# Ch. 7  EM Wellen im Vakuum

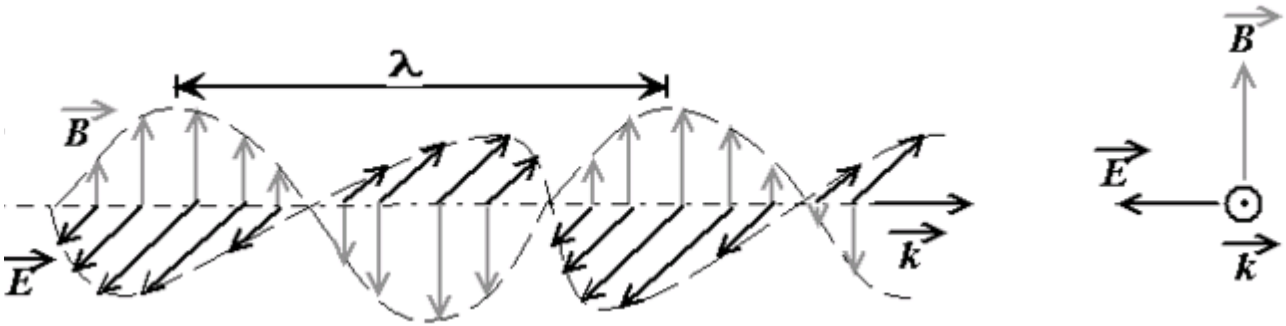
- **Lösung der Maxwell Gleichungen**
- **EM Wellen Spektrum**
- **Polarisation**
- **Energie Transport**
- **Stehende Wellen**

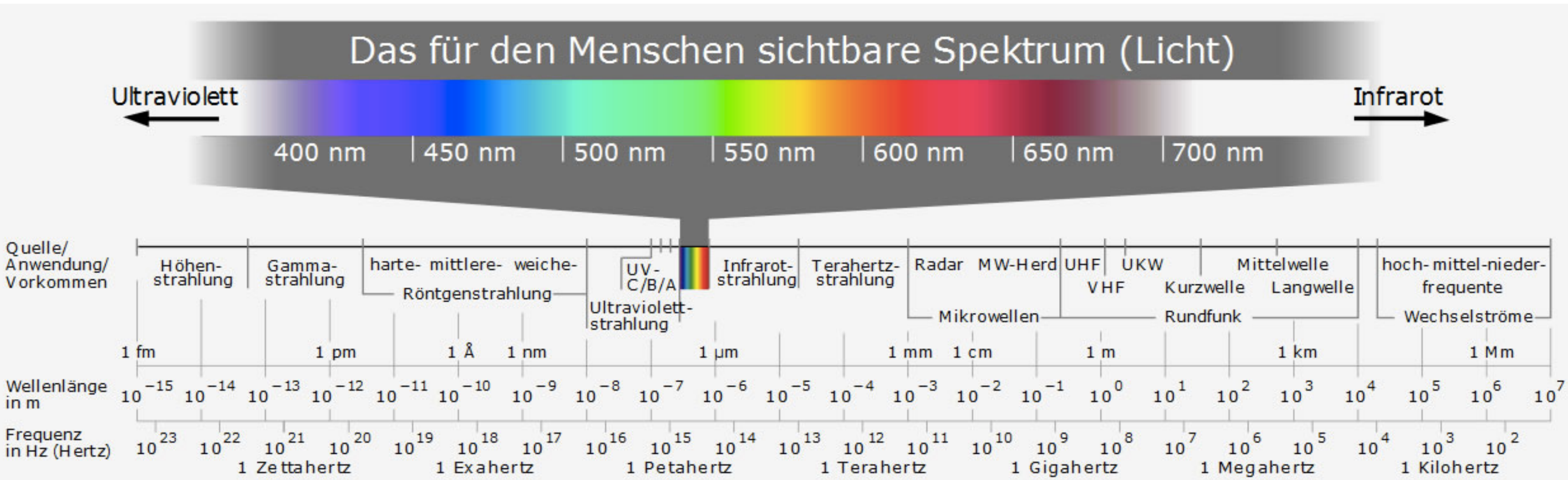
# EM Wellen

$$\nabla \cdot \mathbf{E} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial}{\partial t}\mathbf{B}$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial}{\partial t}\mathbf{E}$$

$$\nabla^2 \mathbf{E} = \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2}\mathbf{E} \qquad c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$
$$\nabla^2 \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2}\mathbf{B}$$

