Wissenschaftliches Rechnen als Anleitung zum wissenschaftlichen Arbeiten

Laser in der Krebstherapie

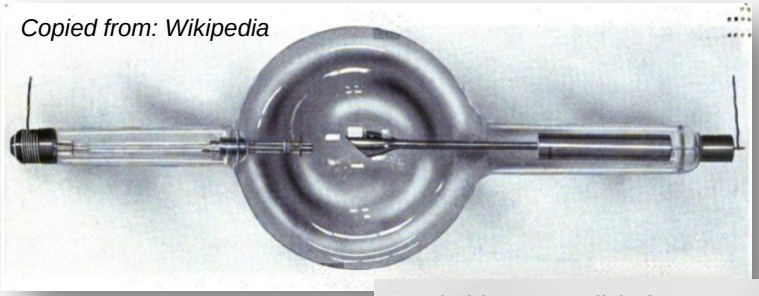
Michael Bussmann, Computergestützte Strahlenphysik

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF


Teilchen-
beschleuniger

100 Jahre Beschleunigerforschung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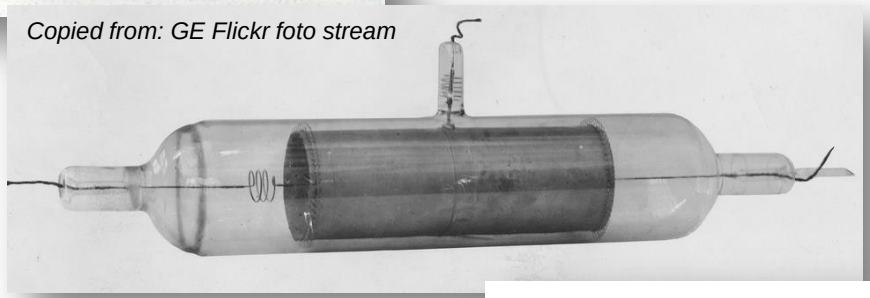
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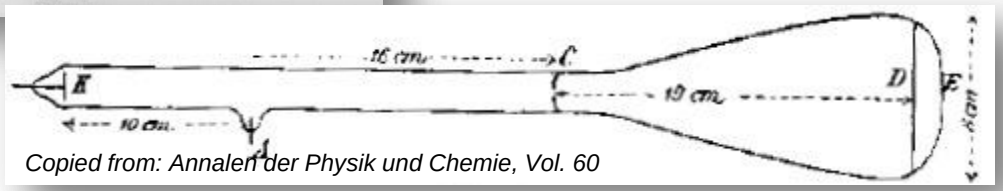

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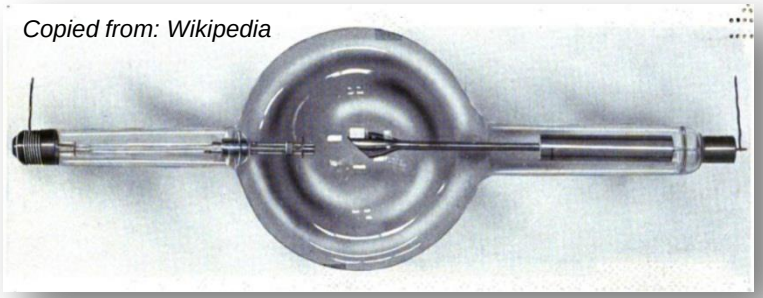
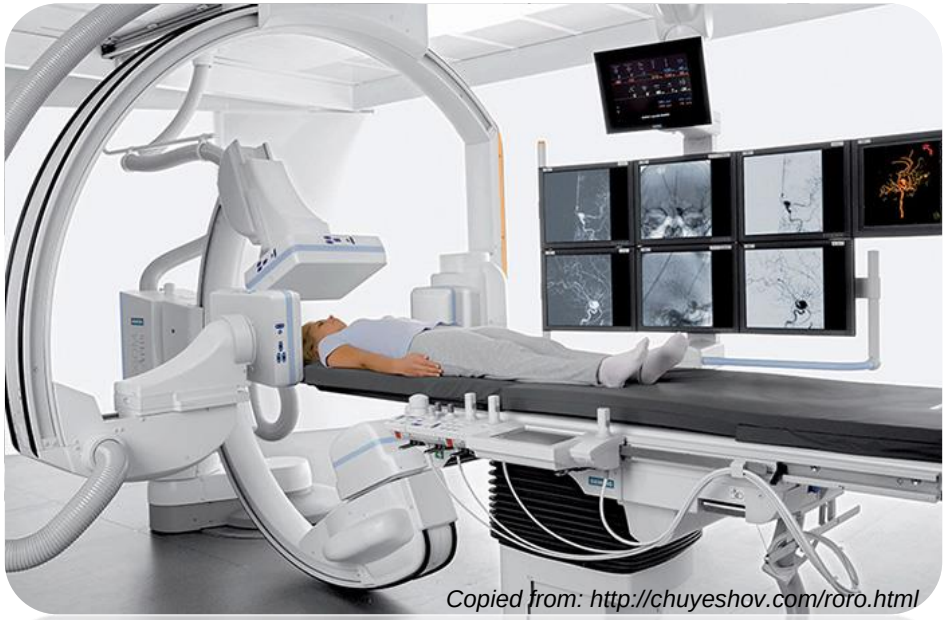
Elektronenröhren vom Beginn des 20. Jahrhunderts

Medizinische Anwendungen



Coolidge X-Ray Tube



Siemens Axiom Artis dBA

Haushaltsgeräte

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Hull Magnetron

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Microwave

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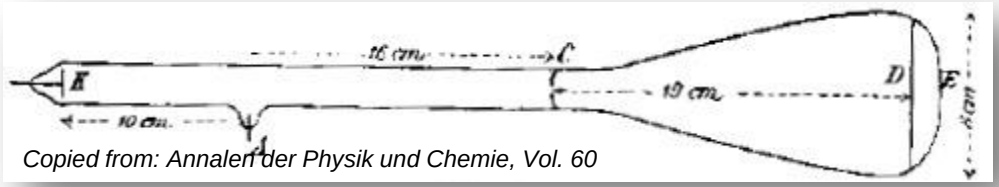
Entertainment



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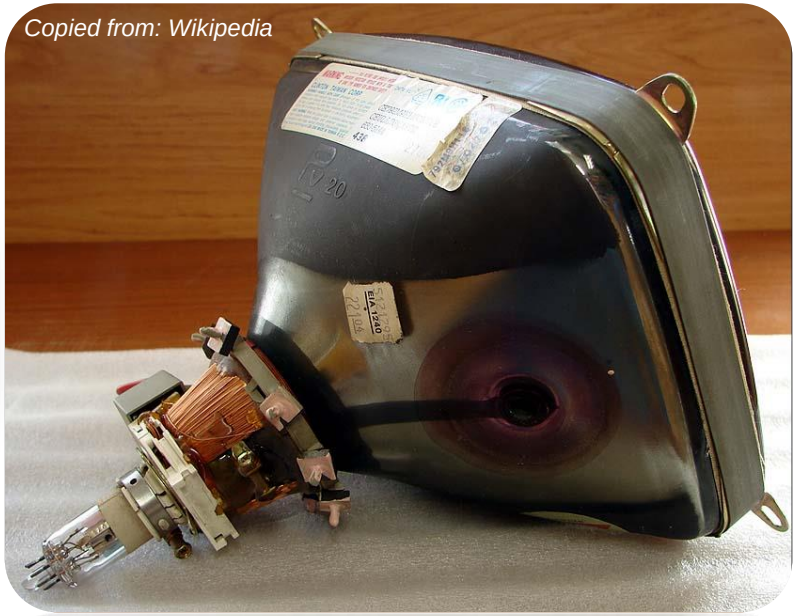
Braun Tube



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TV Cathode Ray Tube

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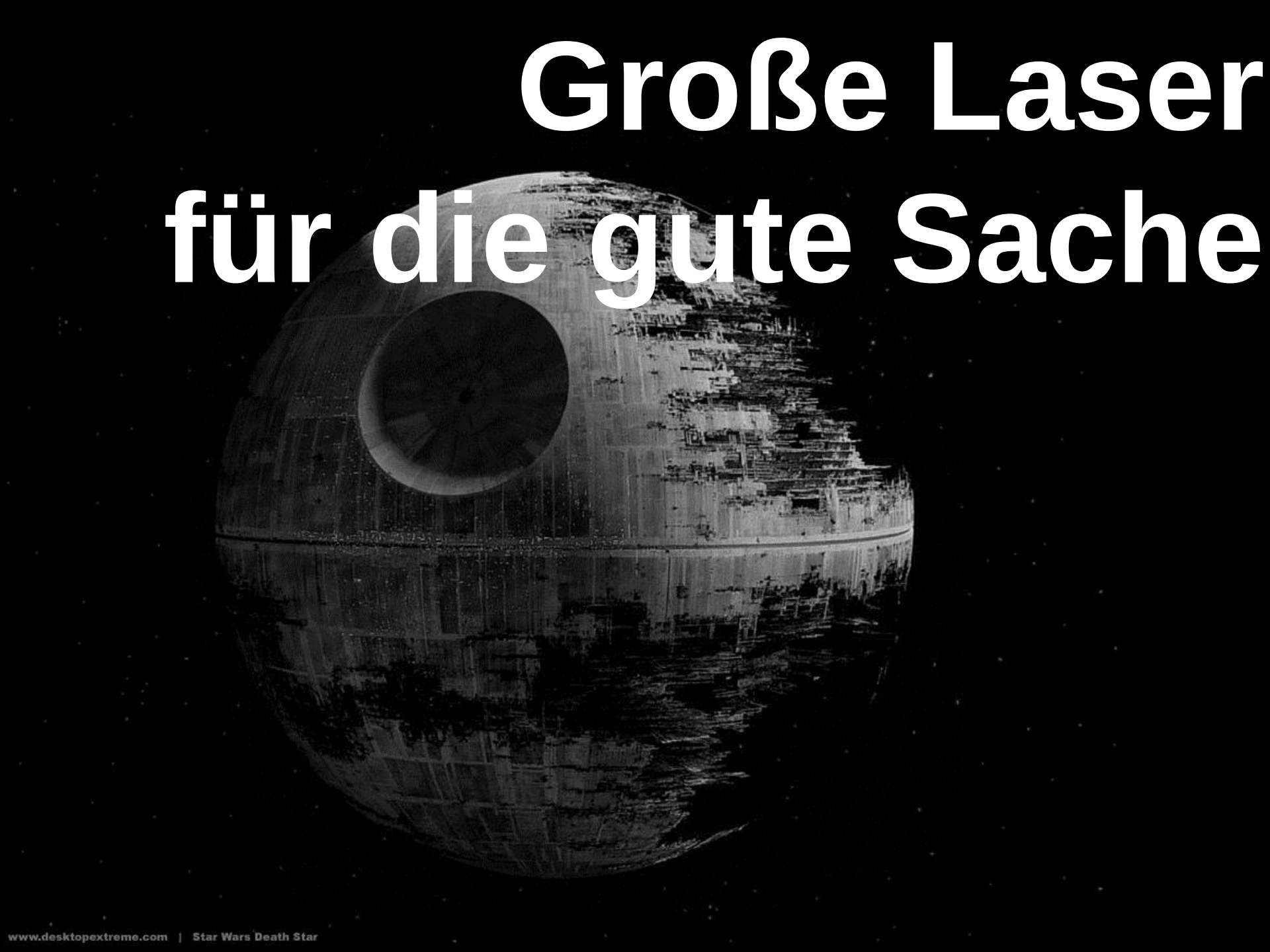
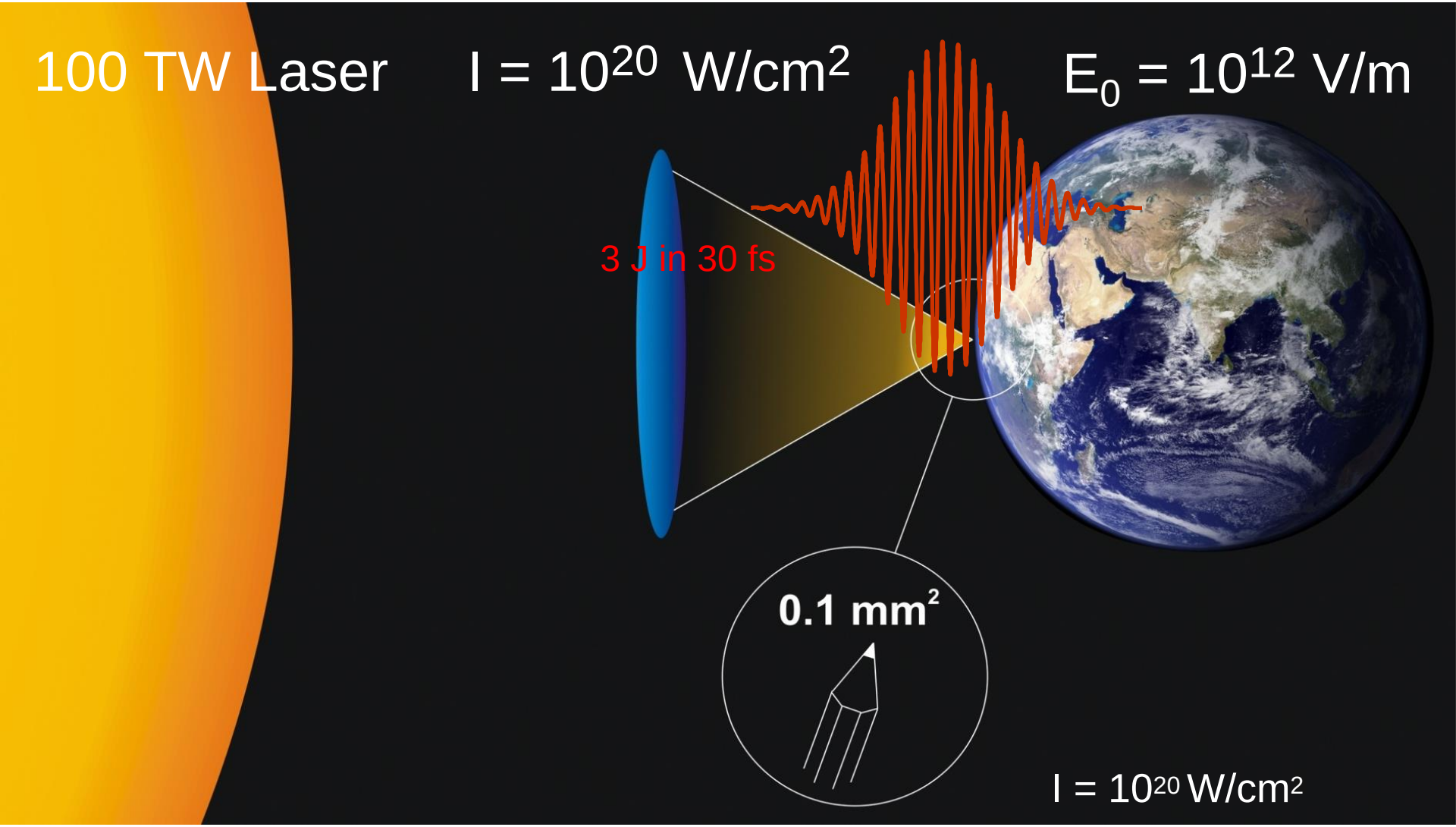
Große Laser für die gute Sache



Laser-Teilchenbeschleunigung

Laserintensität



Laser charakterisieren

Pulsdauer

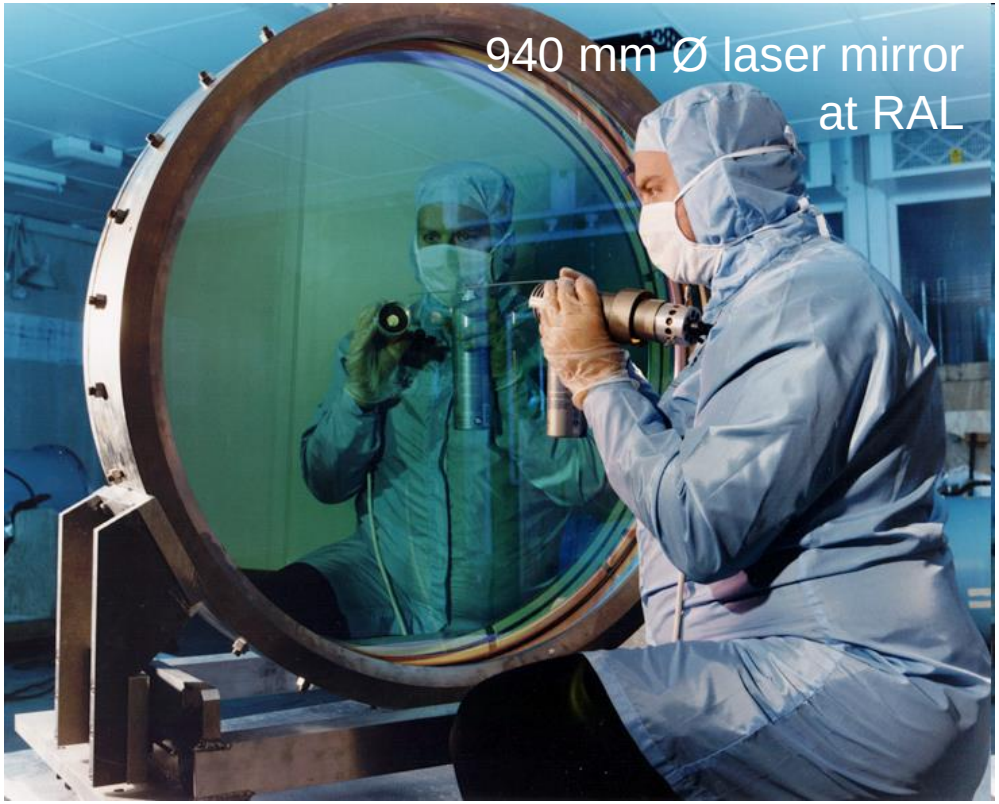
- Ultrakurz (10 fs – 1 fs)
- Kurz (ps - 100 fs)
- Lang (ns)

