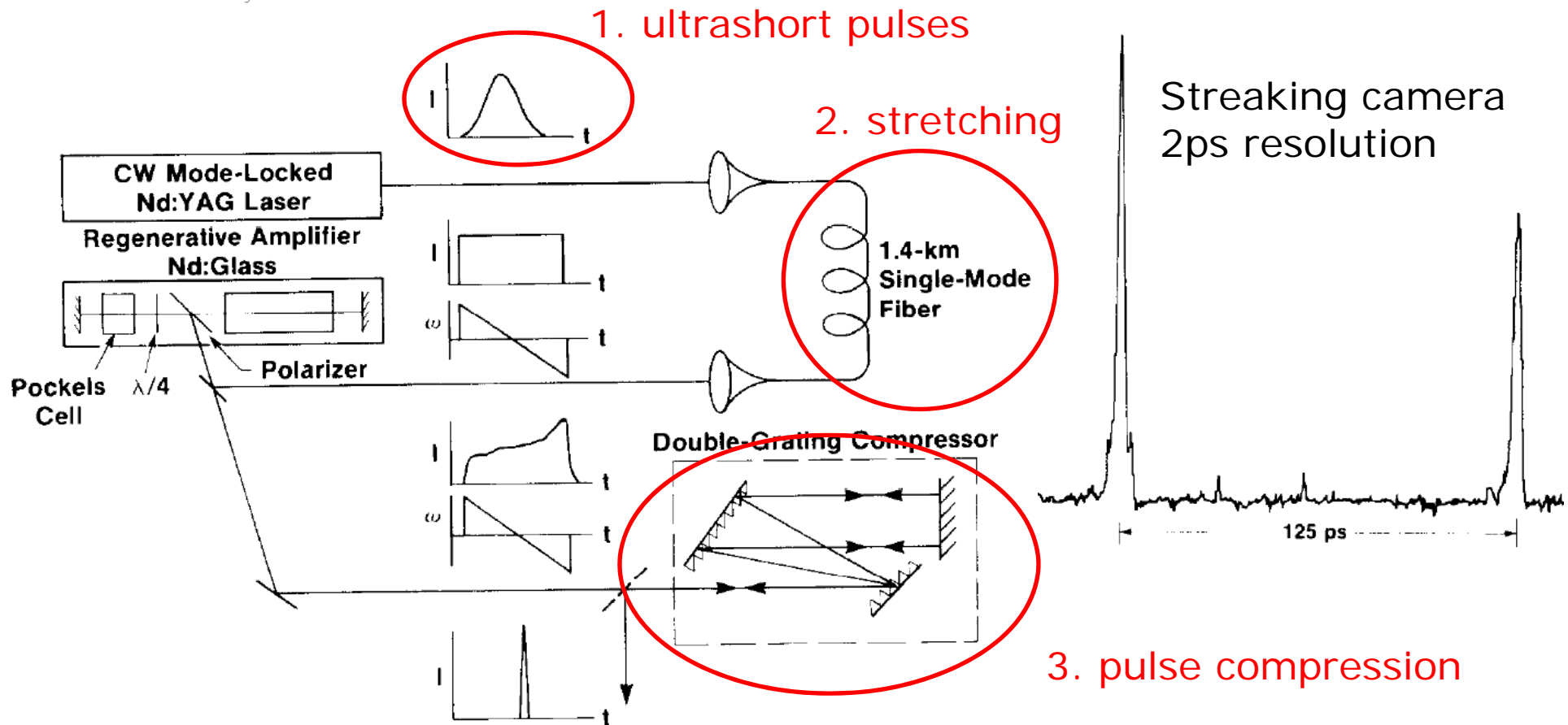


### COMPRESSION OF AMPLIFIED CHIRPED OPTICAL PULSES <sup>☆</sup>

Donna STRICKLAND and Gerard MOUROU