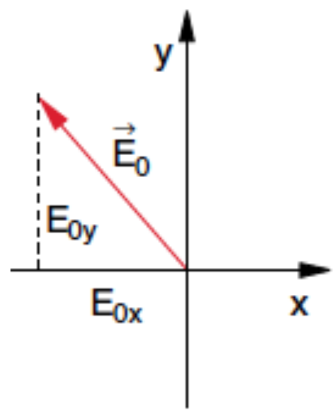
$$\nabla \times (\nabla \times \mathbf{A}) = \nabla (\nabla \cdot \mathbf{A}) - \nabla^2 \mathbf{A}$$

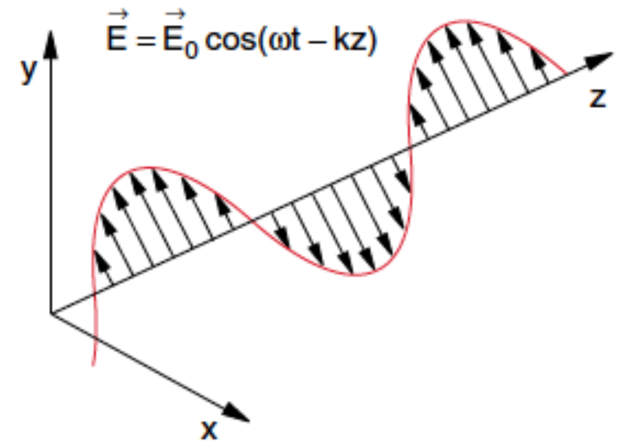


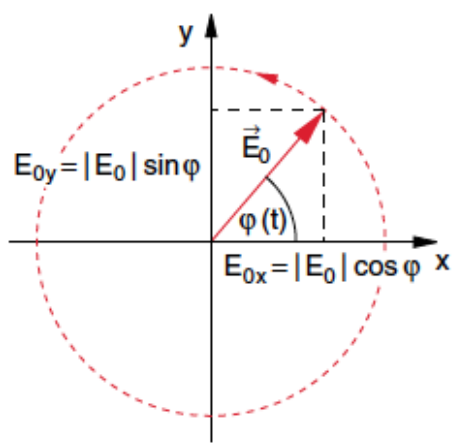
# Polarisation

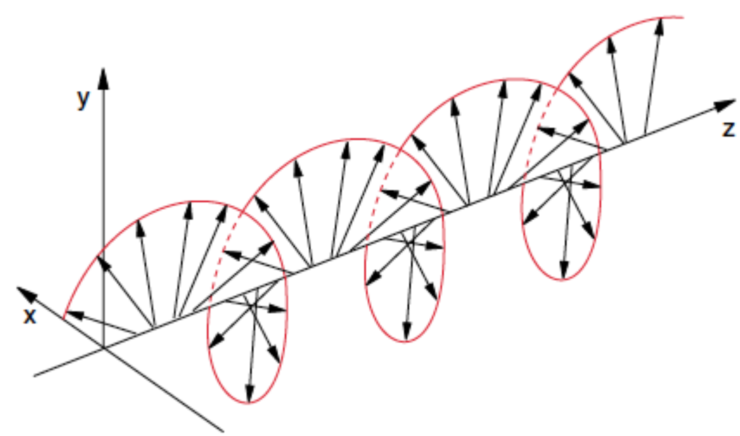
**linear**



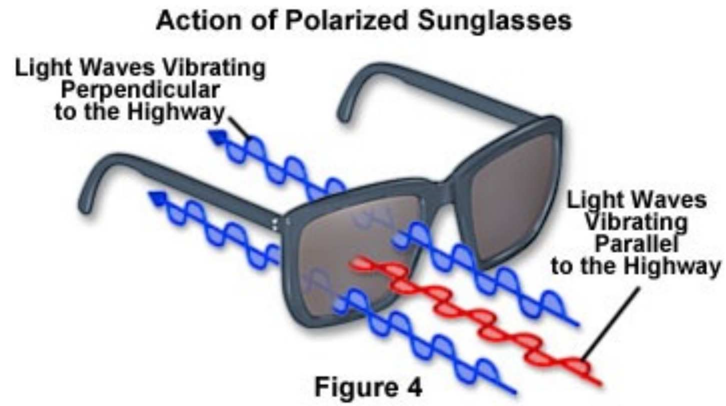



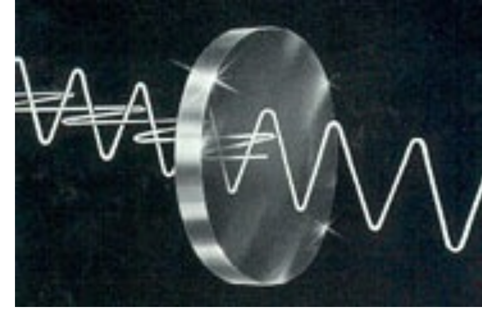

**zirkular**



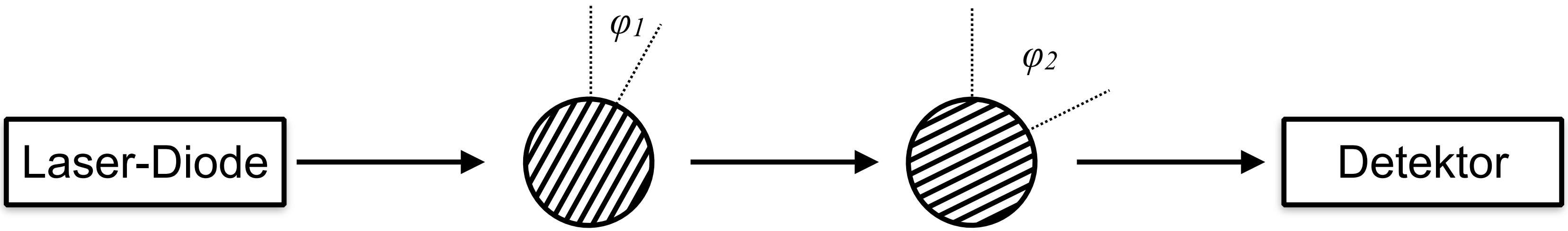



# Polarisation


# Experiment: Laserpolarisation




"Malus-Gesetz":