Energie im Puls

- mJ
- J
- kJ bis MJ

Wiederholrate

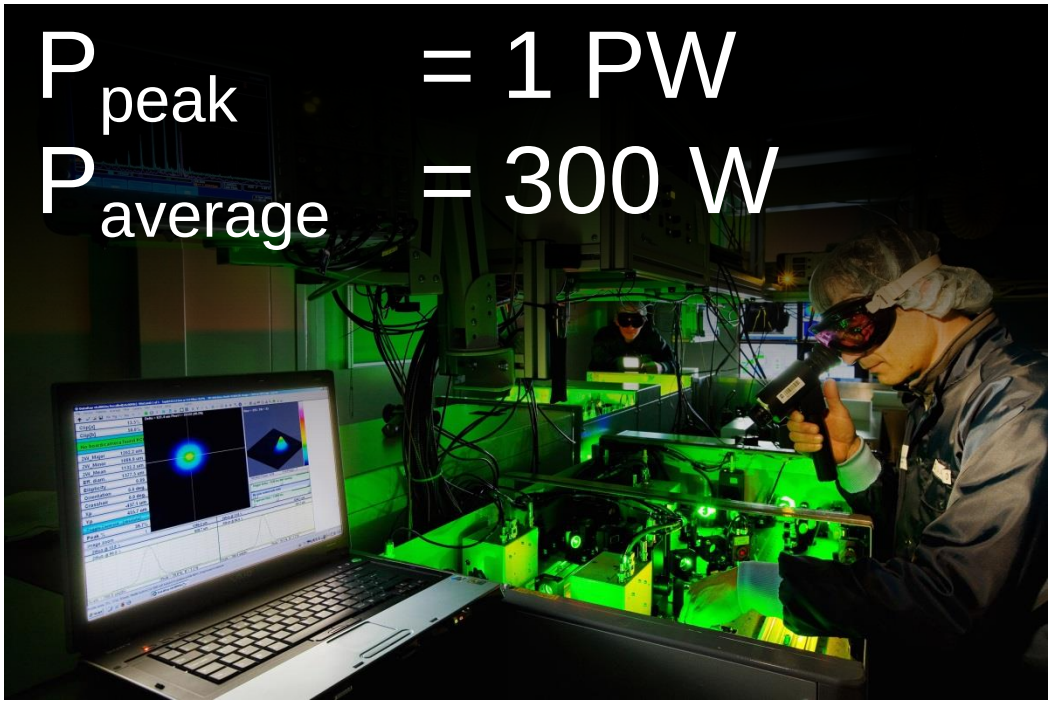
- kHz to MHz
- Hz
- 1/h bis 1/Tag



Spitzenleistung und Durchschnittsleistung

$$P_{peak} = \frac{E_{pulse}}{\tau_{pulse}}$$

$$P_{average} = E_{pulse} f_{repetition}$$



DRACO Laser am HZDR

- Wiederholrate
- Pulsenergie
- Pulsdauer

$f_{repetition} = 10$ Hz
$E_{pulse} = 30$ J
$\tau_{pulse} = 30$ fs

Laserparameter a_0 — Relativistische Intensitäten

$$a_0 = \frac{eE_0\lambda_{Laser}}{2\pi m_e c^2} = 0.85\times10^{-9}\times\sqrt{I_{laser}[W/cm^2]}\times\lambda_{laser}[\mu m]$$

$$a_0 = 1 \Rightarrow \underbrace{eE_0\lambda_{laser}}_{\text{~ kinetische Energie im Laserfeld}} \approx \underbrace{m_e c^2}_{\text{Ruheenergie eines Elektrons}} \underset{\lambda_{laser}=1\mu m}{\Rightarrow} I_0 \approx 1.38\times10^{18} W/cm^2$$

Intensität, bei der Elektronen relativistisch werden

$$a_{0,ion} = \frac{m_{ion}}{m_{electron}} a_{0,electron}$$

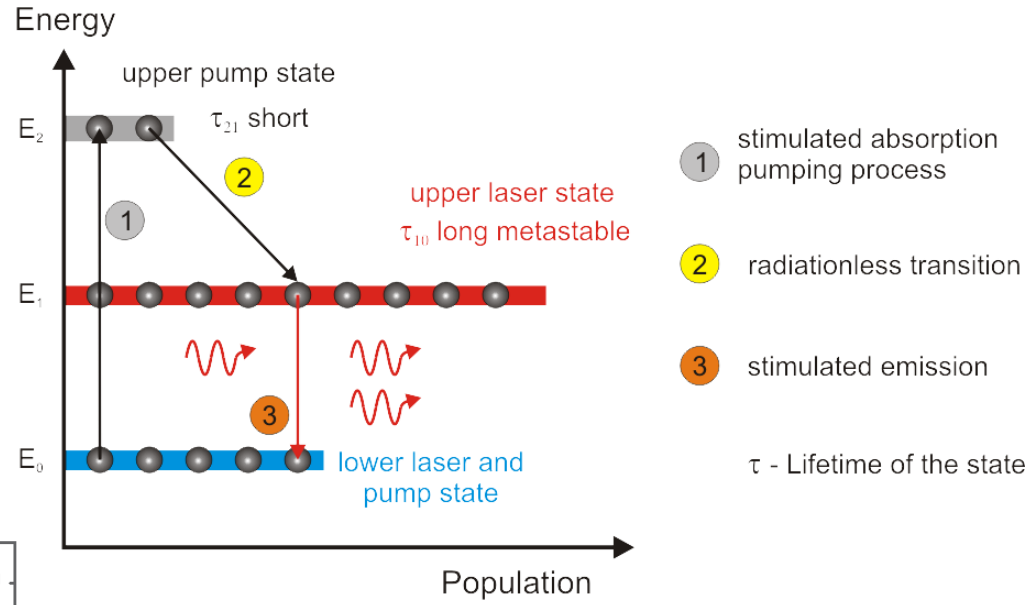
$$\lambda_{laser} \approx 1\mu m$$

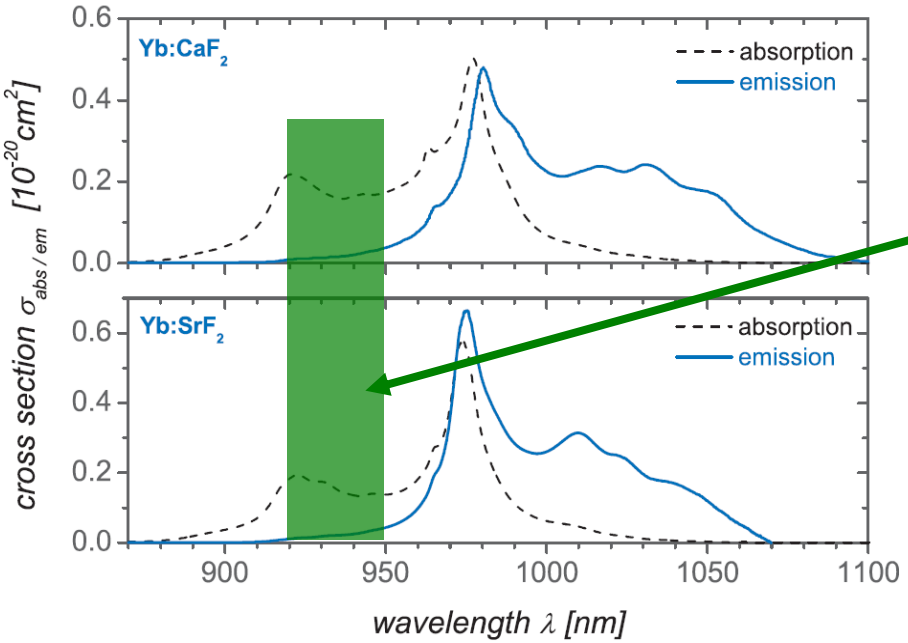
$$I_{DRACO} = 10^{18} W/cm^2 \ldots 10^{21} W/cm^2$$

Laserverstärkung

Dreilevelsystem

- Pumpwellenlänge (grün)
- Schneller Zerfall in langlebigen Zustand
- Populationsinversion
- Stimulierte Emission (Lasing)



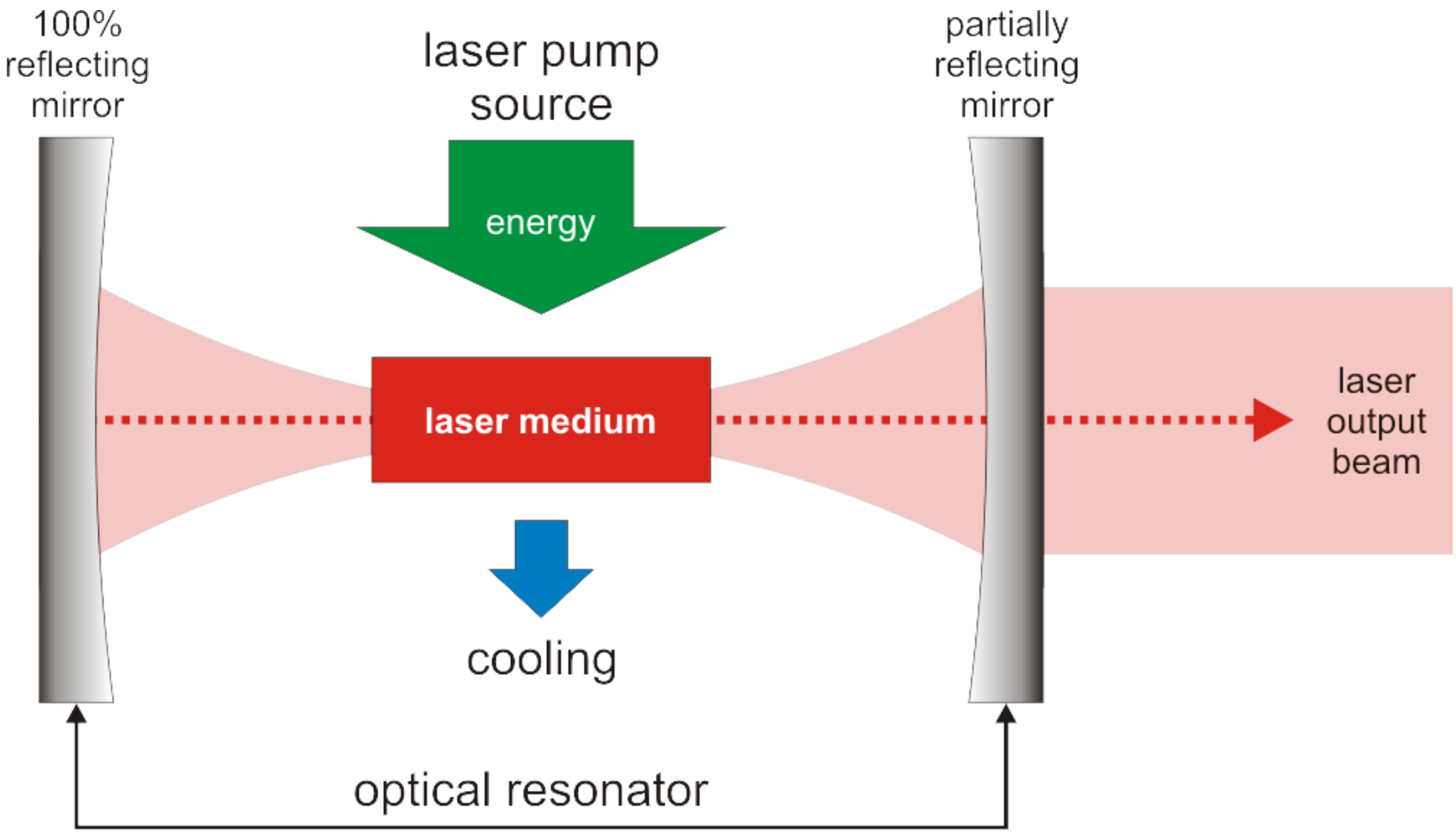


Pumpwellenlänge

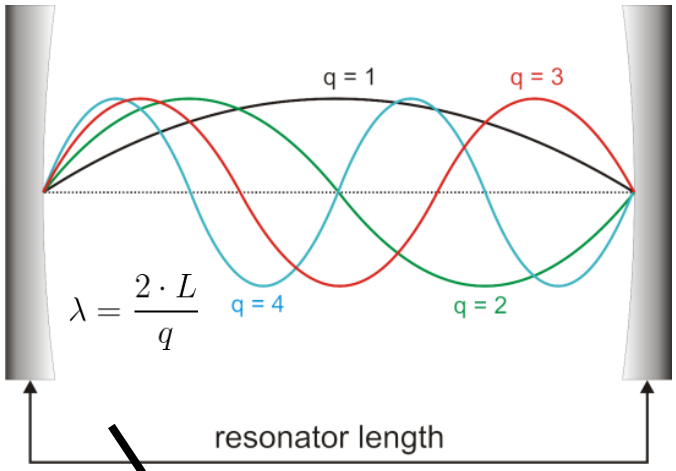
Pumplaserdioden (gestapelt)

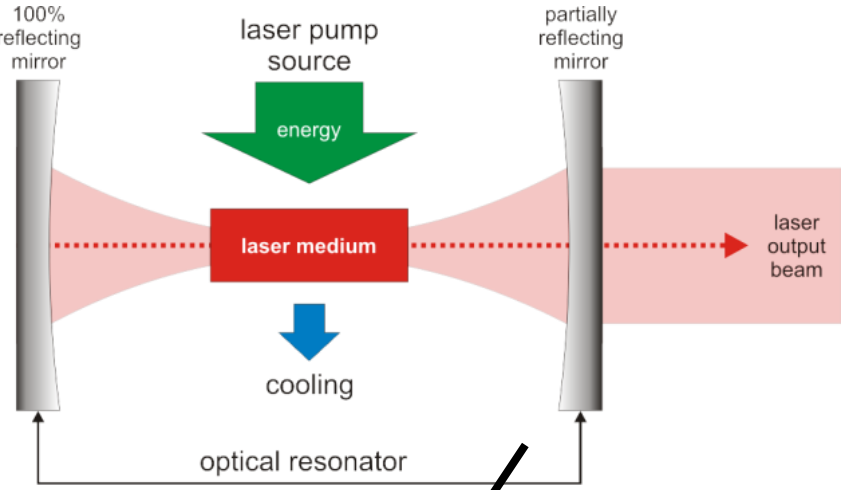
V. Petit et.al., Appl.Phys.B **78**, p.681, (2004).
M. Siebold et. al., Opt.Lett. **32** p.1818 (2007).

Laserberstärkung



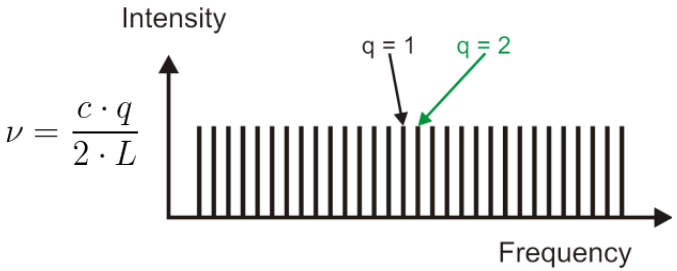
Kurzpulserzeugung durch Interferenz in Resonator





Resonator modes

Gain spectrum



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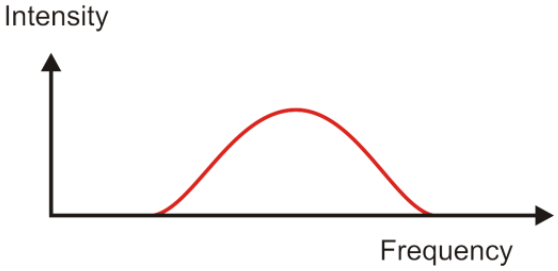

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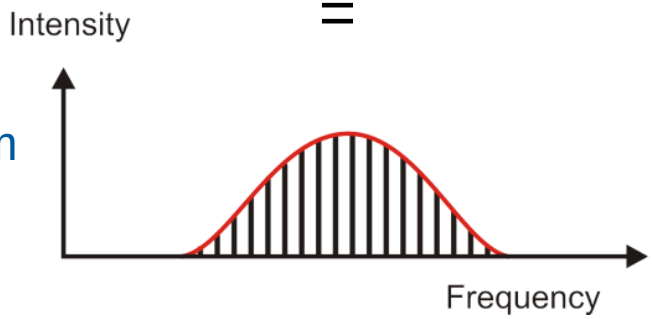

the broader the spectrum
the shorter the pulse

c speed of light
ν frequency
λ wavelength
q mode number
L resonator length

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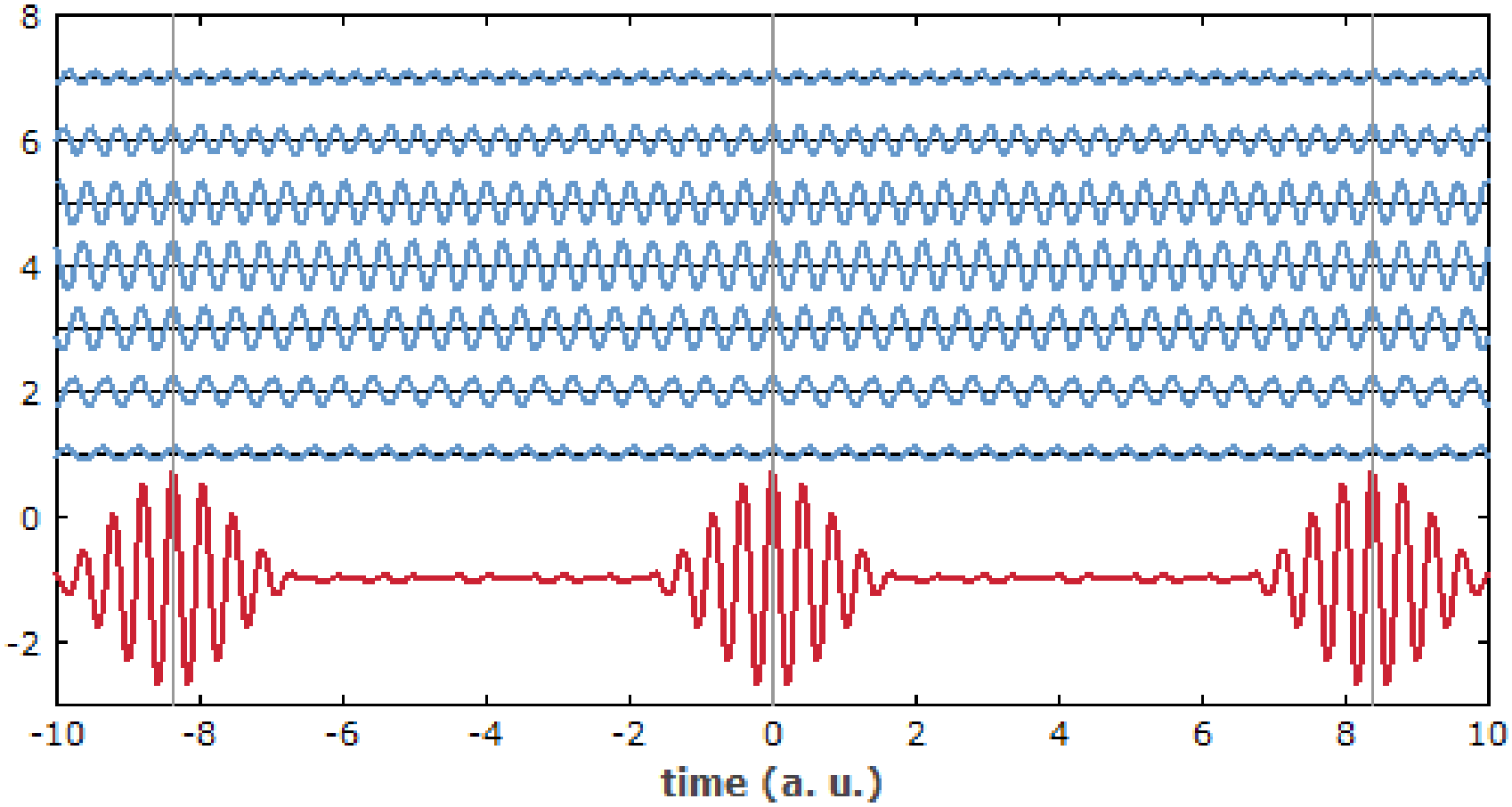
Kurzpulserzeugung durch phasenrichtige Addition



