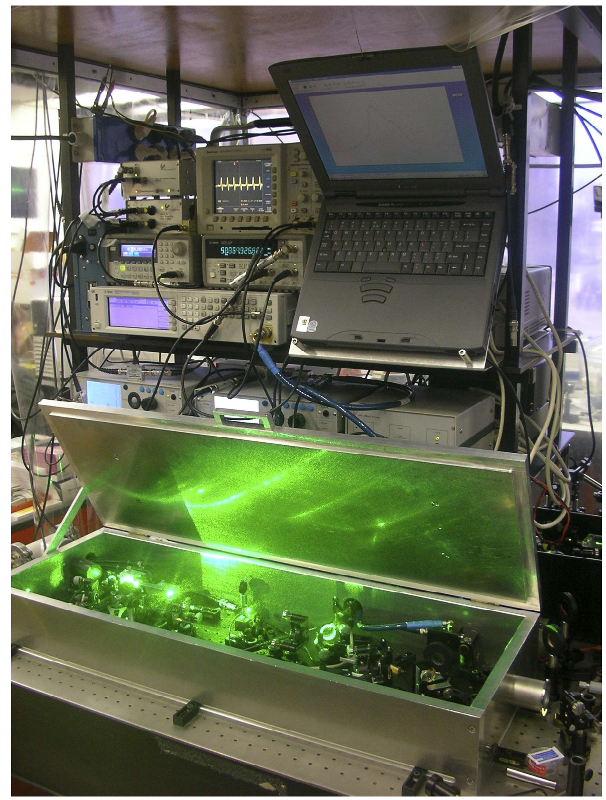
Onwaarschijnlijk intense lasers en hun toepassingen

- de Nobelprijs Natuurkunde 2018 voor “Chirped Pulse Amplification” -

Kjeld Eikema
LaserLaB
Vrije Universiteit Amsterdam
& ARCNL Amsterdam



Viva Fysica, 25 januari 2019

Overzicht

- Nobelprijs voor Natuurkunde 2019
- De meest intense en kortste lichtpuls
- Hoe werkt een laser?
- Korte laser pulsen – hoe maak je die?
- Laserlicht versterken – wat is het probleem?
- “Chirped pulse amplification” - hoe werkt het
- Toepassingen van extreme laserpulsen
- Samenvatting

Nobel prijs voor Natuurkunde 2018

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Optisch pincet

Chirped pulse amplification

De meest intense laser (puls)?

Laser pointer: 0.001 W

De meest intense laserpuls?

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10 000 000 000 000 000 W = 10 PW

1 000 000 000 000 000 W = 1 PW

1 000 000 000 000 W = 1 TW

1 000 000 000 W = 1 GW

1 000 000 W = 1 MW

1 000 W = 1 kW

1 W

Laser pointer: 0.001 W

De meest intense laserpuls = korte puls!

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$$\text{Piekvermogen [W]} = \frac{\text{Energie van de puls}}{\text{Lengte van de puls}}$$

Kortste laserpuls:

0.000 000 000 000 003 s = 3 fs

Stel 30 J energie in 30 fs = 30 J / $30 \cdot 10^{-15}$ s = 10 PW

Hoe werkt een laser?

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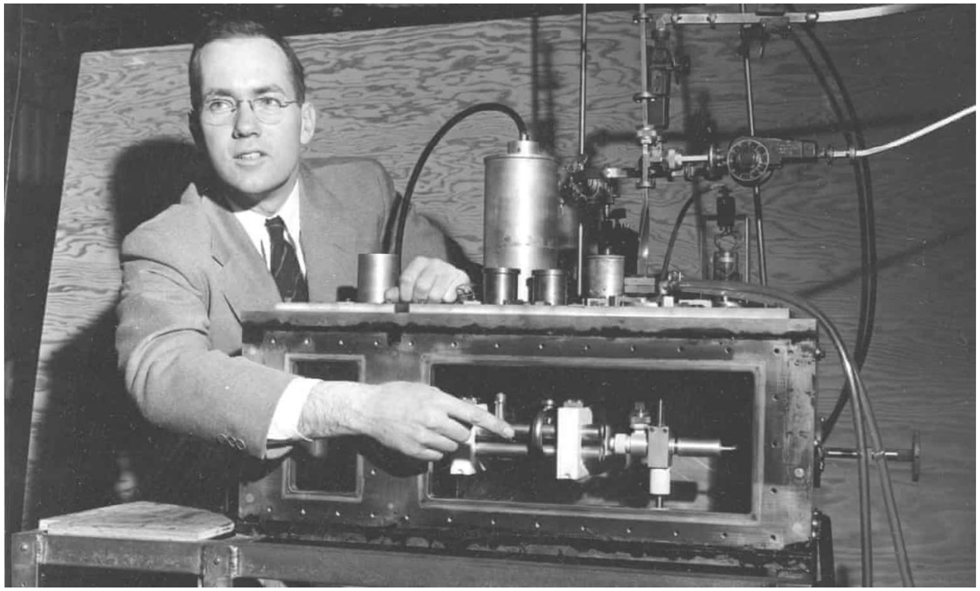
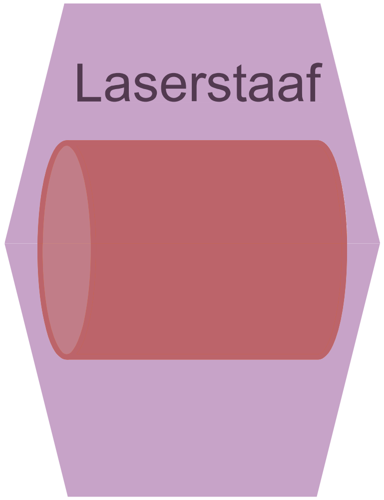
Light Amplification by Stimulated Emission of Radiation