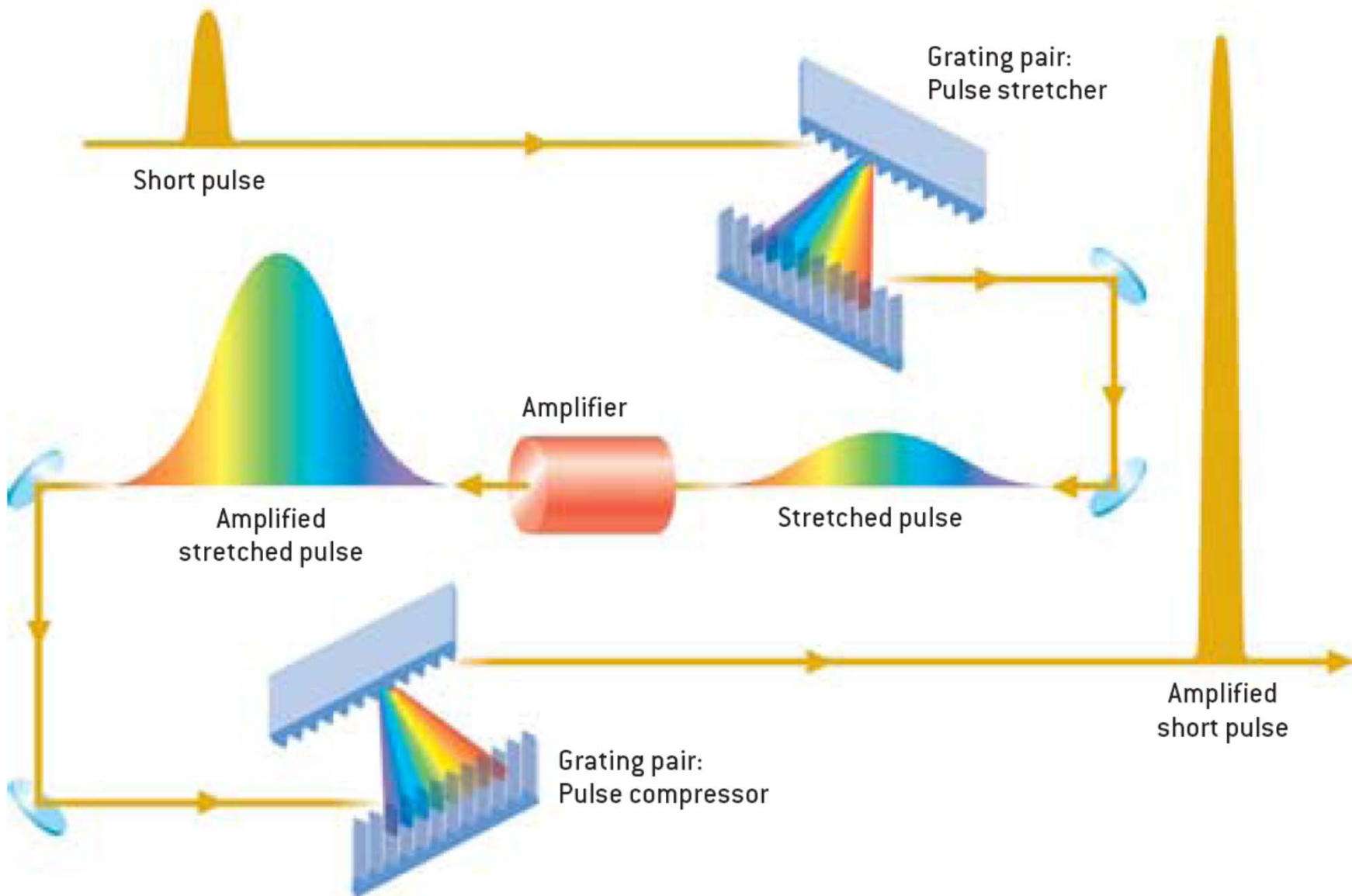
Laboratory for Laser Energetics, University of Rochester, 250 East River Road, Rochester, NY 14623-1299, USA