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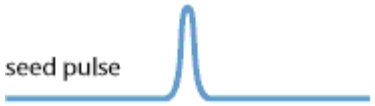
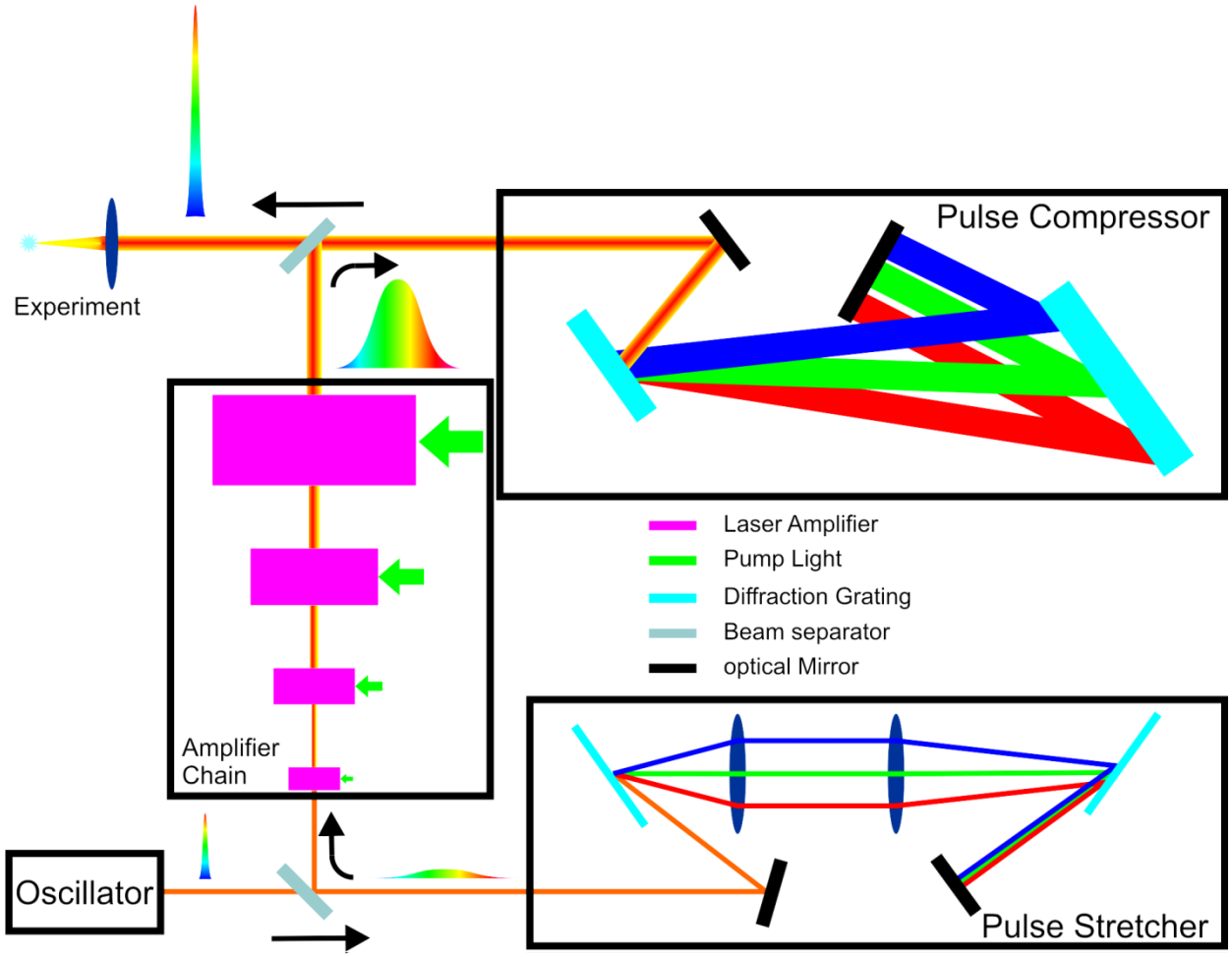
Chirped Pulse Amplification (CPA)

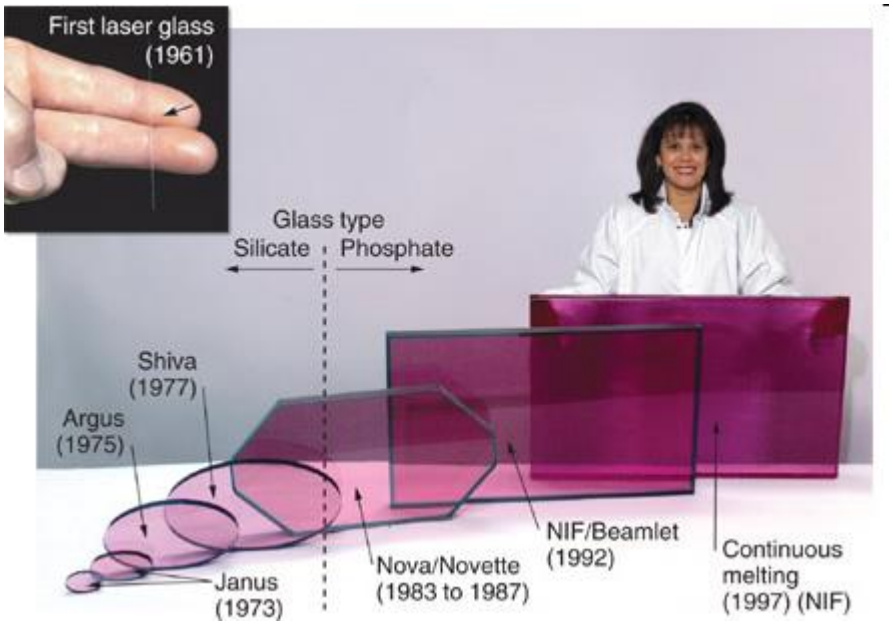


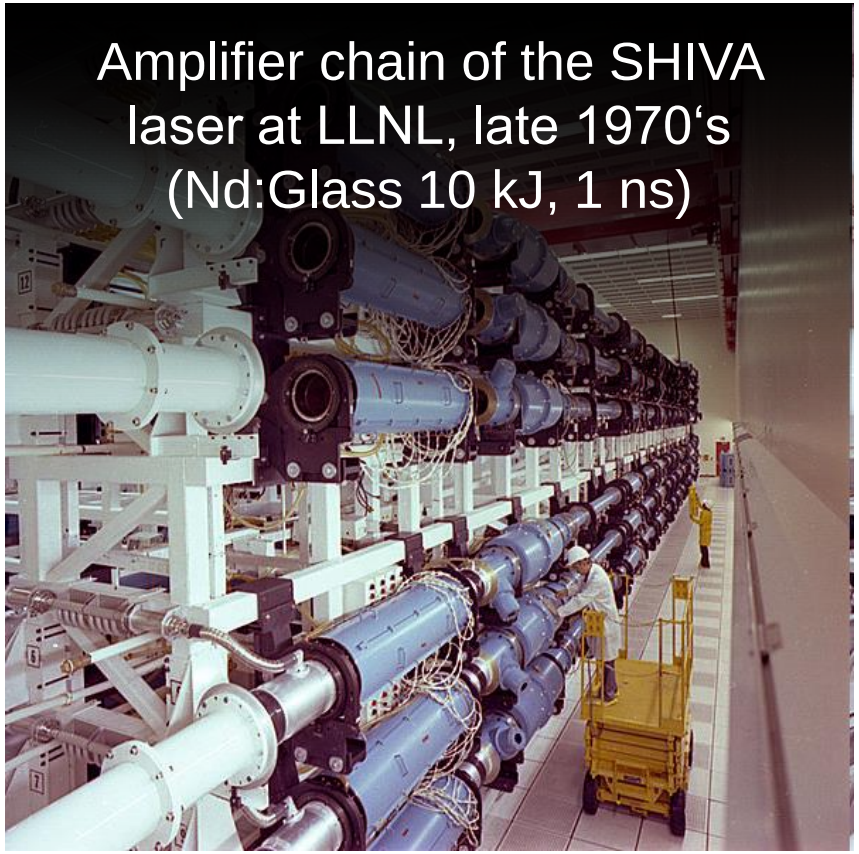


Todessternlaser: kJ, ns, wenige Schüsse pro Tag

Dotiertes Glas als Lasermedium

- isotrop
- Geringe Wärmeleitfähigkeit
- Breites Emissionsspektrum

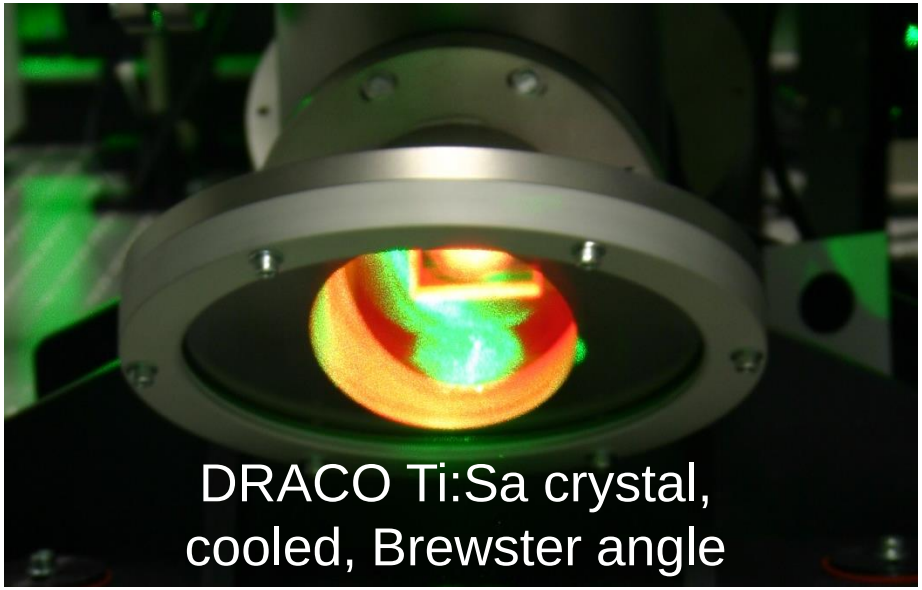




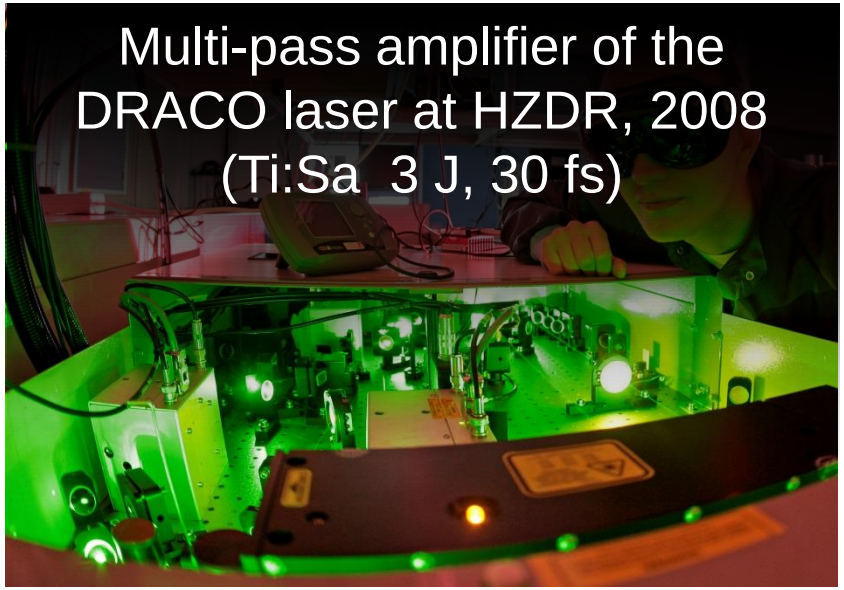
Ultrakurzpulslaser — mJ to J, fs, Hz to kHz

Dotierte Kristalle als Lasermedium

- Hohe Verstärkung
- Hohe Wärmeleitfähigkeit
- Geringe optische Qualität



DRACO Ti:Sa crystal,
cooled, Brewster angle



Multi-pass amplifier of the
DRACO laser at HZDR, 2008
(Ti:Sa 3 J, 30 fs)

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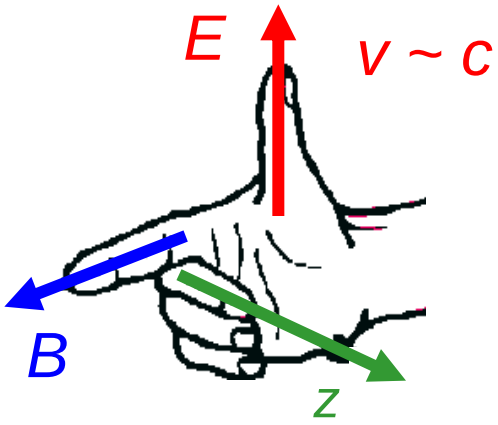
2000000000000000 W
in
0.000000000000025 s
DRACO Hochleistungslaser
25 x 10-15 Sekunden Pulsdauer
2 x 1015 Watt Spitzenleistung
100 x worldwide power consumption

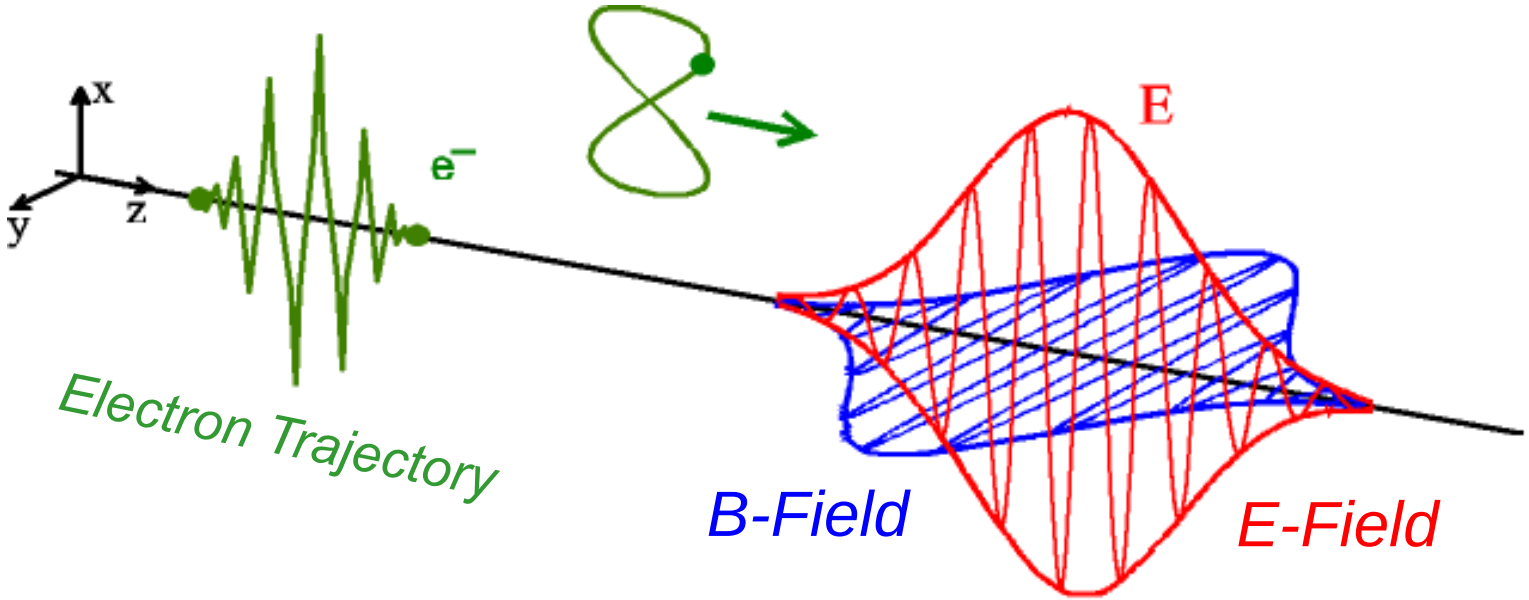
Laser und Plasmen

Star Trek Into Darkness vs. National Ignition Facility

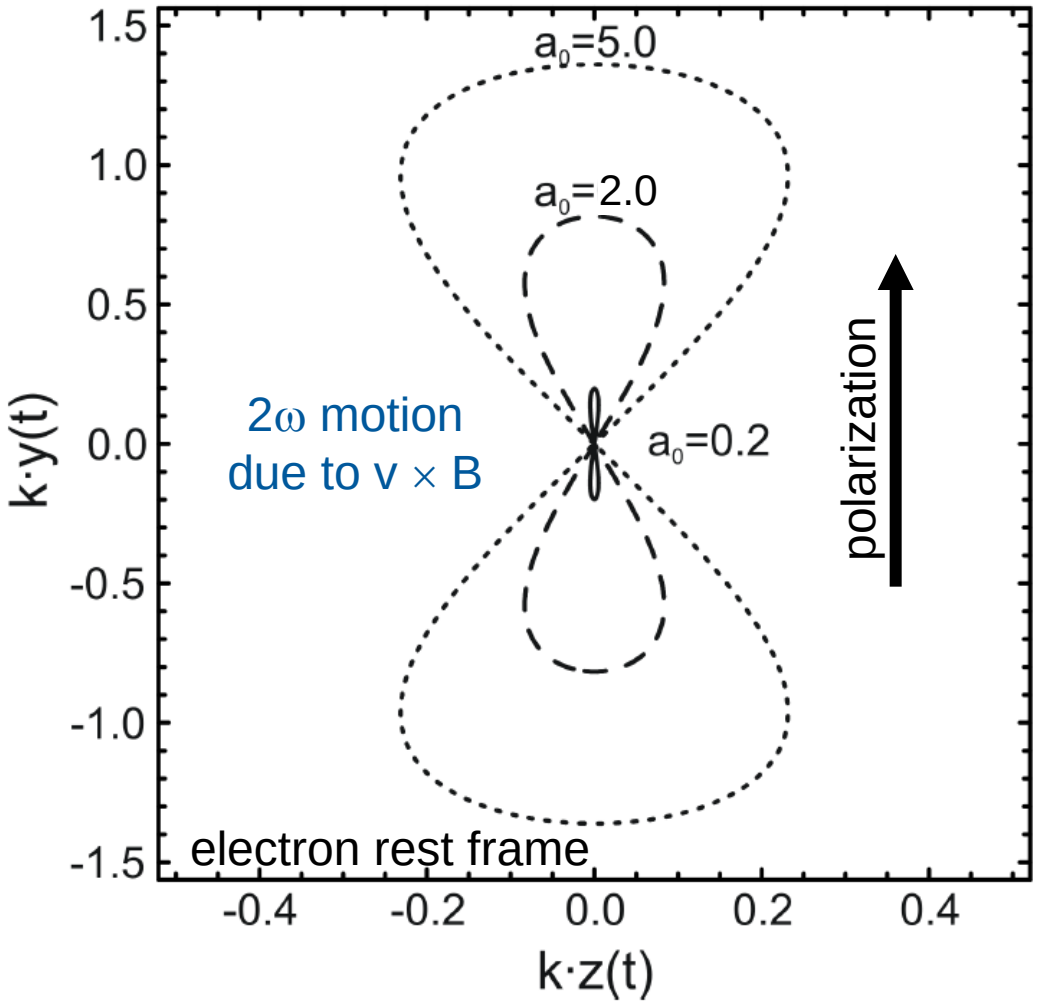
Die Lorentzkraft



$$\vec{F}_{Lorentz} = e\left(\vec{E} + \vec{v} \times \vec{B}\right) \quad \left(B_0 = E_0 / c\right)$$