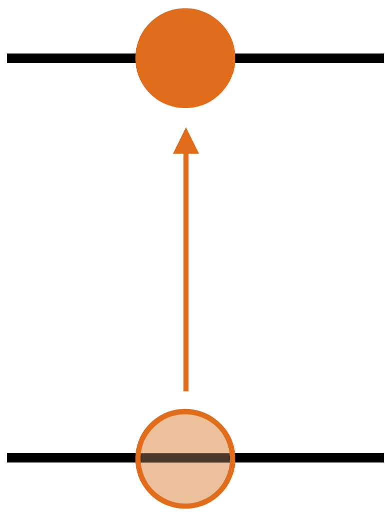
Charles Townes: uitvinder laserprincipe in 1951. Nobelprijs in 1964 samen met Aleksandr Prokhorov and Nicolai Basov

1960: Theodore Mayman bouwt eerste laser (robijnlaser)

Gestimuleerde emissie



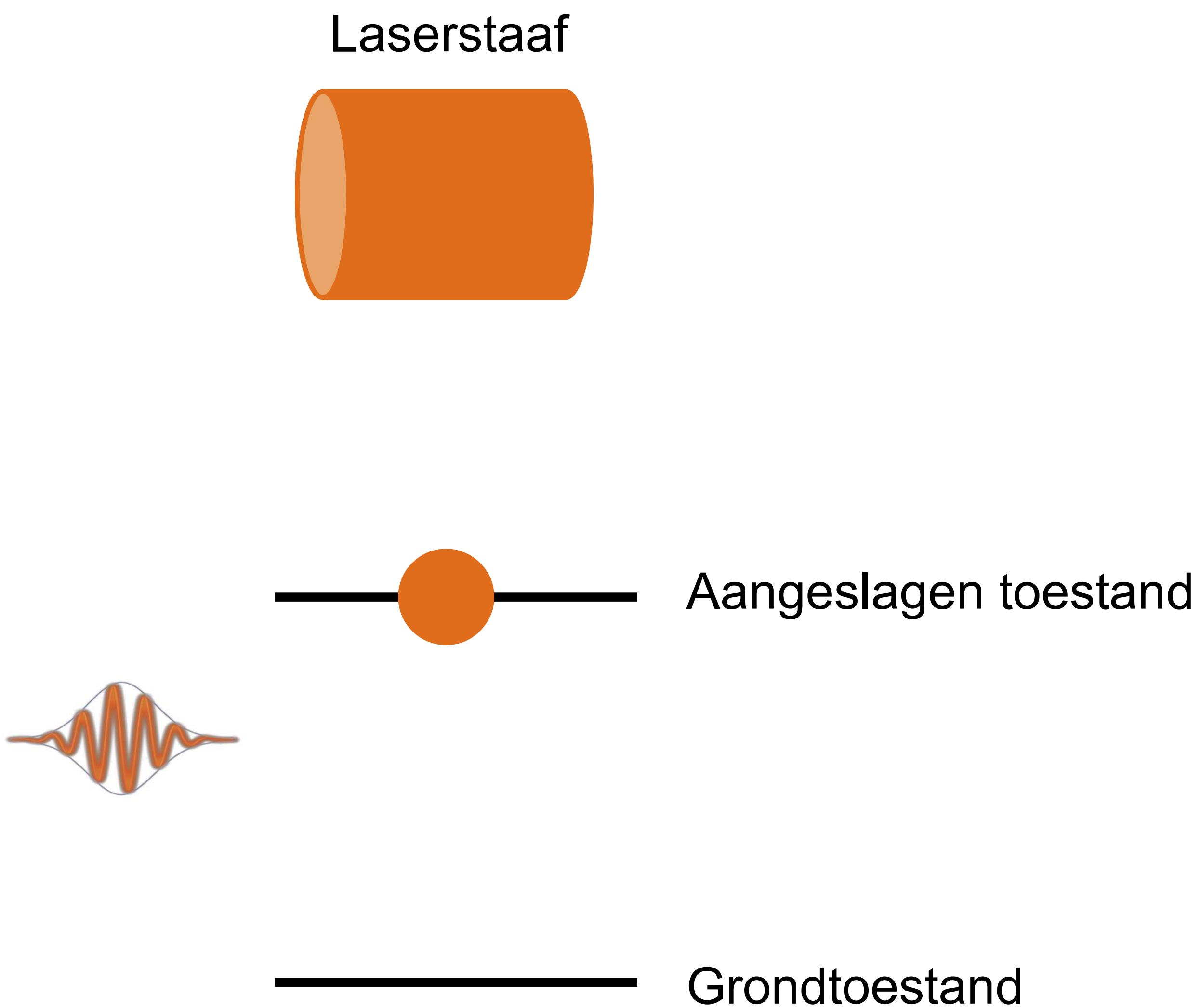
Energie in laserstaaf door bijvoorbeeld flitslampen of laser diodes