Received 5 July 1985



# Chirped Pulse Amplification (CPA)

G.A. Mourou, D. Umstadter, Scientific American, May (2002) 81



# Anwendungen

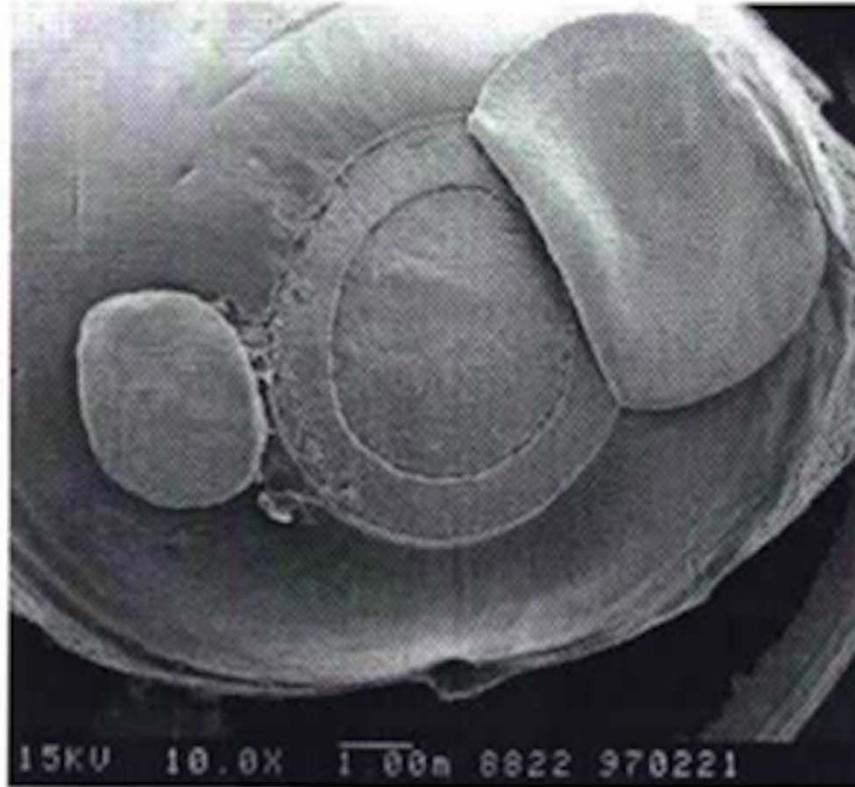
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- **Lasermaterialbearbeitung**
- Zeitaufgelöste Spektroskopie von THz bis EUV
- Femtochemie
- **Attosecond science**
- Durchstimmbare Laserquellen (OPA, NOPA, ...)
- **Ultrahohe Laserintensitäten**
- ...

# LASIK - Laserskalpell

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*Ultrashort Femtosecond Pulses*



Lifted corneal flap (top right) and extracted lenticule (left)