Bei hohen Feldstärken wird das Magnetfeld wichtig



$$\vec{E} = E_0 \sin(\omega t - kz)\vec{e}_y$$

$$\frac{d}{dt}\vec{p} = -e\left(\vec{E} + \vec{v}\times\vec{B}\right)$$

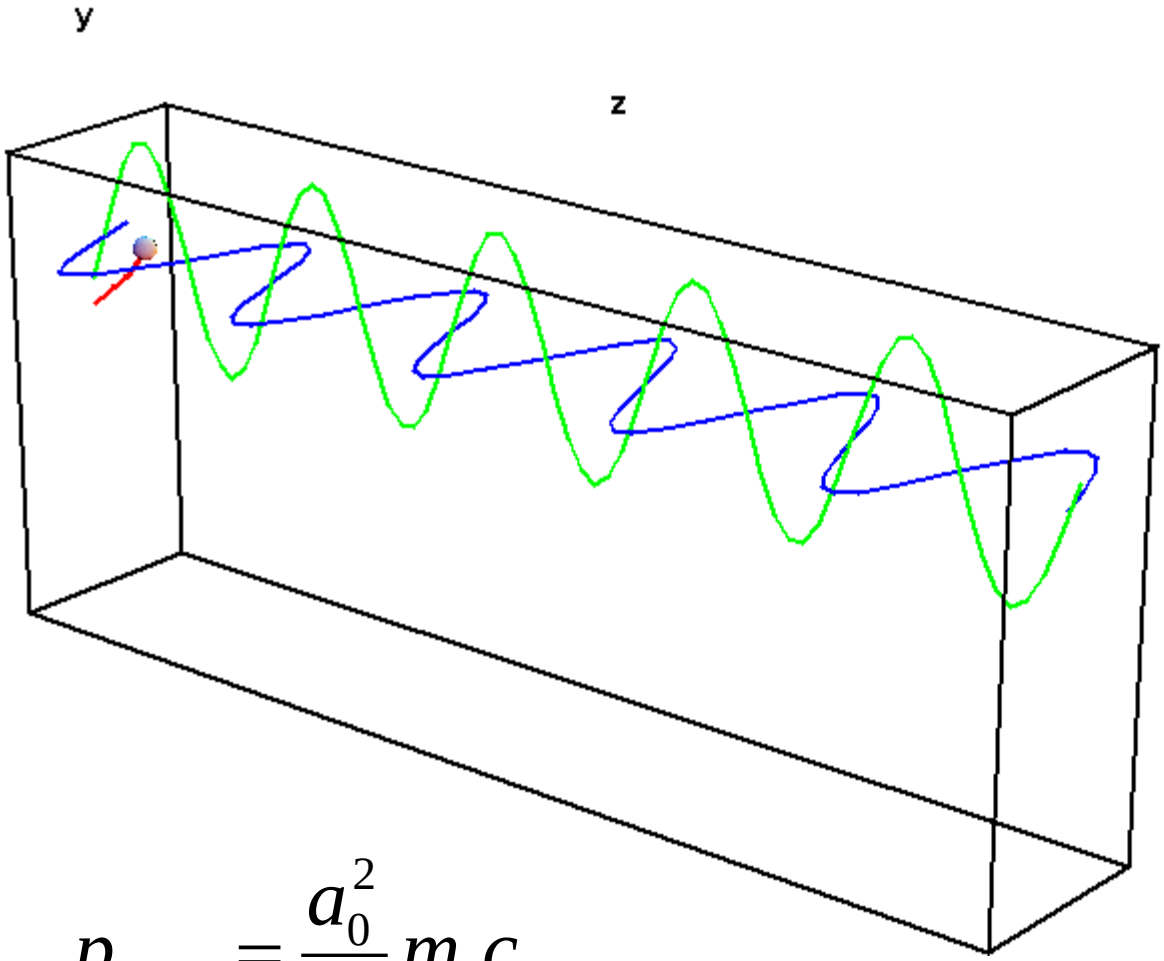
$$k \cdot y(t) = a_0 \sin\left(\varphi(z,t)\right)$$

$$k \cdot z(t) = \frac{a_0^2}{4}\left[\varphi(z,t) + \frac{1}{2}\cos\left(2\varphi(z,t)\right)\right]$$

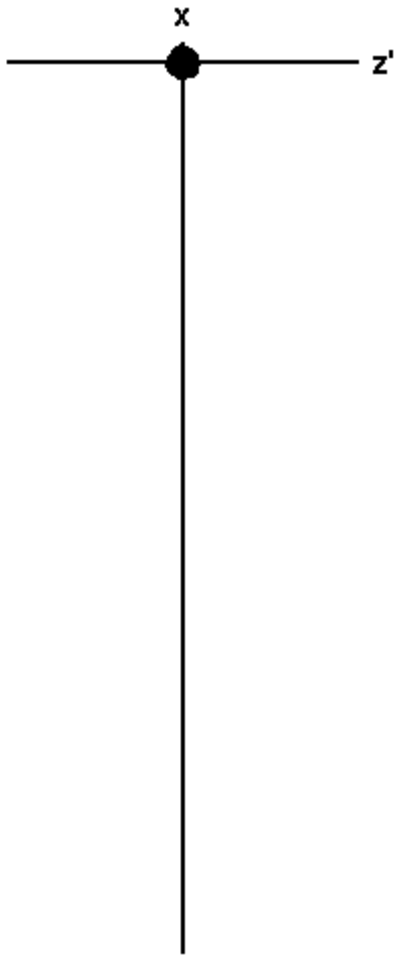
$$\varphi(z,t) = \omega t - kz(t)$$

Relativistische Bewegung

Labor

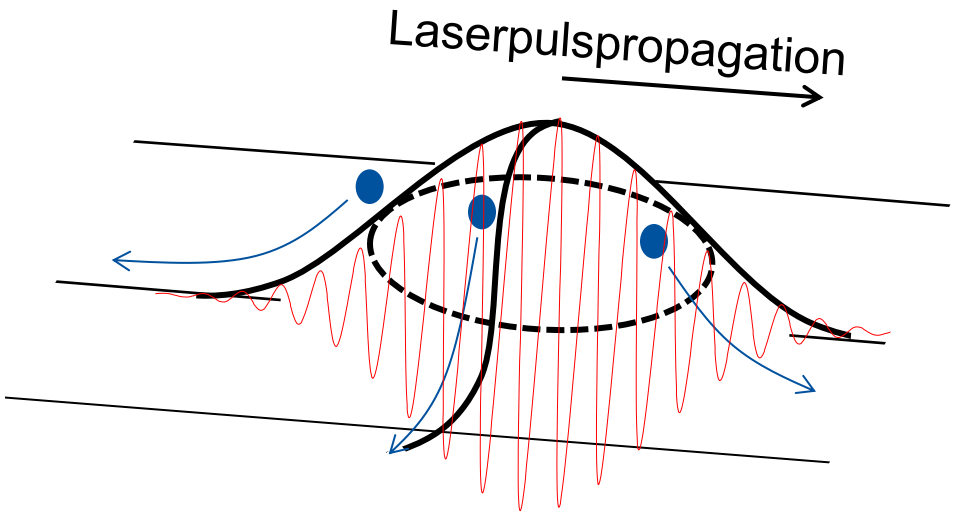


Ruhesystem des Elektrons



$$p_{Drift} = \frac{a_0^2}{4} m_e c$$

Ponderomotive (zeitgemittelte) Kräfte



$$\vec{F}_{Ponderomotive} = \frac{d\langle \vec{p} \rangle_{phase,focus}}{dt} \begin{cases} \xrightarrow[a_0 \to 0]{} -\frac{m_e c^2}{4} \nabla \langle a_0 \rangle^2_{phase,focus} \\ \xrightarrow[a_0 \to \infty]{} -\frac{m_e c^2}{\sqrt{2}} \nabla \left| \langle a_0 \rangle_{phase,focus} \right| \end{cases}$$

Elektronenenergie ~ MeV

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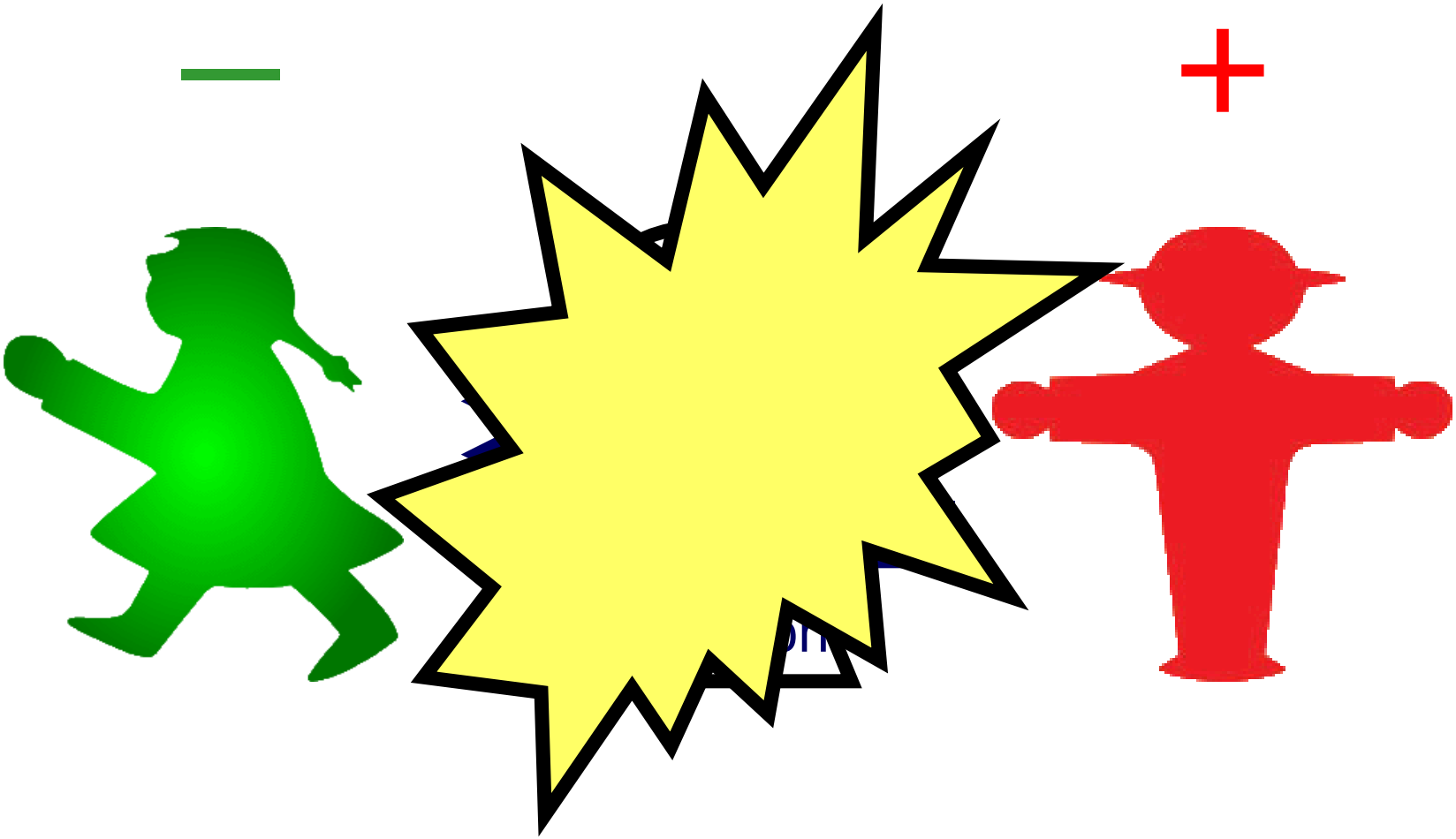
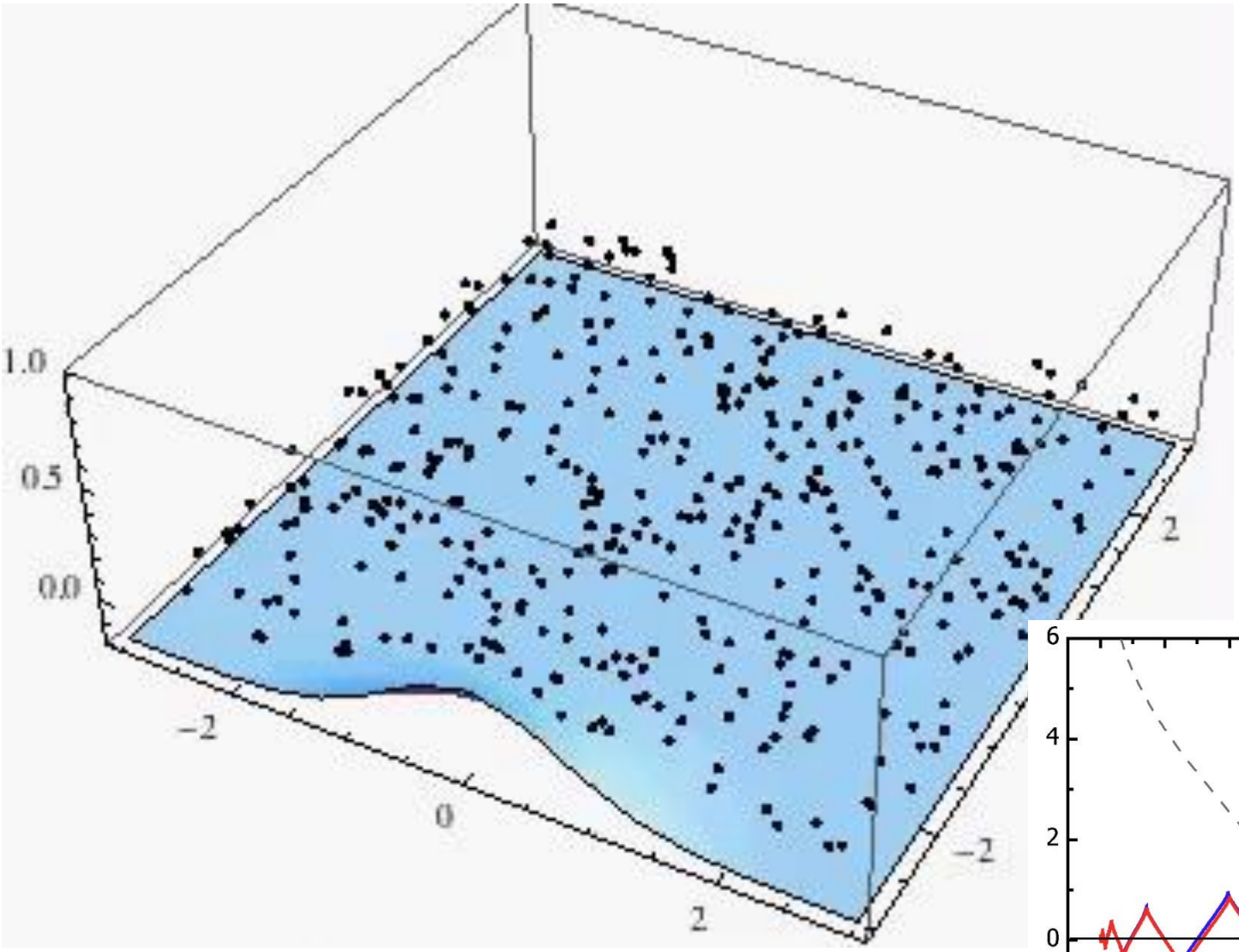
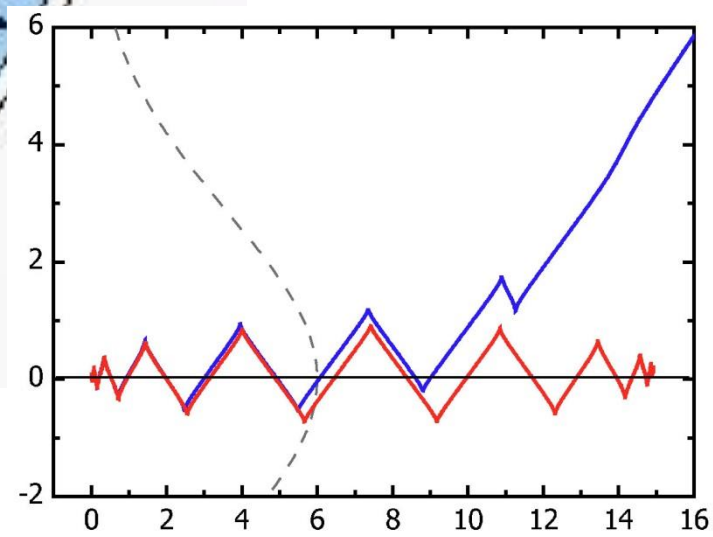
Plasmen