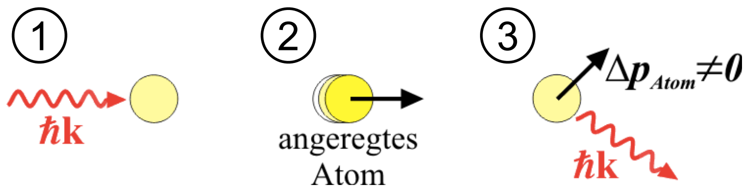
$$I(\varphi) = I_0 \cos^2(\varphi) \quad (\varphi=\varphi_2-\varphi_1)$$

| Winkel Analysator, φ | Gemessene Leistung, % | Cos |
|---|---|---|
| 0 | 100 | 1 |
| 30 | ~75 | 0.75 |
| 45 | ~50 | 0.5 |
| 60 | ~25 | 0.25 |
| 90 | 0 | 0 |

# Strahlungsdruck (radiation pressure)

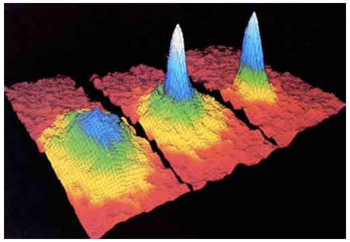
ein äusserst aktuelles Forschungsgebiet

## Atom-Kühlung mit Laser-Licht:

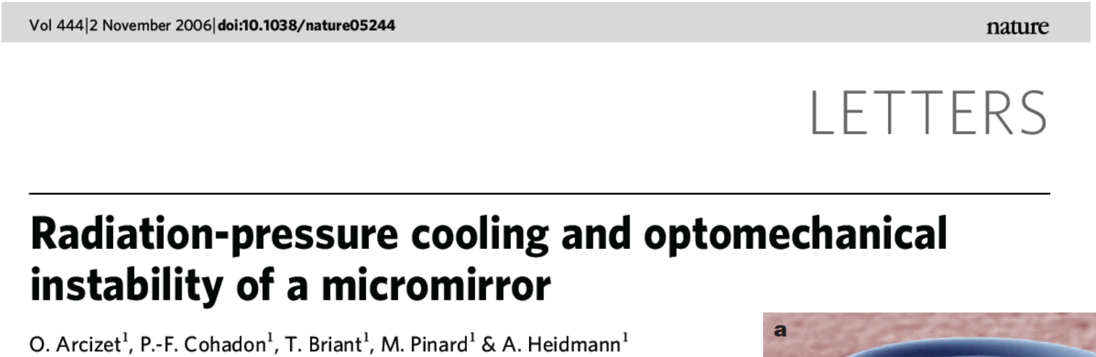



Nobel-Preise:
1997, 2001

Bose-Einstein Kondensat:



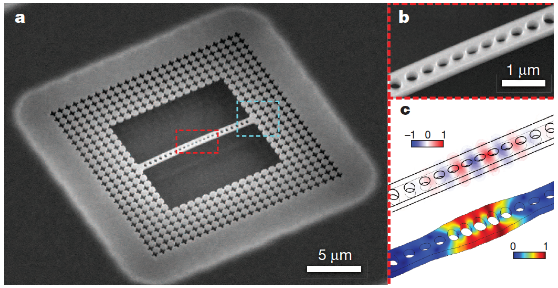
## Laserkühlung von "makroskopischen" mechanischen Oszillatoren:

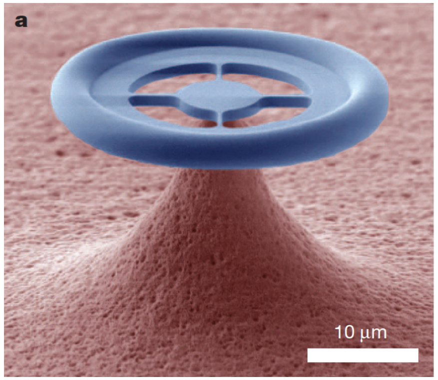

Vol 444|2 November 2006|doi:10.1038/nature05244 nature

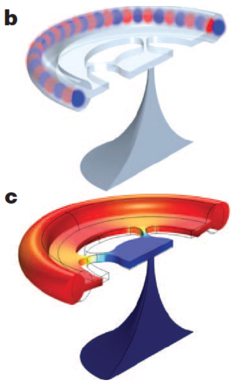
LETTERS

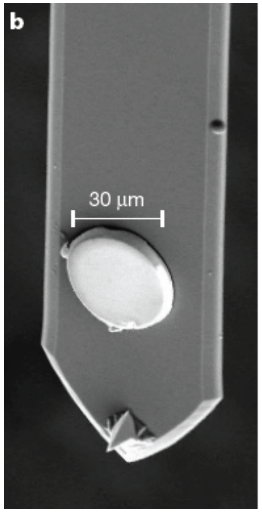
**Radiation-pressure cooling and optomechanical instability of a micromirror**