*Longer 60-Picosecond Pulses*



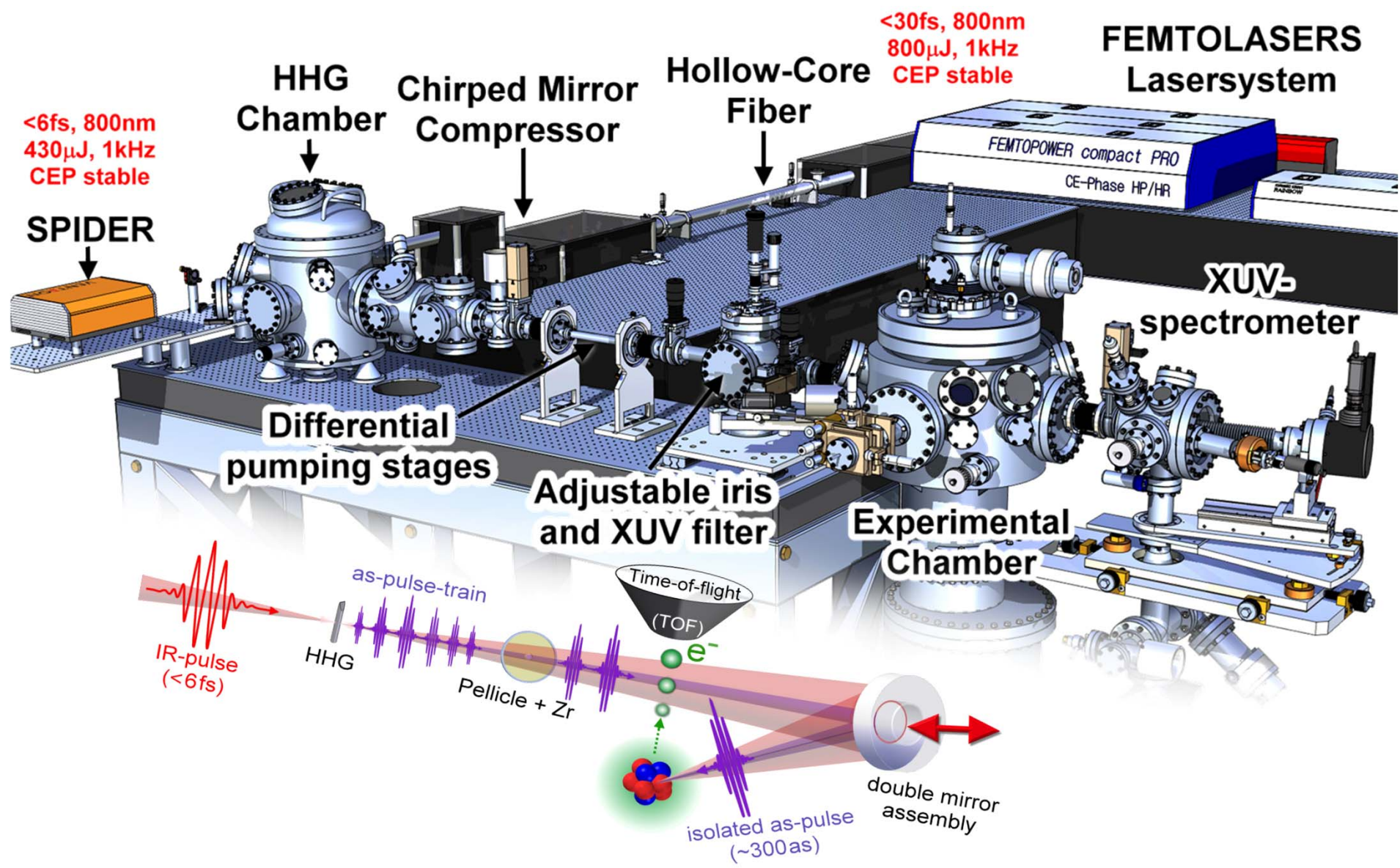
Unsatisfactory dissection with the 60-ps pulses

T. Juhasz *et al.*, Corneal refractive surgery with femtosecond lasers. *IEEE J. Select. Topics Quantum Electron.* **5**, 902–910 (1999).