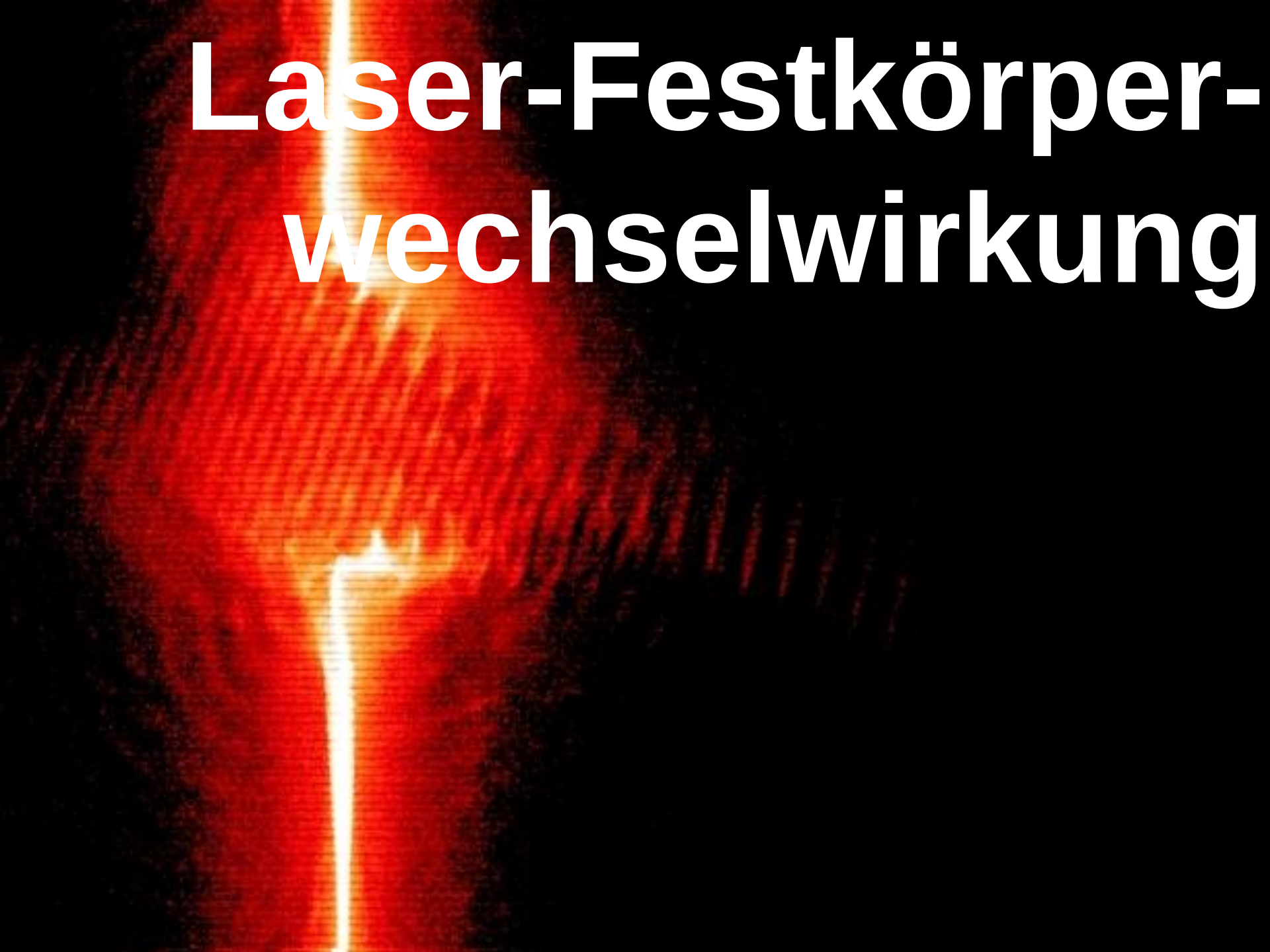


Ponderomotive Kraft im Plasma



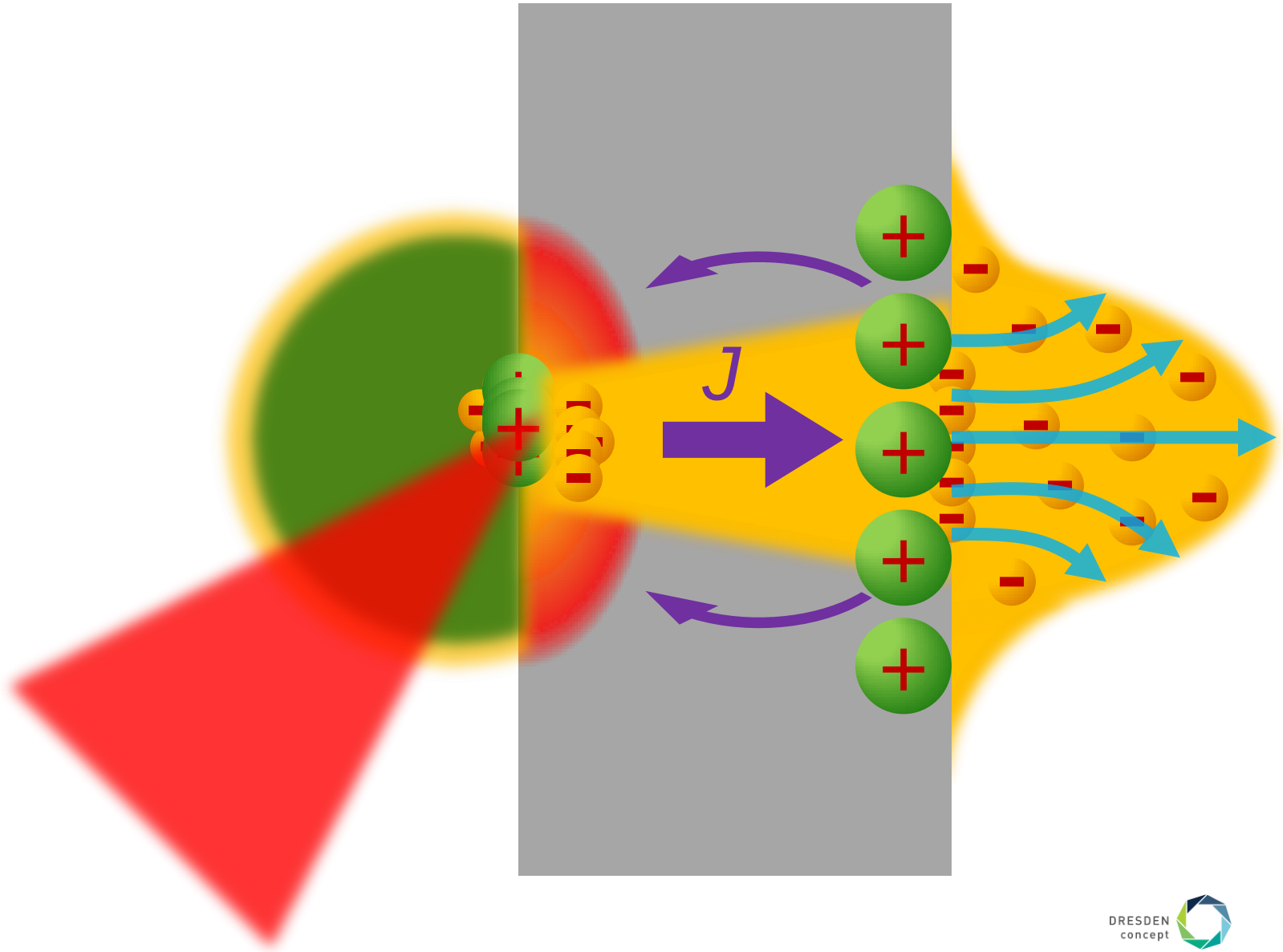


Laser-Festkörper-wechselwirkung

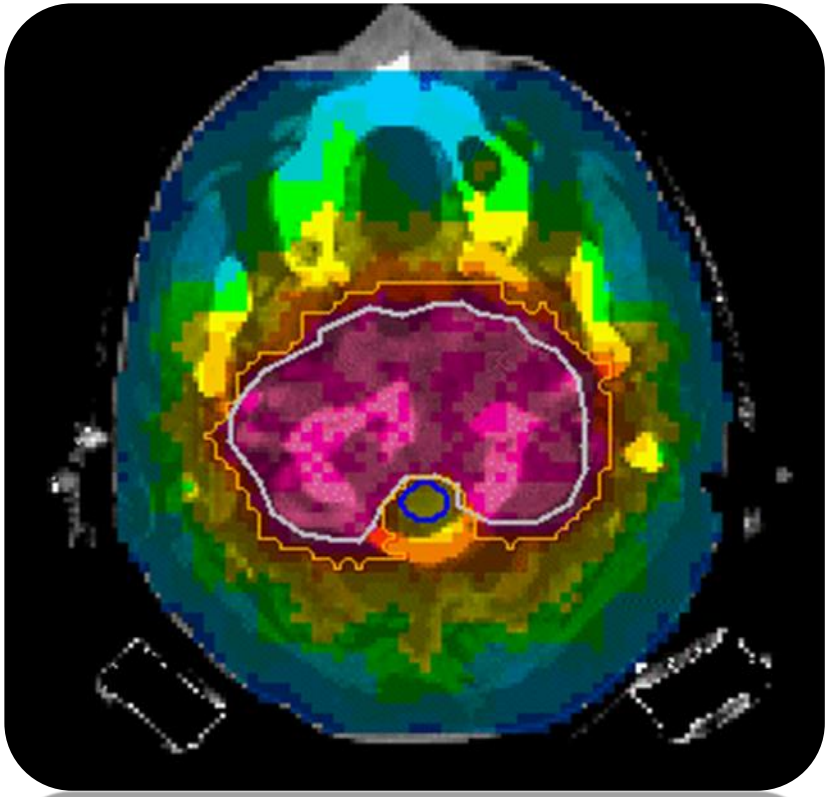


In Aktion

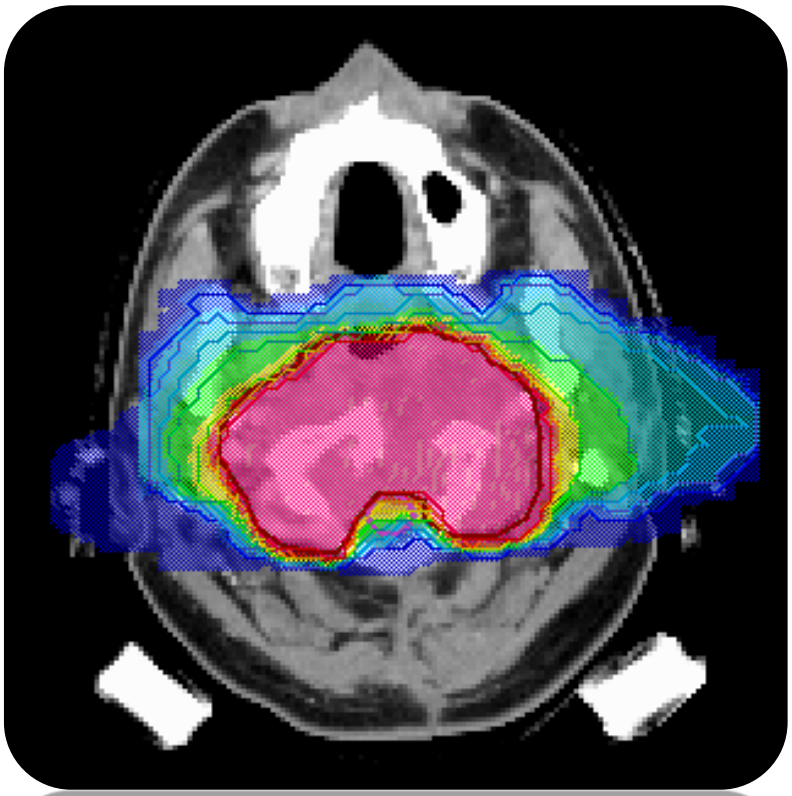
Target-normal sheath acceleration (TNSA)



Protonentherapie von Krebs



8 Röntgenstrahlen



2 Ionenstrahlen

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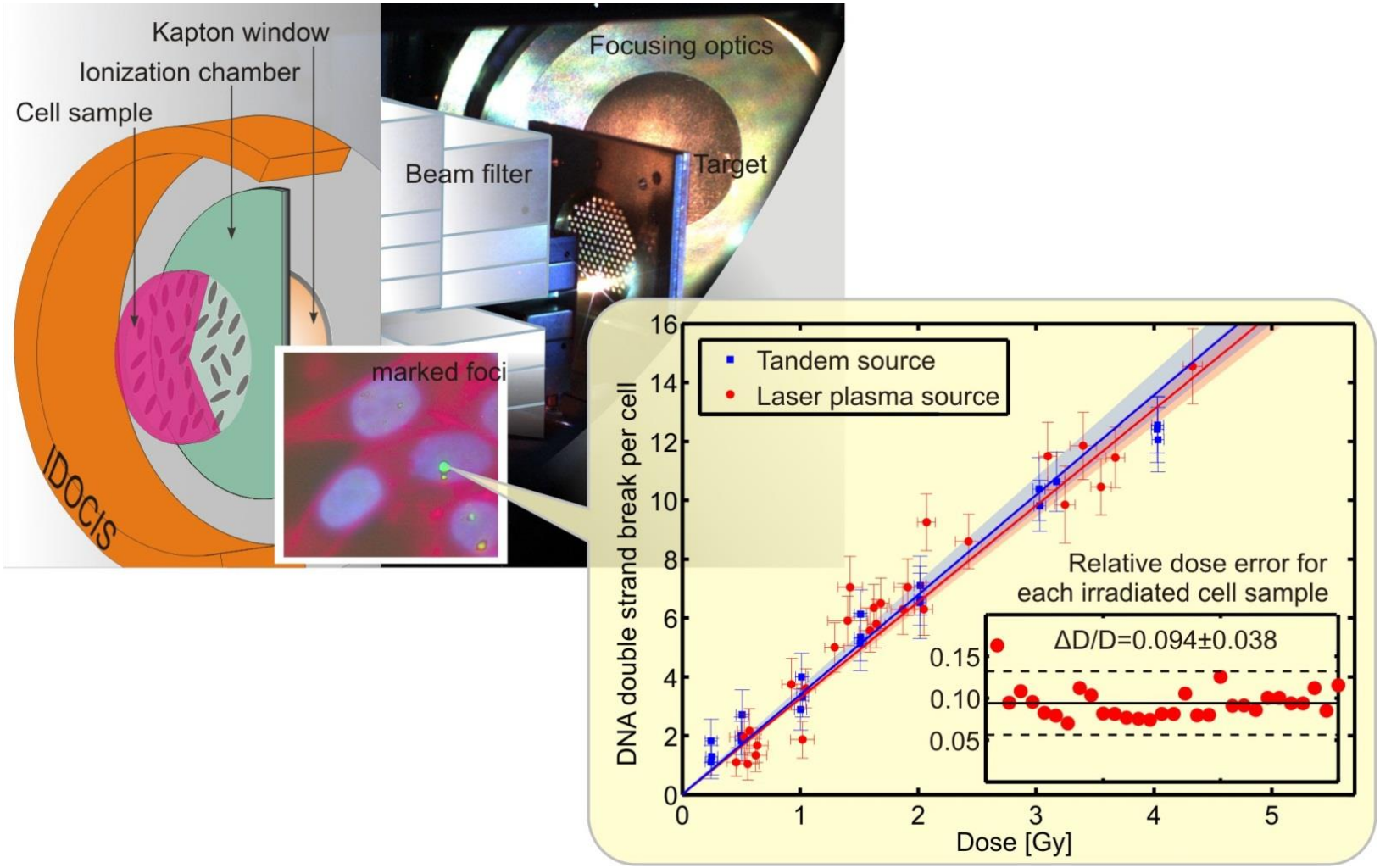
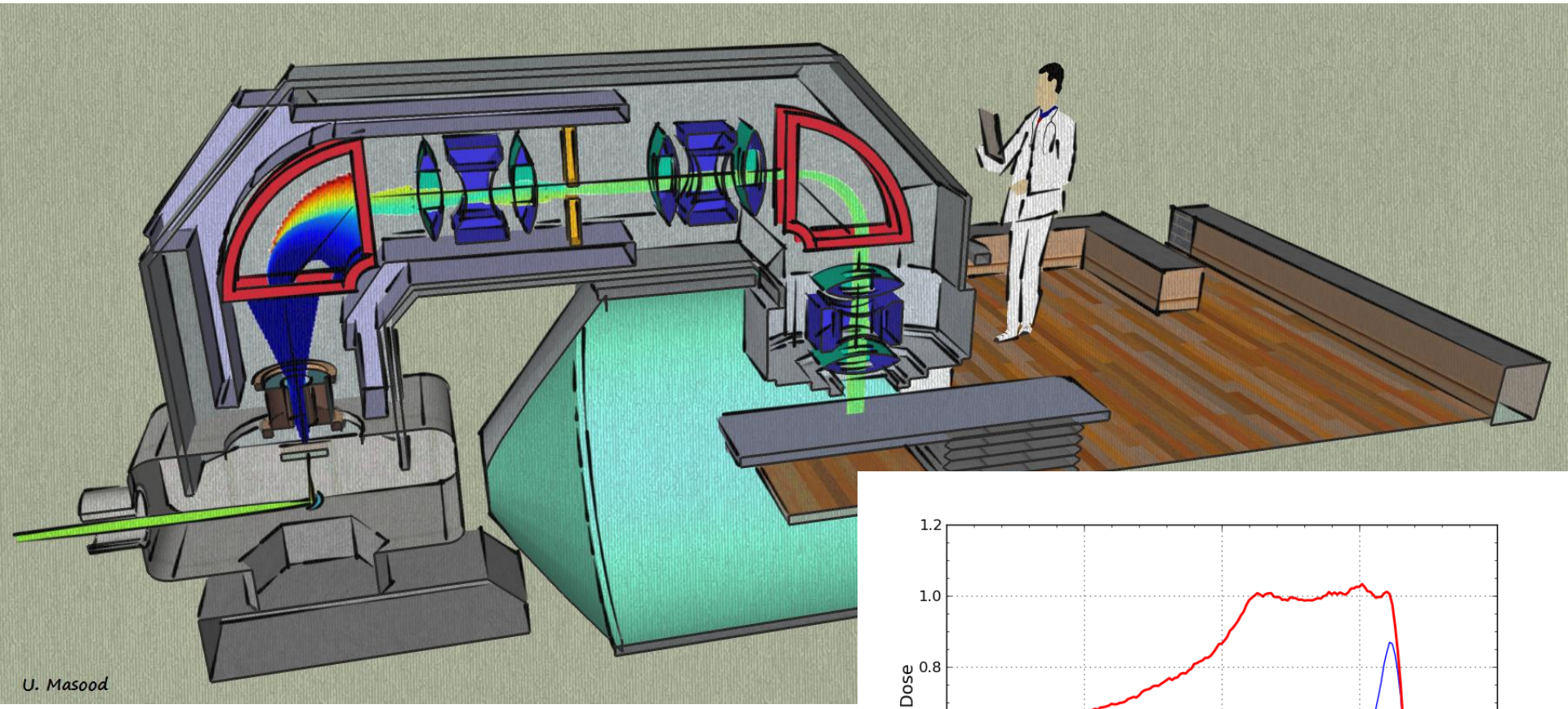
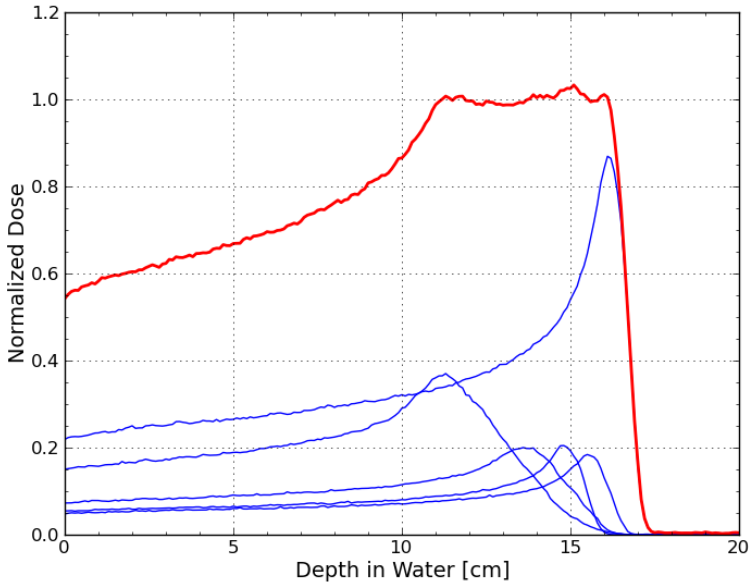
Damaging living Cells by laser-driven Proton Beams