O. Arcizet[1], P.-F. Cohadon[1], T. Briant[1], M. Pinard[1] & A. Heidmann[1]



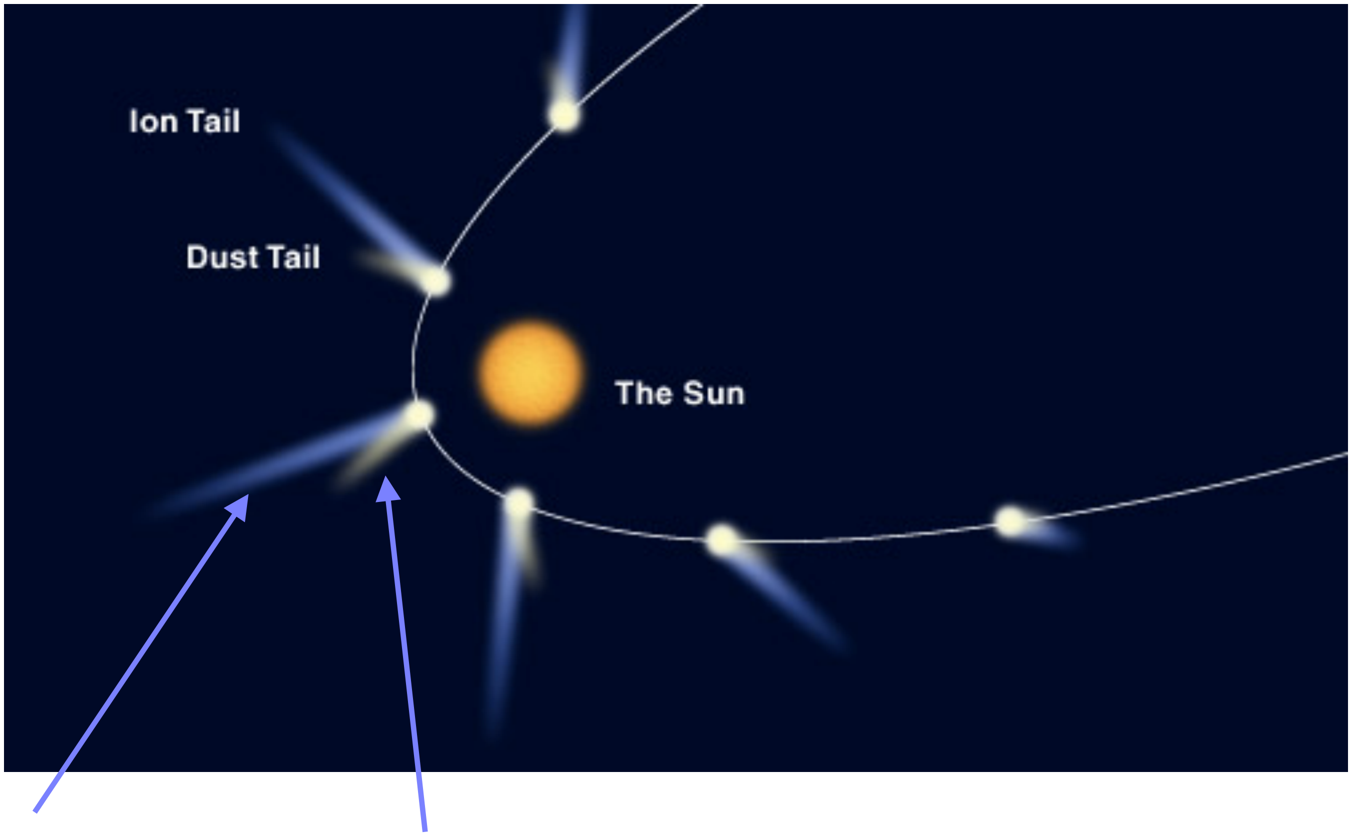



# Strahlungsdruck (radiation pressure)

Schweif eines Kometen

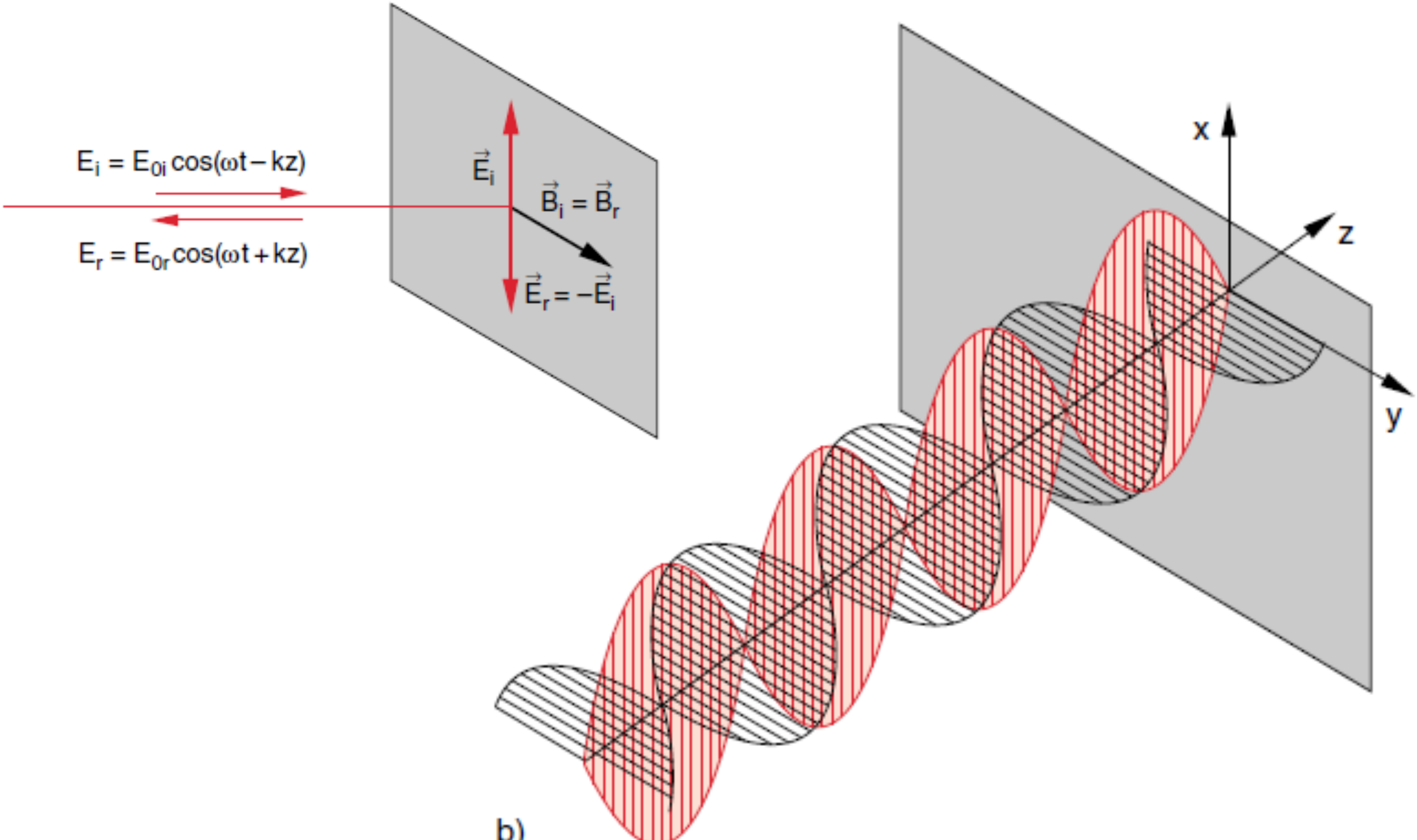



<u>Ionen-Schweif:</u>
Durch **Strahlungsdruck** abgelenkt

<u>Staub-Schweif:</u>
Durch Sonnenwind (Teilchen) abgelenkt