<https://news.engin.umich.edu/2017/08/lasik-the-bladeless-scalpel/>



# Attosecond Laser Labor Bielefeld

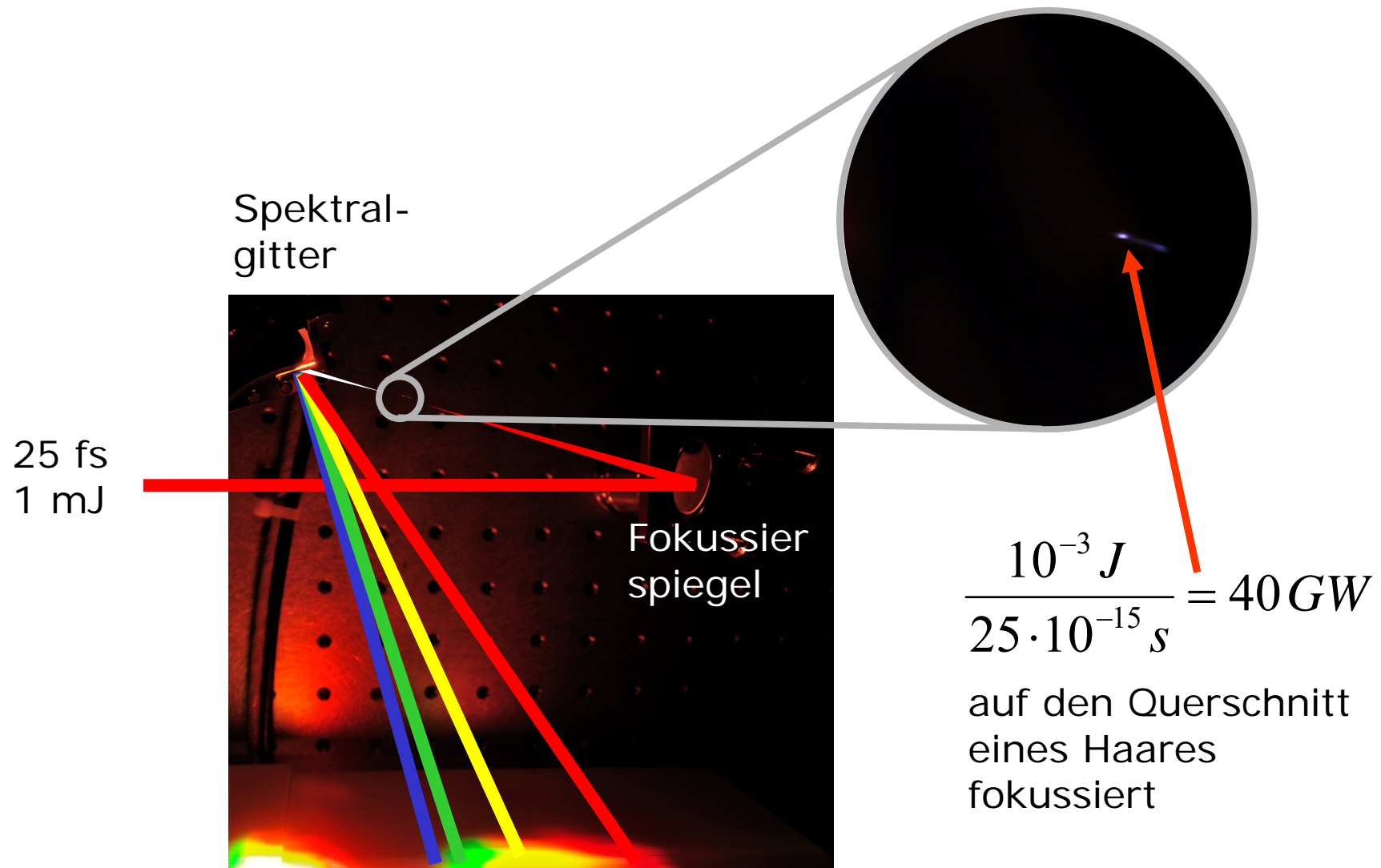


S.Neb: „Attosekunden-Streaking-Experimente an Neon“, Master Thesis (2013)