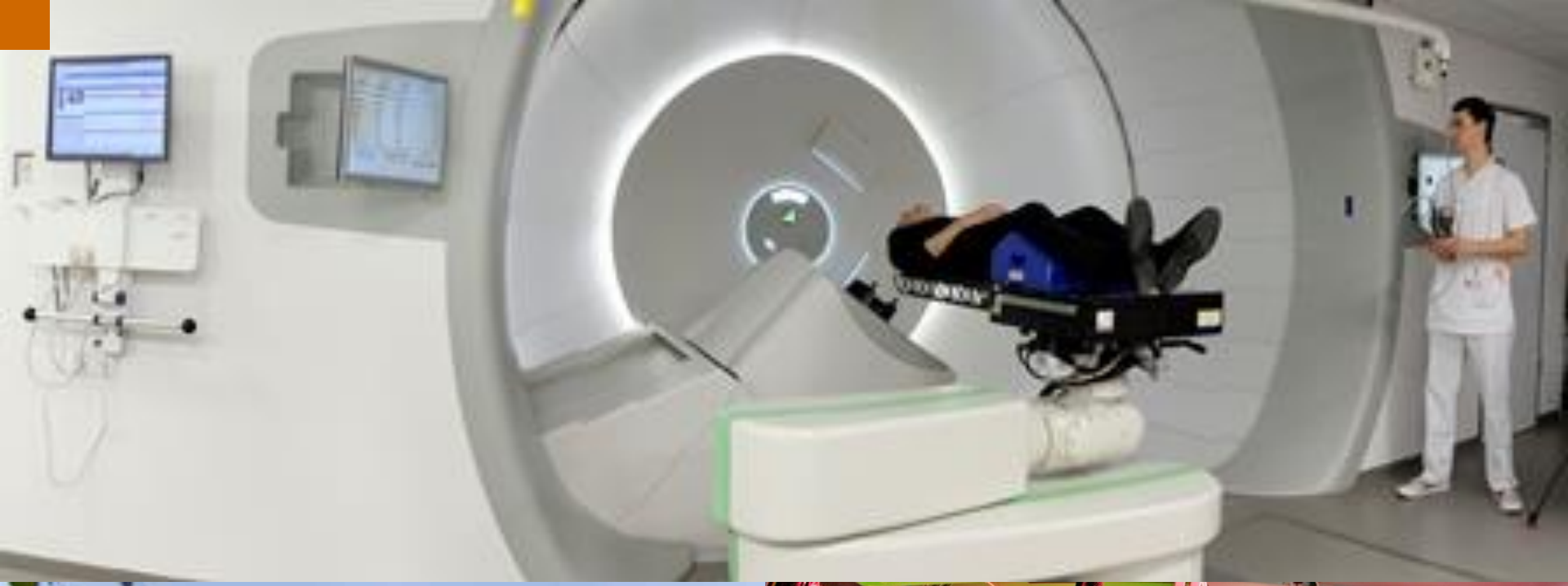


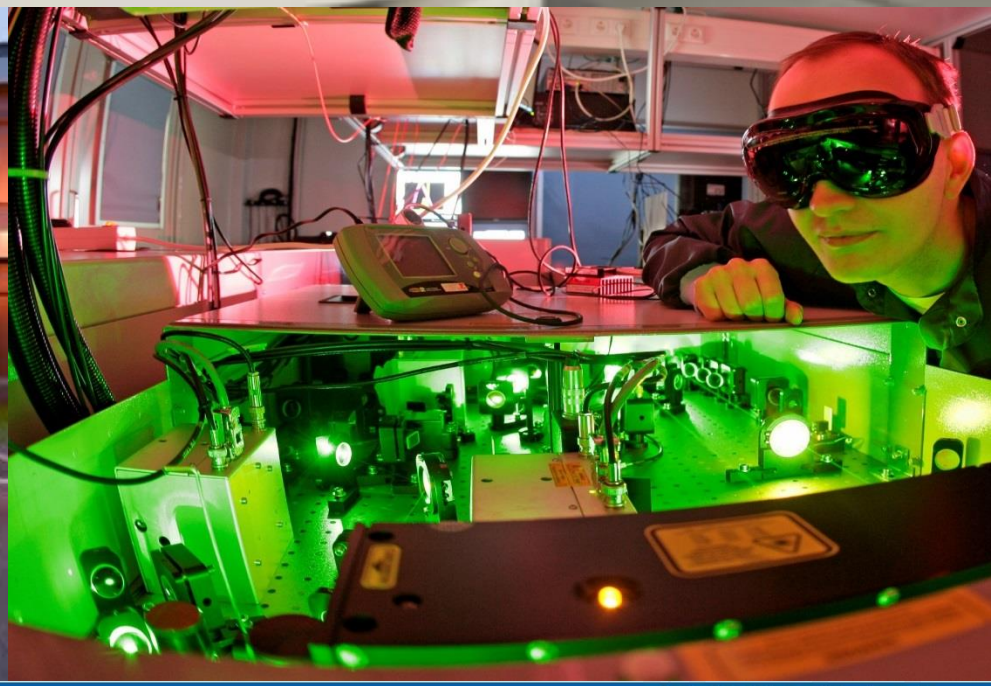
Kompakt = Preiswerter





OncoRay (ZIK) Radiation Research in Oncology





www.oncoray.de

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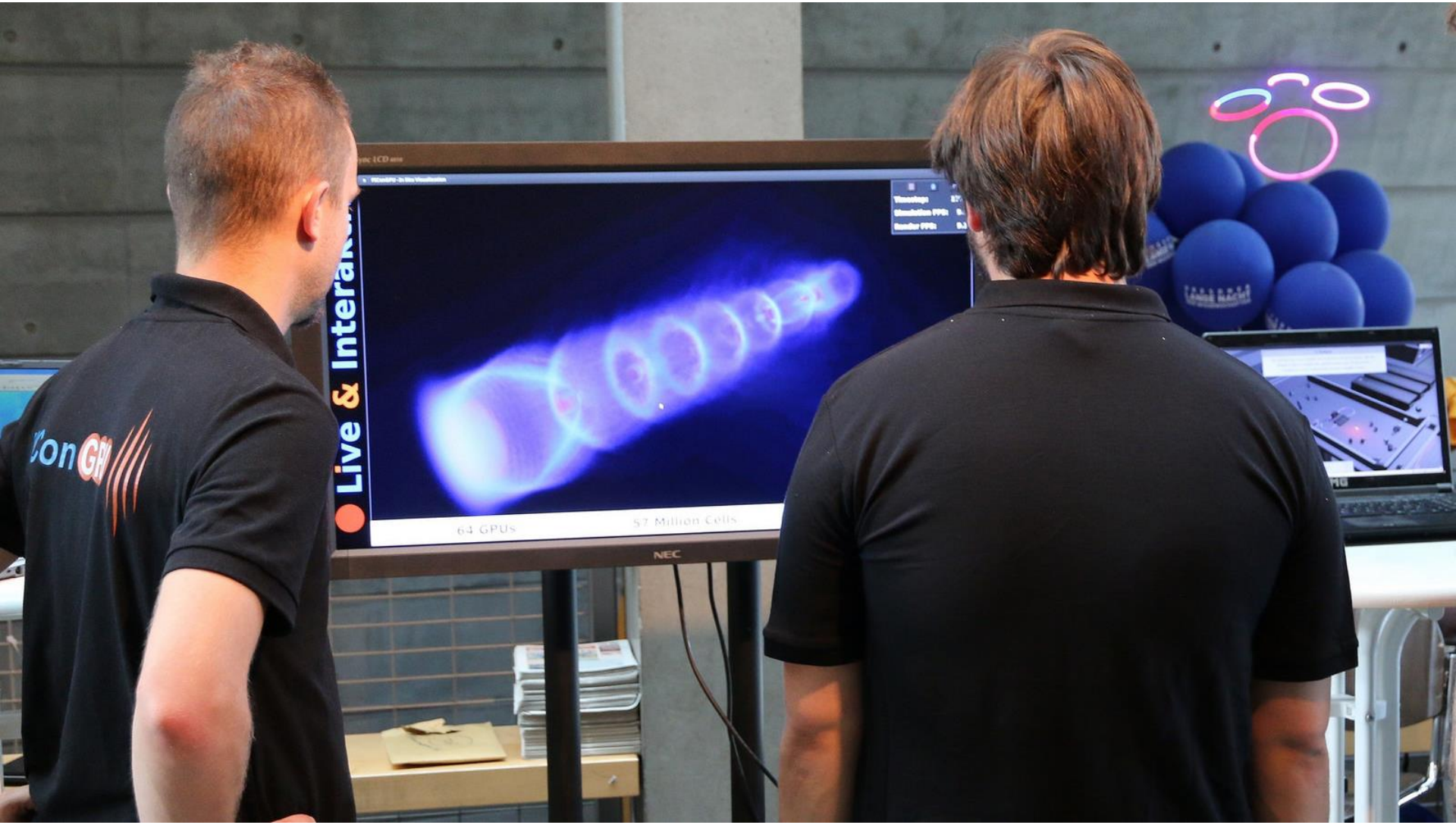
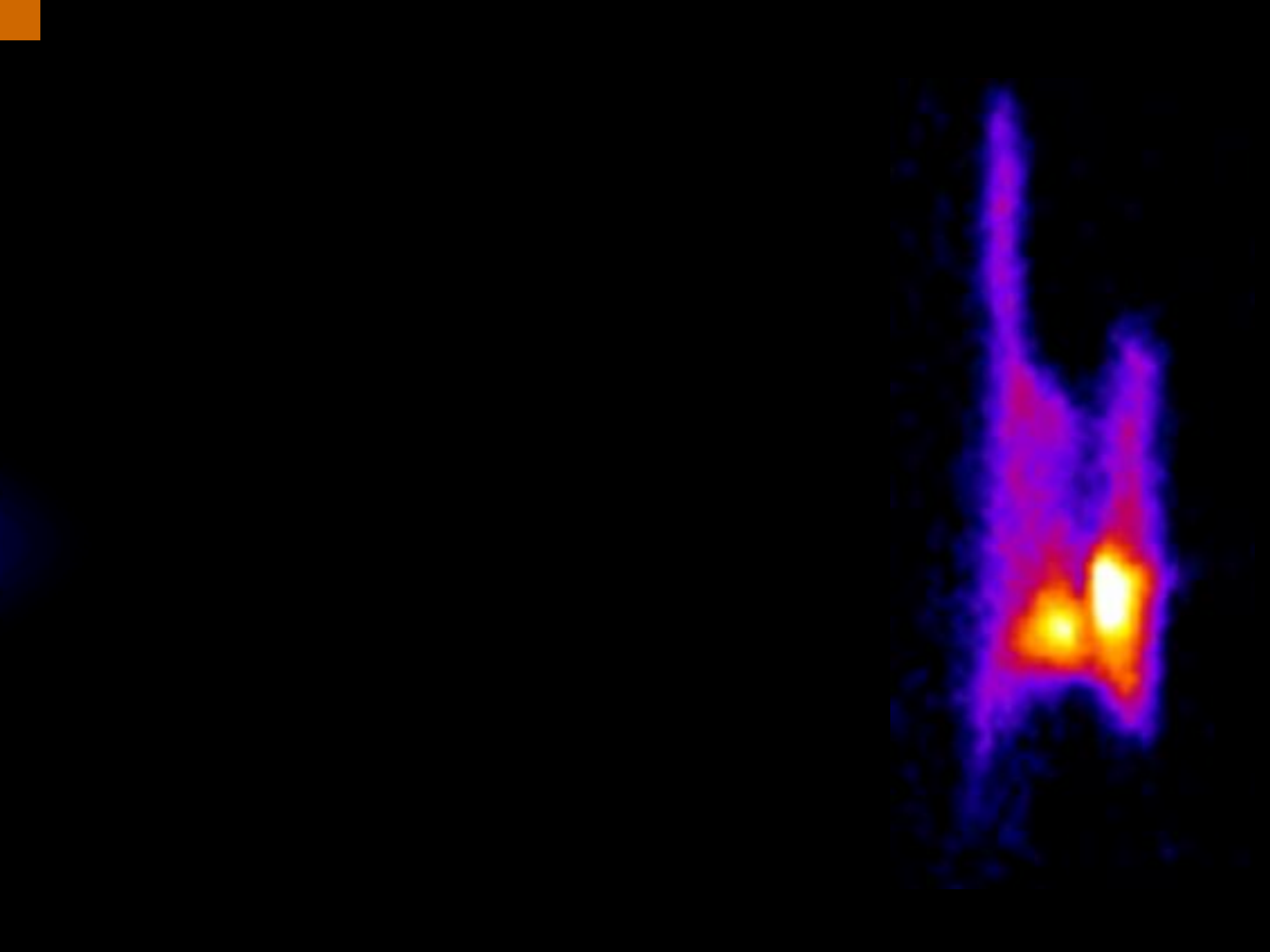
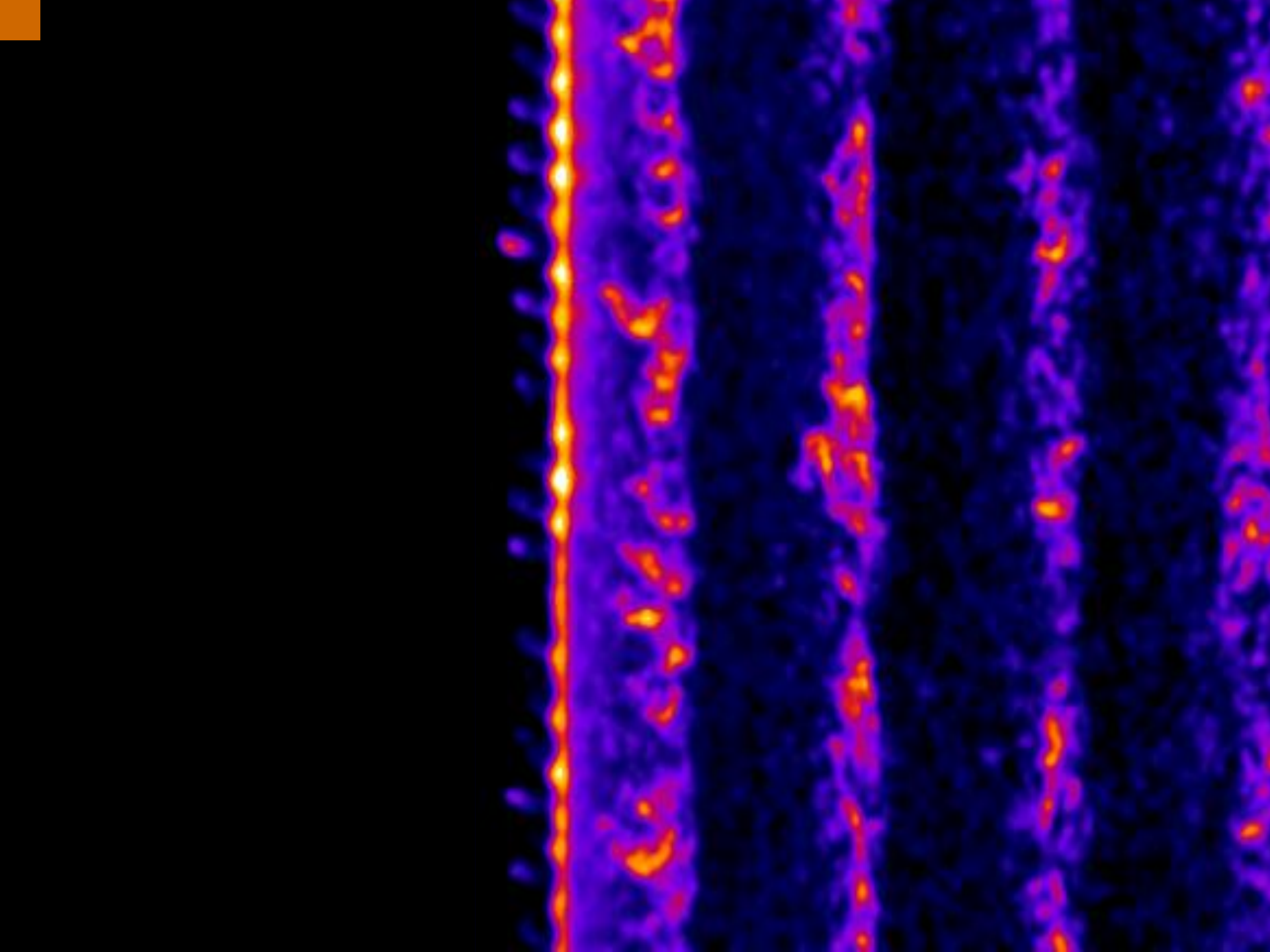
Simulationen