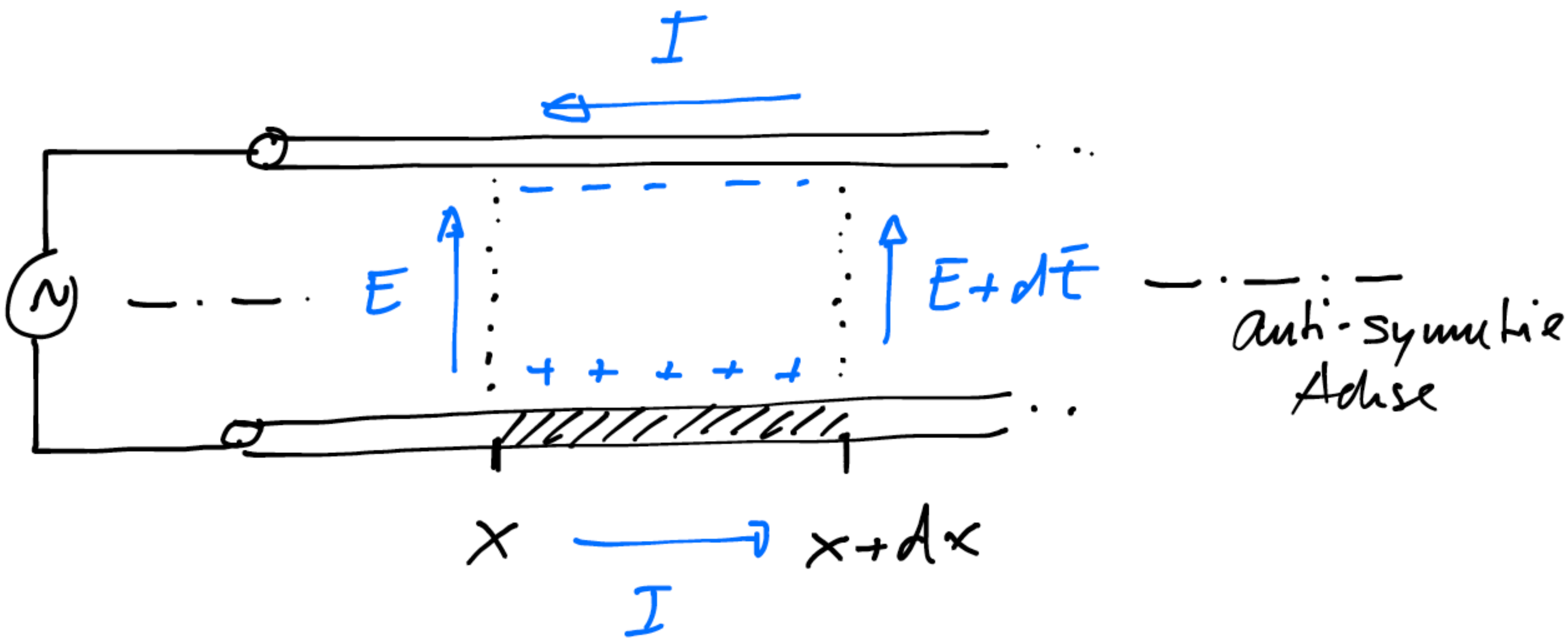
# 1D stehende Welle

durch Reflexion and leitende Ebene

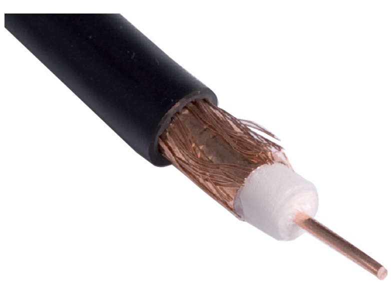


# Koaxialkabel

Die Lecher-Leitung

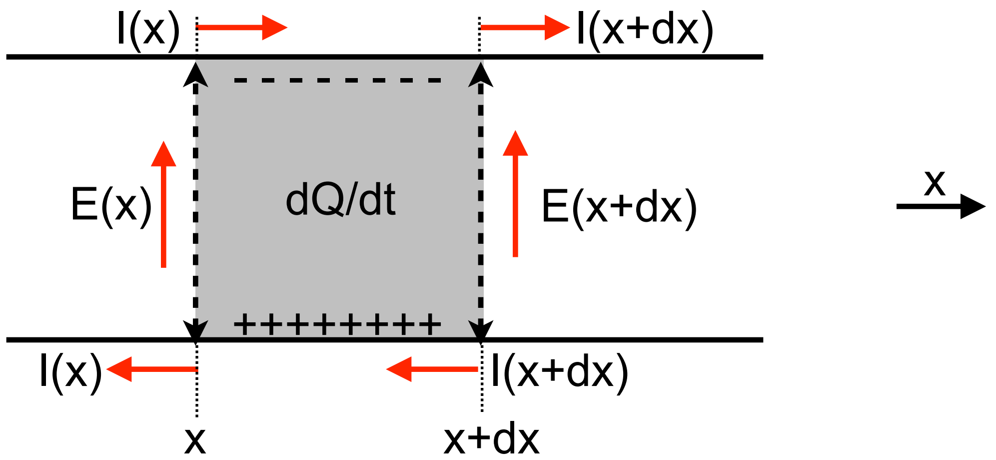



- Situation analog zu “üblichen” Koaxialkabeln



# Koaxialkabel

Die Lecher-Leitung



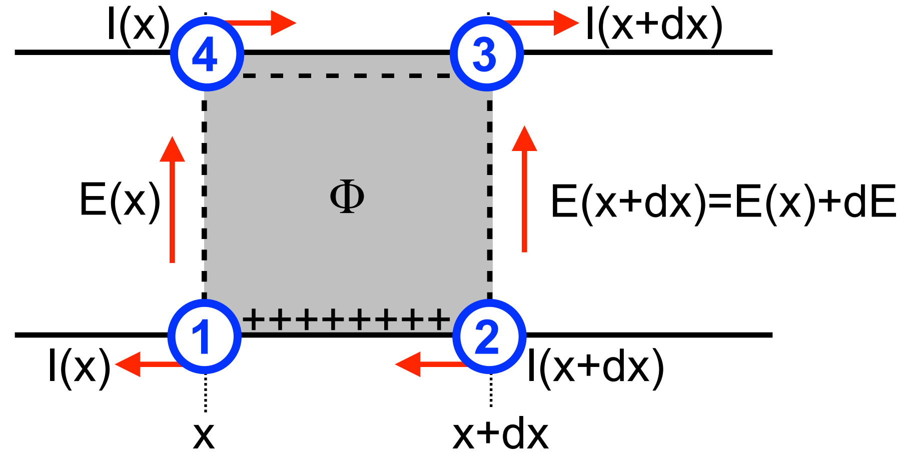

1.) Ladungsänderung im Leiterstück: x…x+dx: $d^2Q = \{I(x) - I(x+dx)\}dt = -\frac{\partial I}{\partial x}dx\,dt$

2.) Leitung als Kondensator: $C^* = \frac{C}{\text{Länge}} \Rightarrow d^2Q = (C^* dx)\,dU = C^* \frac{\partial U}{\partial t} dx\,dt$

$$\Rightarrow \underbrace{\frac{\partial U}{\partial t} = -\frac{1}{C^*}\frac{\partial I}{\partial x}} \quad (1)$$