# Weißlichterzeugung

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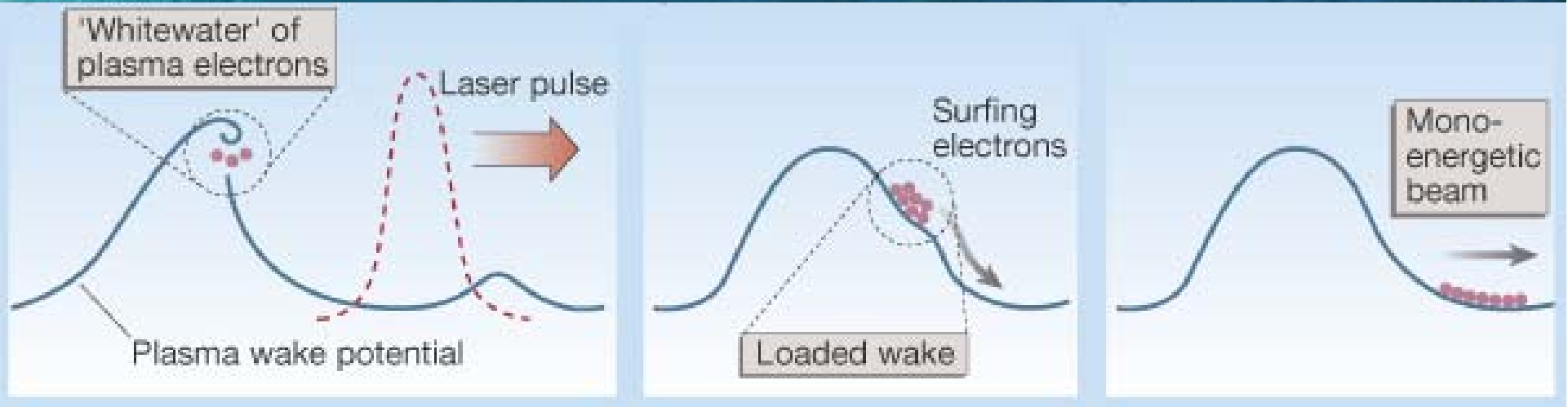
A 3D visualization of a molecular structure, likely a protein, rendered in various colors (orange, blue, green, purple). The structure is composed of numerous spheres and connecting lines. A prominent feature is a trail of small, bright green particles that starts from a larger green sphere and extends upwards and to the right, suggesting a path of electron movement or a specific reaction coordinate. The background is a gradient of purple and blue.

Siek et al., Science **357** (2017) 1274.

Attosekunden-  
Zeitauflösung liefert  
bislang unzugängliche  
Information über  
Elektronenbewegung auf  
atomaren Längenskalen.

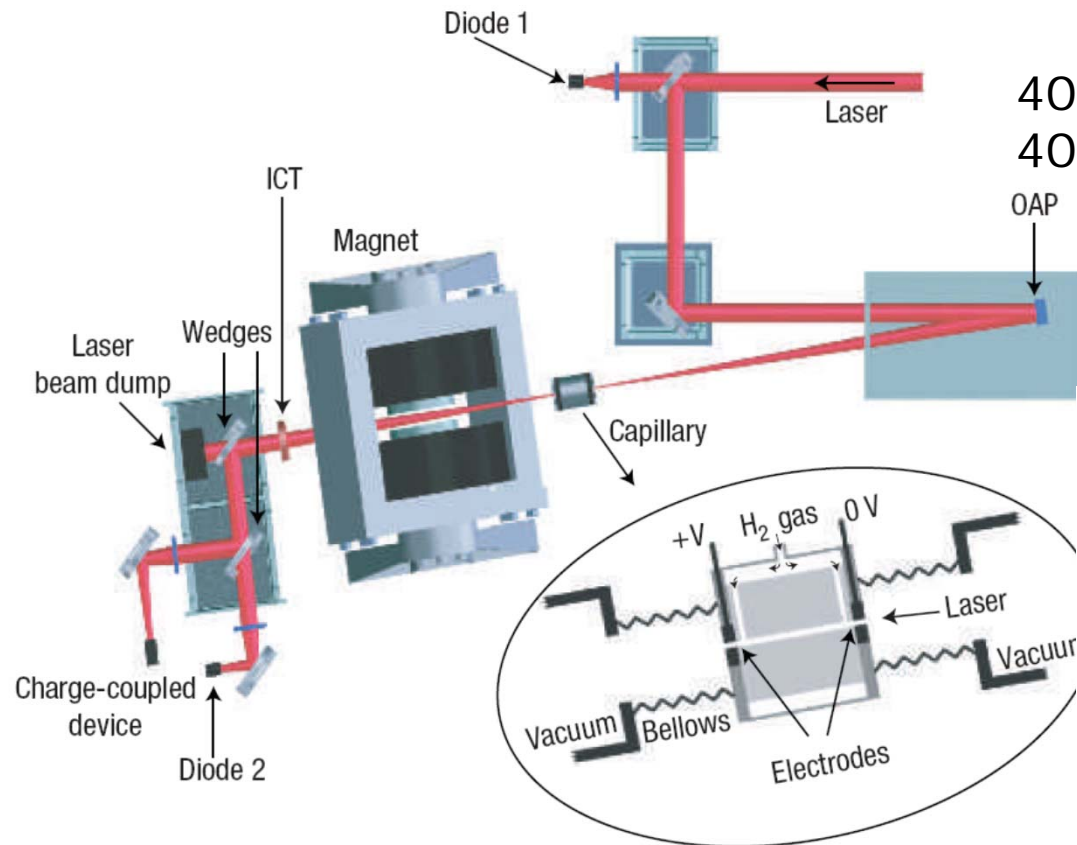
Pete Cabrinha takes a record-breaking ride on the 70-foot 'Jaws' wave off the north shore of Maui, Hawaii, on 10 January 2004