Dresdner Nacht der Wissenschaften

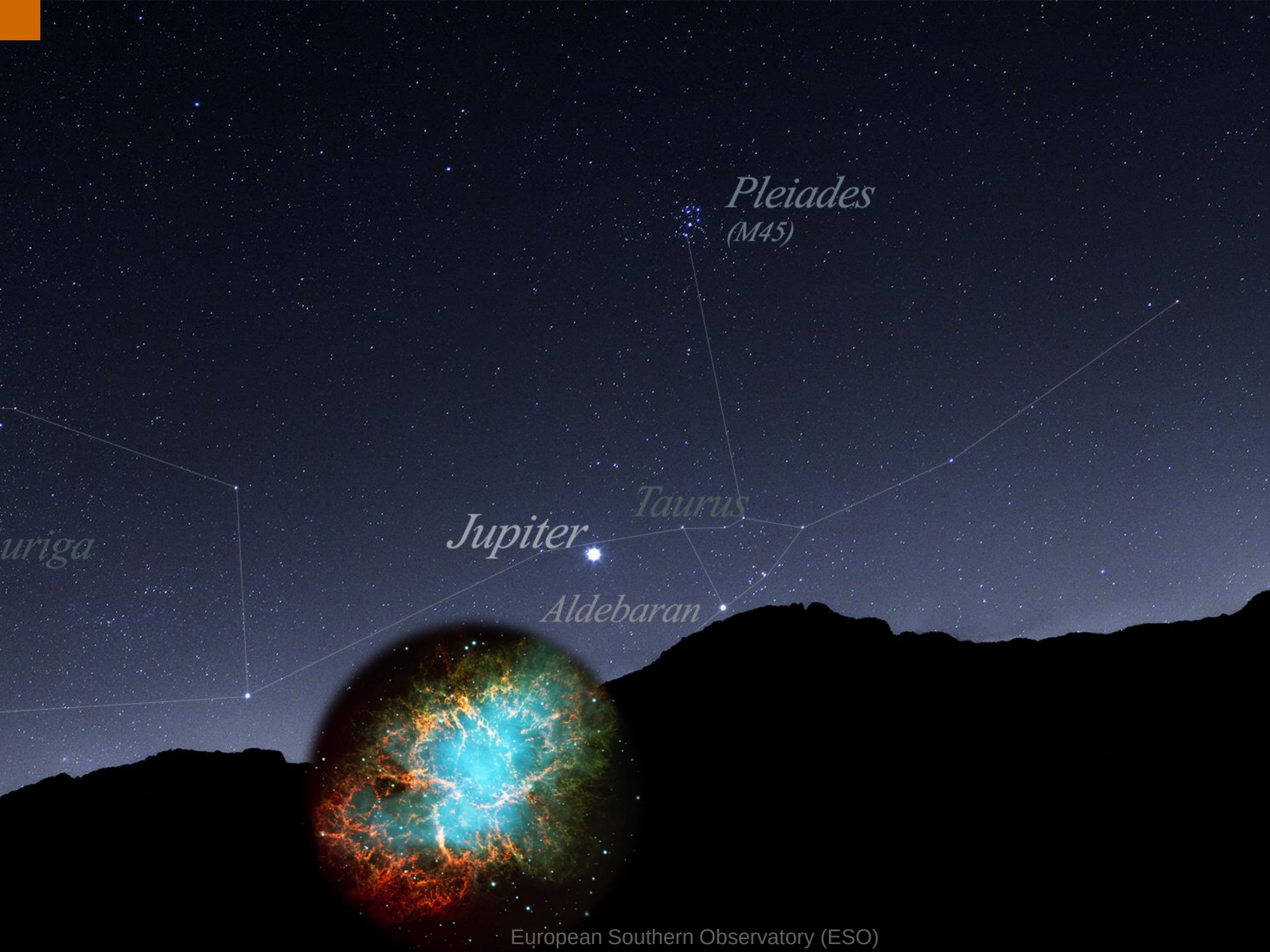






Astrophysik mit Computern

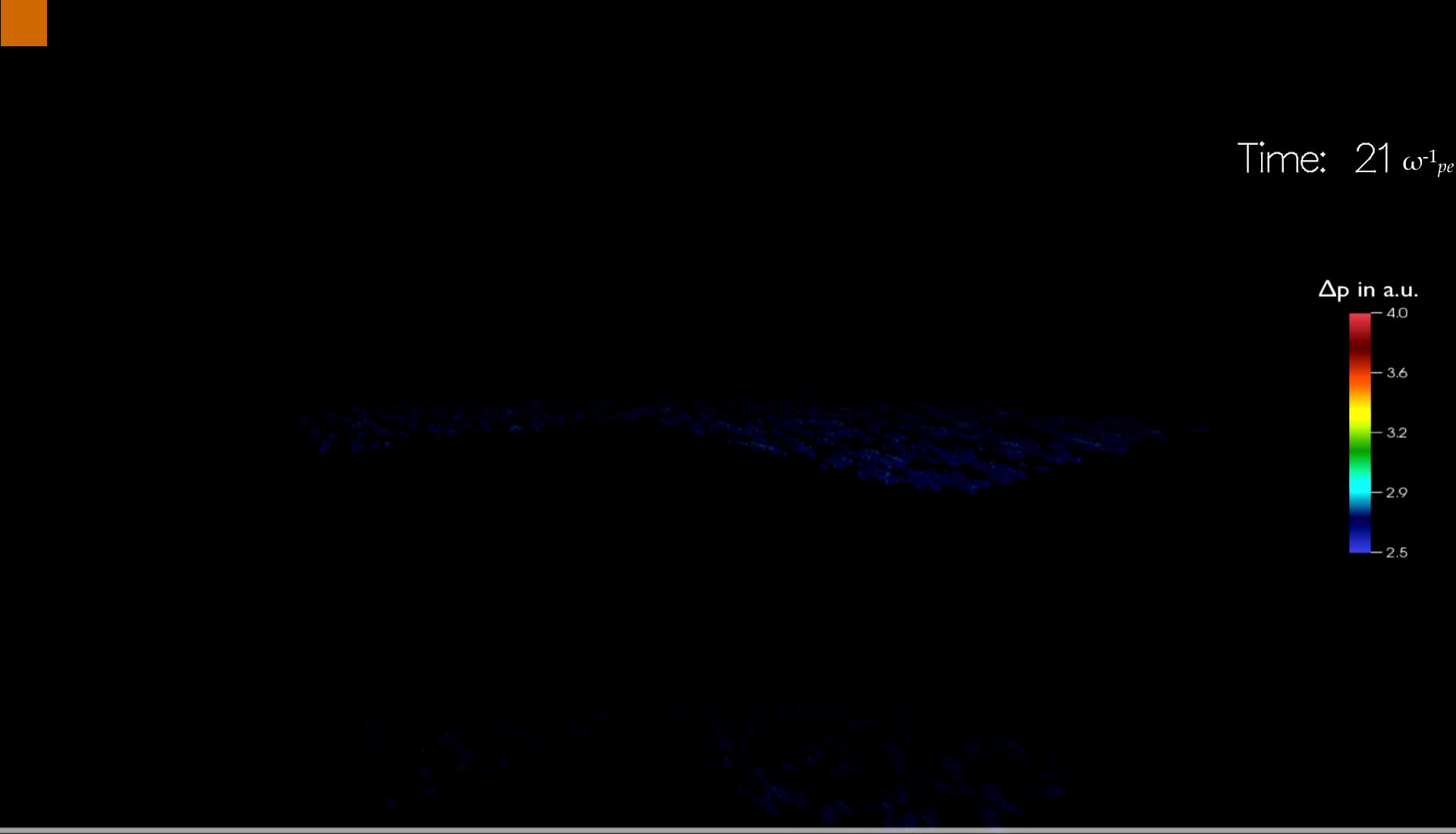
Wir sehen nur das Licht der Sterne



European Southern Observatory (ESO)

Aber unsere Teleskope werden immer besser

X-Ray: NASA/CXC/J.Hester (ASU); Optical: NASA/ESA/J.Hester & A.Loll (ASU); Infrared: NASA/JPL-Caltech/R.Gehrz (Univ. Minn.)



OLCF
Oak Ridge Leadership Computing Facility

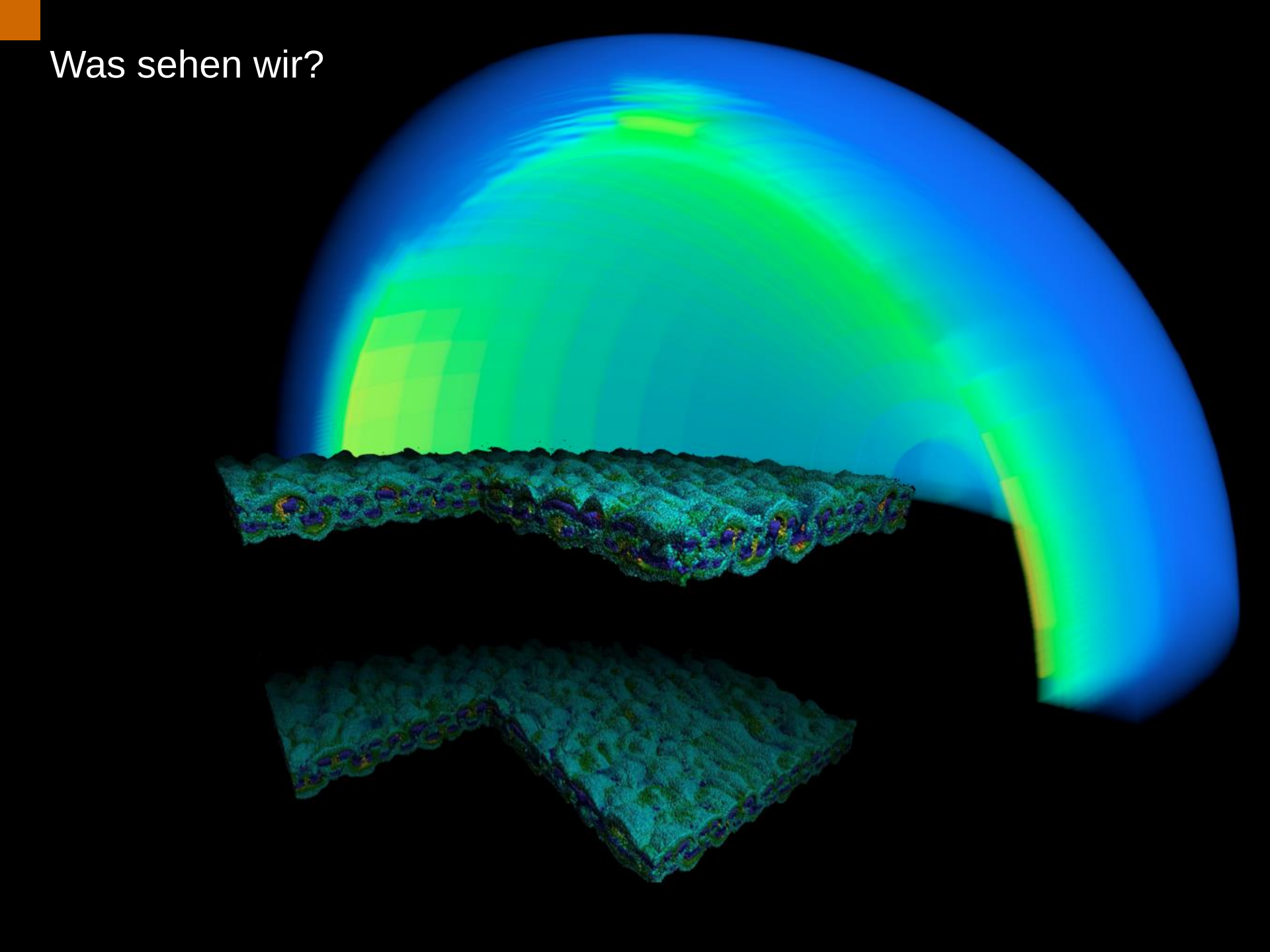
ZIH
Center for Information Services & High Performance Computing

HZDR
Helmholtz Zentrum Dresden Rossendorf

PIConGPU

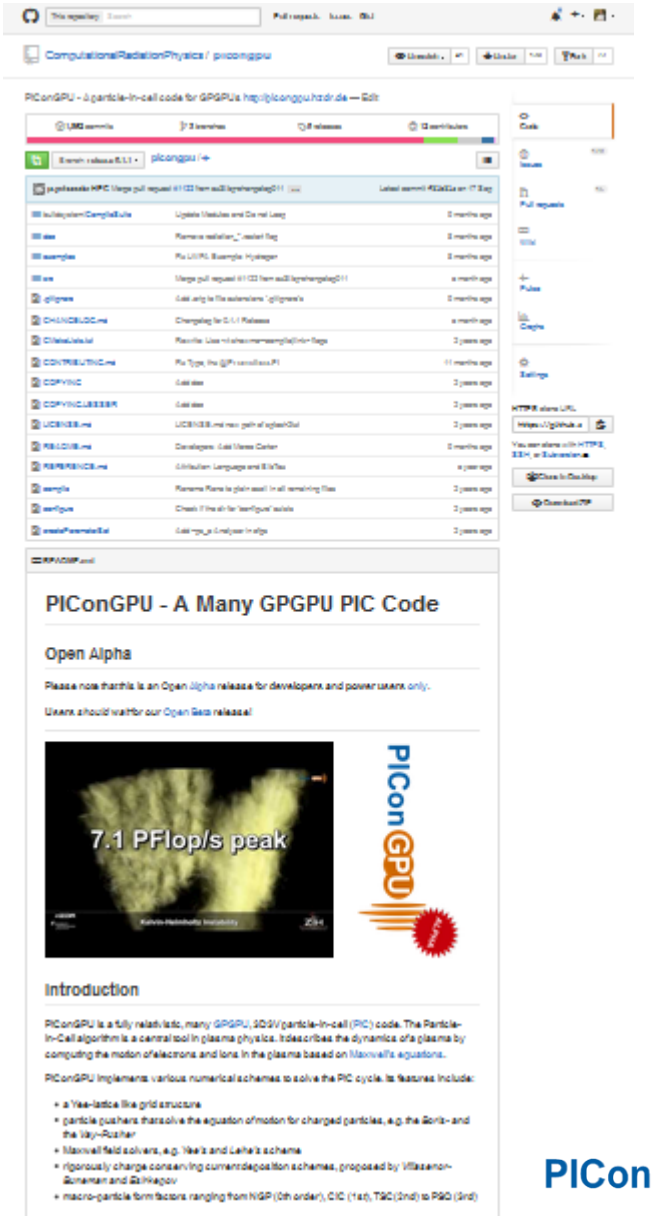
75 Milliarden Teilchen

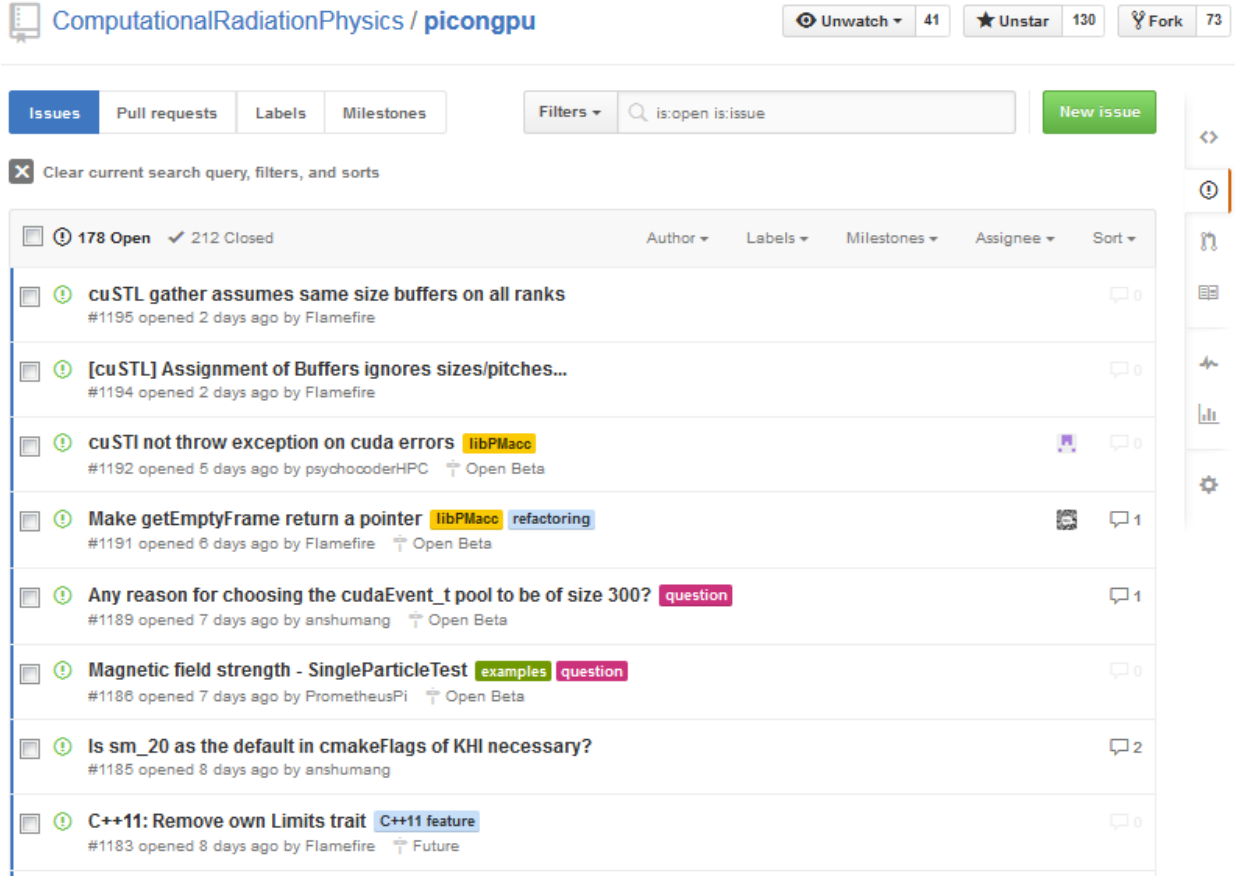
Was sehen wir?