# Koaxialkabel

## Die Lecher-Leitung




Induktionsgesetz:

$$\oint_{1-2-3-4-1} \vec{E}\, d\vec{s} = -\frac{\partial \Phi}{\partial t} = -L^* dx \frac{\partial I}{\partial t}$$

$\Phi = L \cdot I$ ; $L^* = \frac{L}{\text{Länge}}$

$$\oint_{1-2-3-4-1} \vec{E}\, d\vec{s} = U + dU + \frac{1}{2} R^* dx\, I - U + \frac{1}{2} R^* dx\, I = dU + R^* I\, dx$$

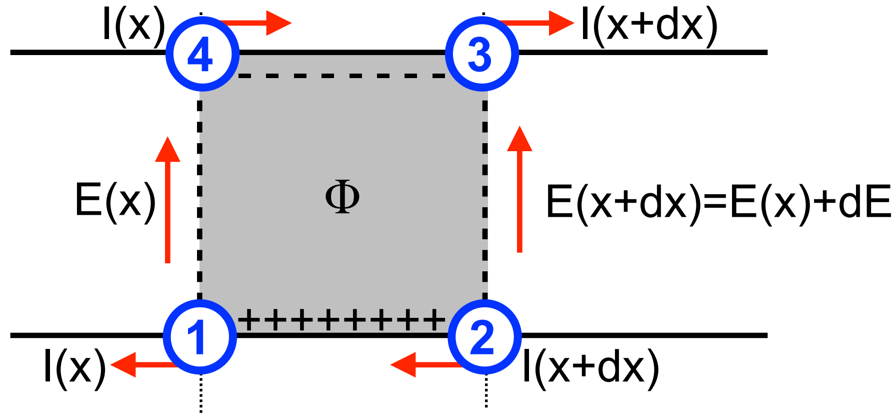
$R^* = \frac{R}{\text{Länge}}$ , gleichverteilt auf beide Leiter

$$\Rightarrow -L^* dx \frac{\partial I}{\partial t} = dU + R^* I\, dx$$

$$\Rightarrow \frac{\partial U}{\partial x} = -L^* \frac{\partial I}{\partial t} - R^* I \qquad (2)$$

# Koaxialkabel

## Die Lecher-Leitung




$$\frac{\partial}{\partial t}(2) \rightarrow \frac{\partial^2 U}{\partial t\,\partial x} = -L^* \frac{\partial^2 I}{\partial t^2} - R^* \frac{\partial I}{\partial t}$$

$$\frac{\partial}{\partial x}(1) \rightarrow \frac{\partial^2 U}{\partial t\,\partial x} = -\frac{1}{C^*} \frac{\partial^2 I}{\partial x^2}$$

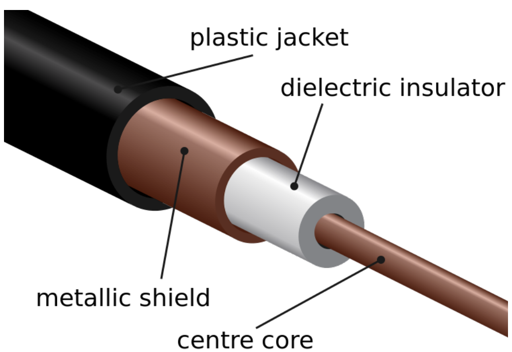
$$\boxed{\frac{\partial^2 I}{\partial t^2} + \frac{R^*}{L^*}\frac{\partial I}{\partial t} = \frac{1}{L^* C^*}\frac{\partial^2 I}{\partial x^2}}$$ „Telegraphengleichung“

Die entsprechende Gleichung gilt identisch für U

## Beschrieben durch Telegraphengleichung

$$\frac{\partial^2 I}{\partial t^2} + \frac{R^*}{L^*}\frac{\partial I}{\partial t} = \frac{1}{L^* C^*}\frac{\partial^2 I}{\partial x^2}$$

- Wellengeschwindigkeit: $v=1/(L^*C^*)^{1/2}$
- Impedanz (Z=U/I): $Z=(L^*/C^*)^{1/2}$
- Reflexion an Impedanz-Sprung: $R=(Z_1-Z_2)/(Z_1+Z_2)$




Typische Werte (Kabel-typ "RG-58"):

C*~ 68 pF/m
L*~ 170 nH/m
Z = 50 Ω

Z = 50 Ω weit verbreitet. Grund: minimiert Verluste

Für <u>TV-Kabel</u>: Z = 75 Ω
Grund: Antennenwiderstand von Dipol-Antenne: 75 Ω