## Wakefield Acceleration



# Beschleunigung auf GeV Energien

W.P. Leemans, et al, Nature Physics 2 (2006) 697.

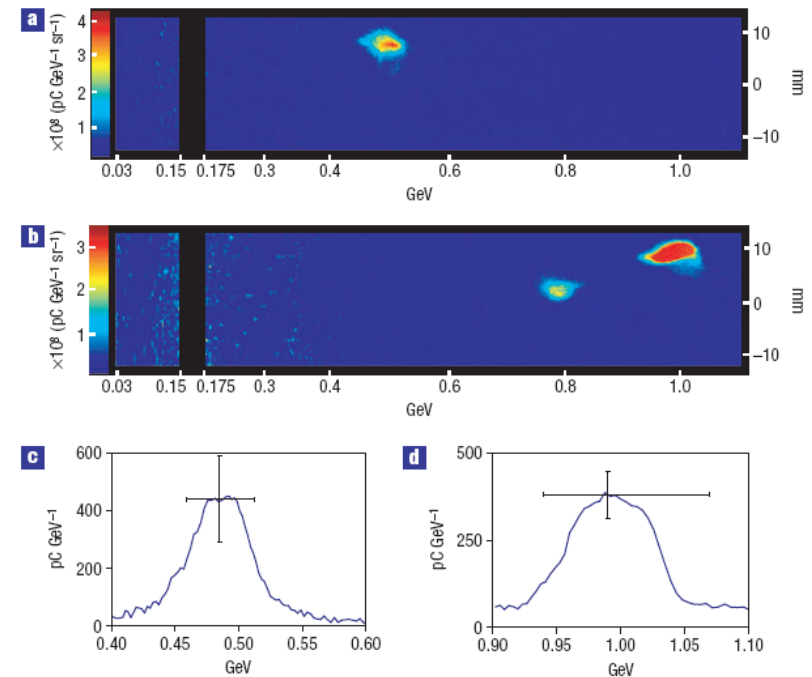


40 fs, 1000 J, 800 nm  
40 TW Spitzenleistung

1 GeV e<sup>-</sup>

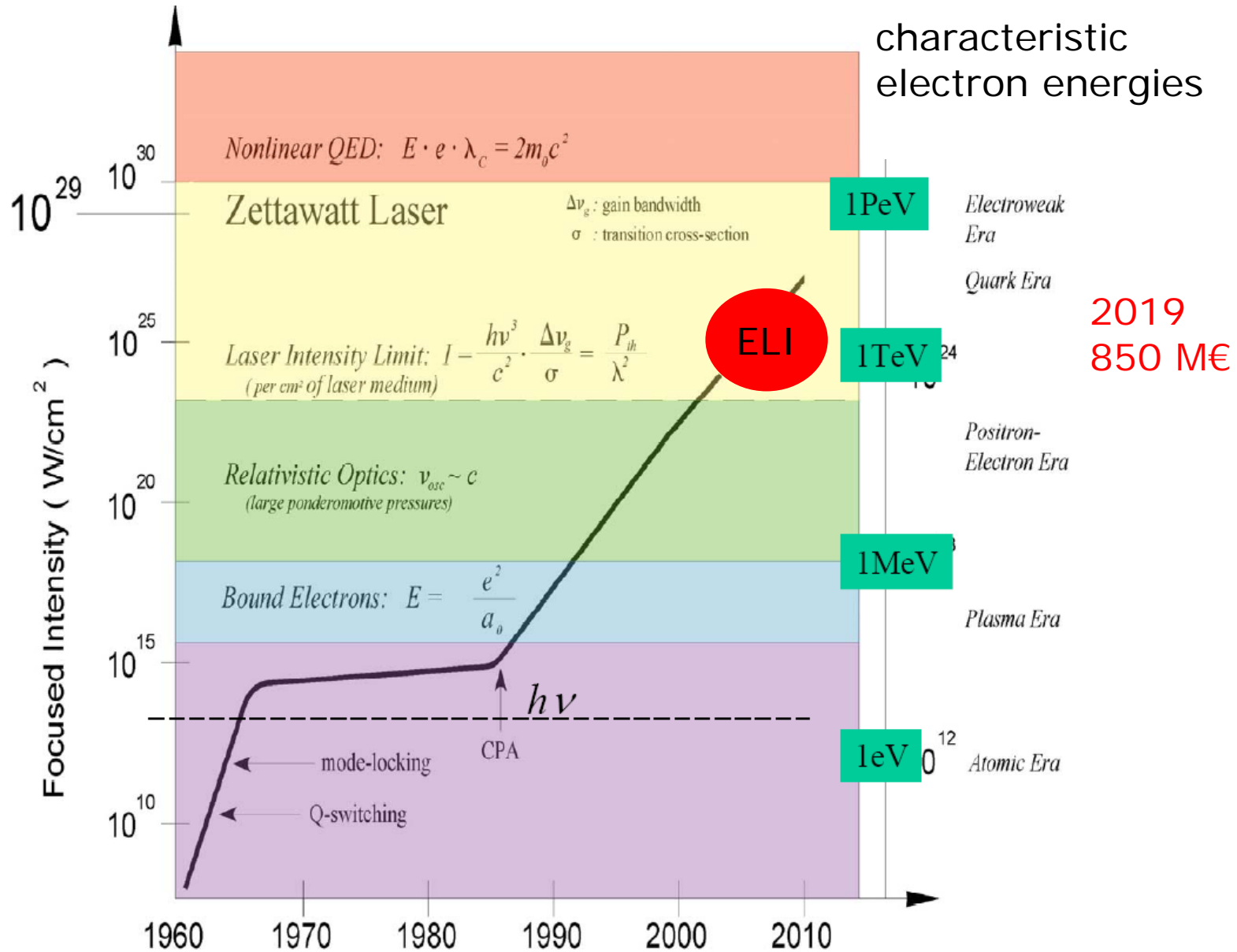
10<sup>18</sup> W cm<sup>-2</sup>

3 cm Beschleunigungsstrecke



# Ultrahohe Laserintensitäten

G. A. Mourou, T. Tajima, S. V. Bulanov, *Rev. Mod. Phys.* **78** (2006) 309.





## Dank an

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- Sie, für Ihr Interesse
- die Fachschaft,  
insbesondere Julia Burbach, Alica Grohs, und  
Torben Tappe
- Walter Enns und Tillmann Schabbehard im Labor
- Hans Bartels

# Fragen?

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## Jetzt

und gleich im Anschluss vor dem Hörsaal  
es gibt Brezeln und Bionade

Dort starten auch die Laborführungen in  
Gruppen von maximal 8 Teilnehmern