Freie Software

GPL Open Source Entwicklung (picongpu.hzdr.de)





PIConGPU

DRESDEN concept

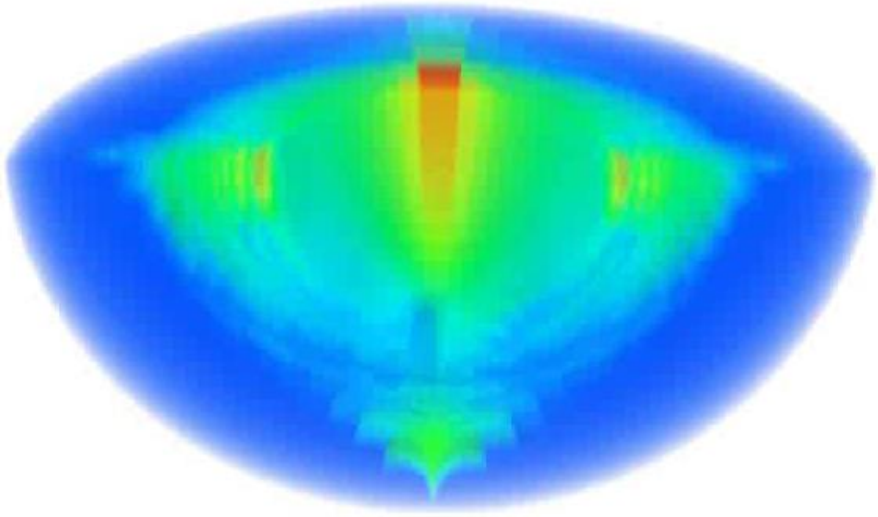
HZDR

Michael Bussmann · Laser-Particle Acceleration · www.hzdr.de/fwt
m.bussmann@hzdr.de

Physiker und Informatiker arbeiten zusammen

Alexander Debus	Postdoc
Thomas Kluge	Postdoc
Jan Vorberger	Postdoc
Axel Hübl	PHD Student
Marco Garten	PHD Student
Richard Pausch	PHD Student
Klaus Steiniger	PHD Student
Erik Zenker	PHD Student
Heiko Burau	Master Student
Carlchristian Eckert	Master Student
Alexander Grund	Master Student
Alexander Matthes	Master Student

René Widera	Programmer
Sven Brieden	Bachelor Student
Maximilian Böhme	Student Intern
Daniel Gräveling	Student Intern
Fabian Jung	Student Intern
Malte Zacharias	Student Intern



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DRESDEN concept

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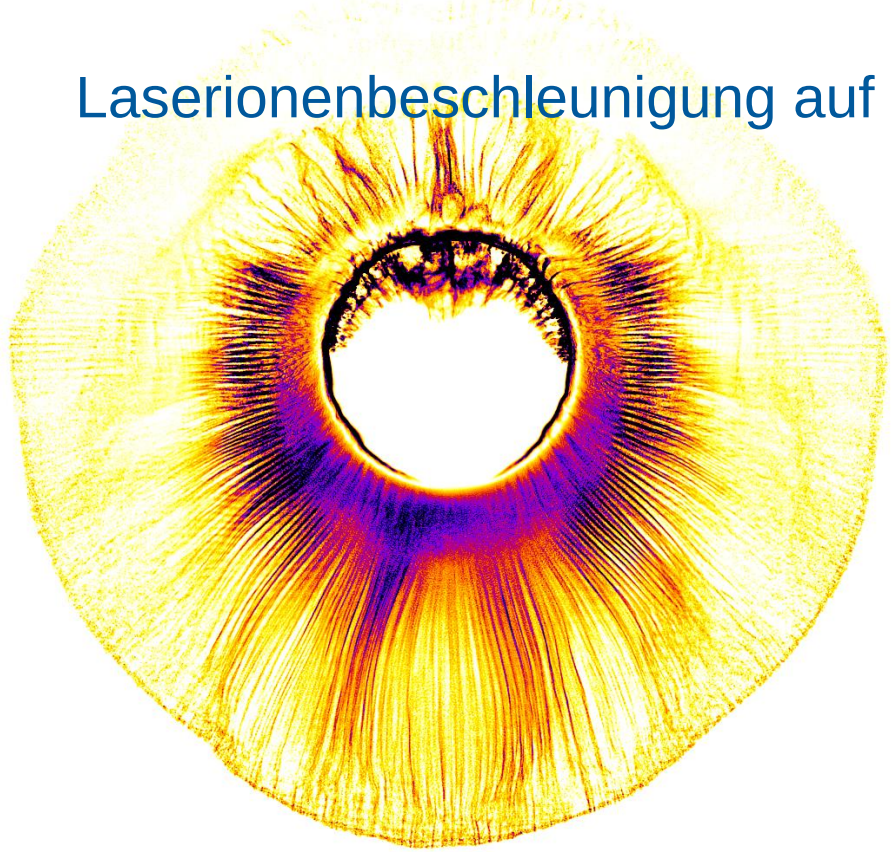
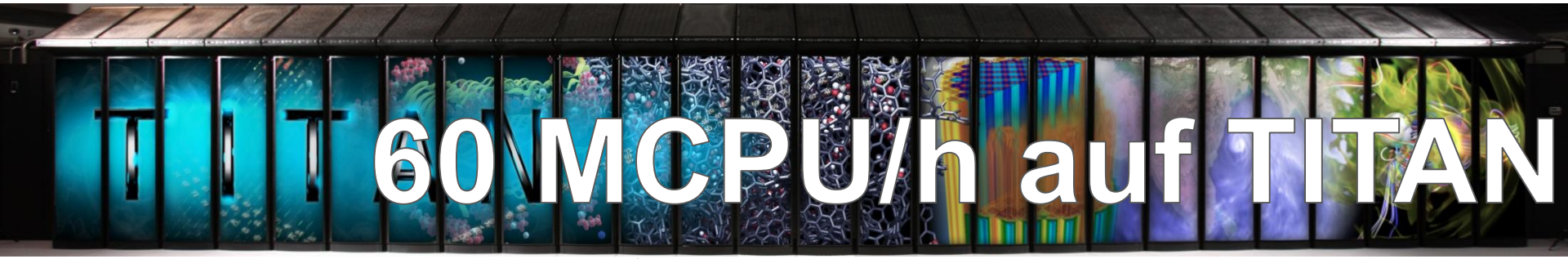
m.bussmann@hzdr.de

Wenn Menschen zusammenarbeiten

Laserionenbeschleunigung auf Supercomputern



- Fünf 3D Simulationenen
- 100 n_c, λ_{plasma} Auflösung
- 1 ps Dauer @ as Auflösung



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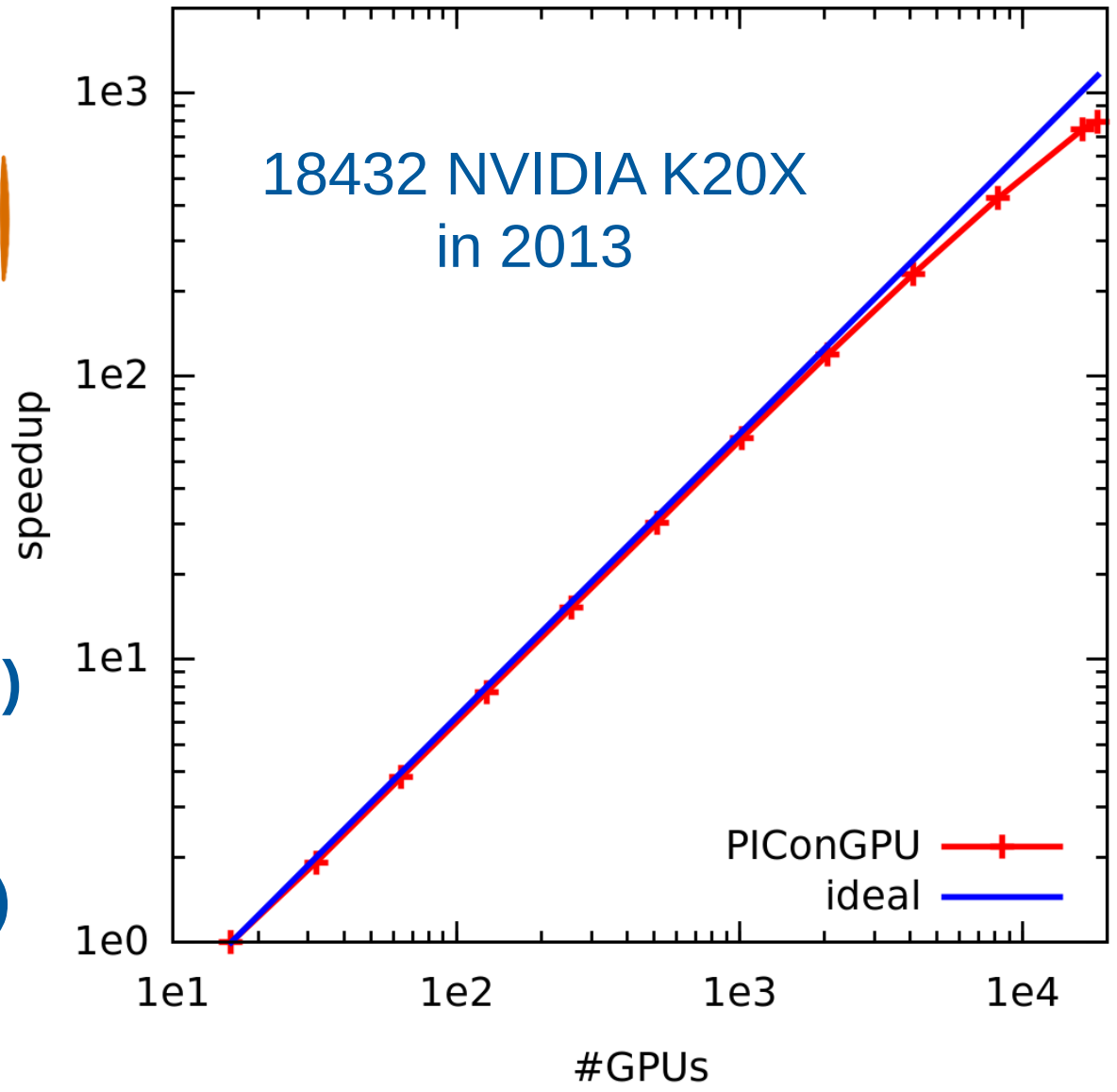
m.bussmann@hzdr.de

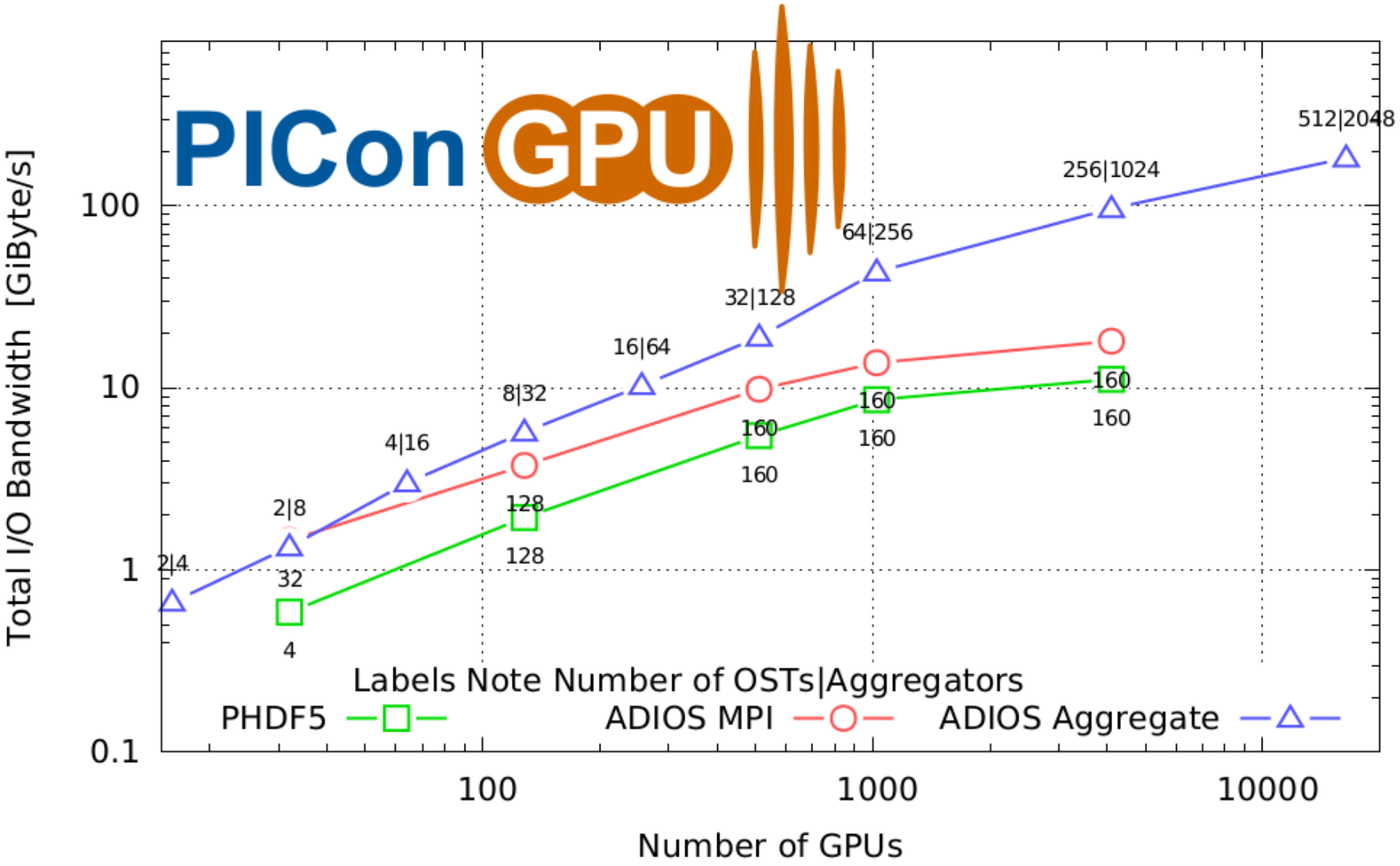
Parallele Skalierung

PIConGPU

7.176 PFLOPs/s (double-precision) plus 1.449 PFLOPs/s (single-precision)



Dateien schreiben und lesen wird zum Problem



PIConGPU ADIOS

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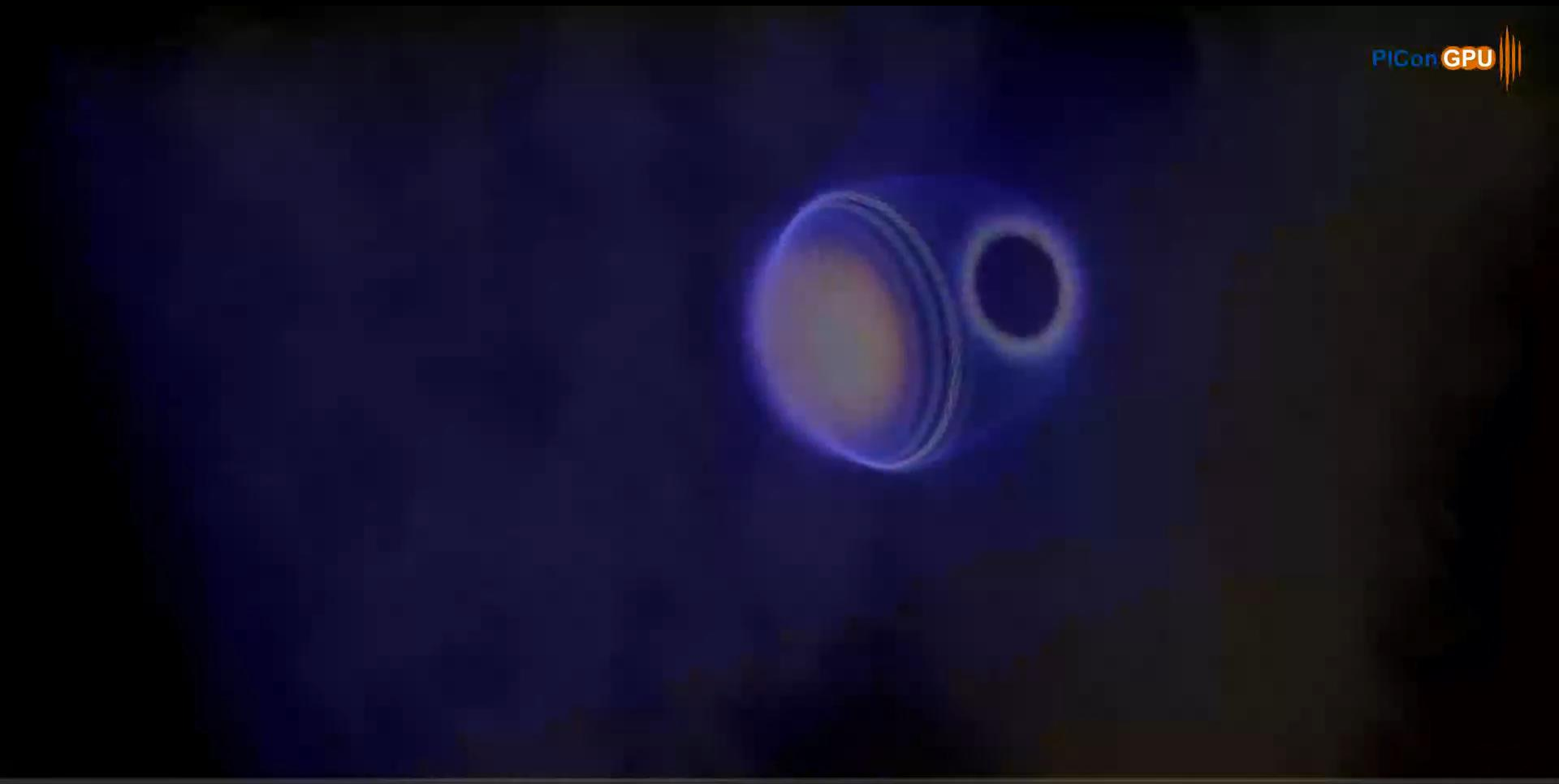

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HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

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