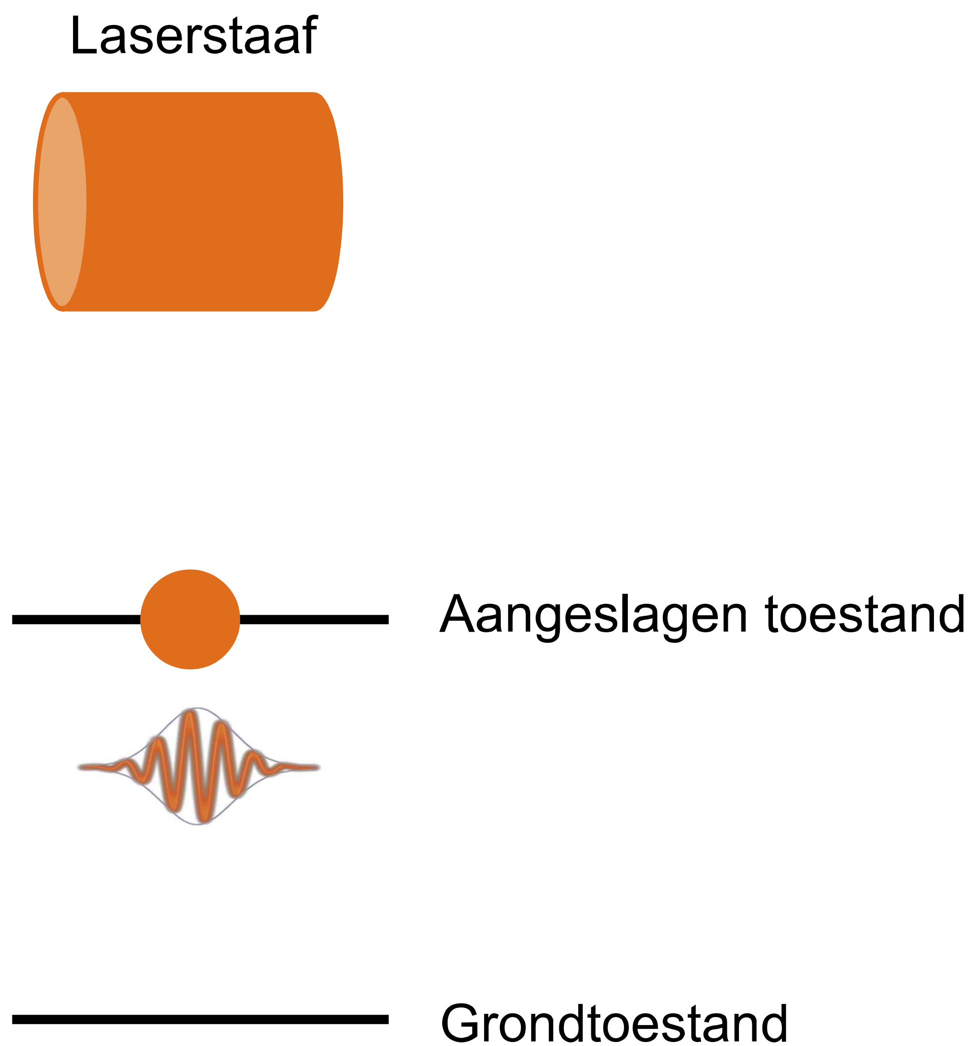
Aangeslagen toestand

Grondtoestand

Gestimuleerde emissie



Gestimuleerde emissie



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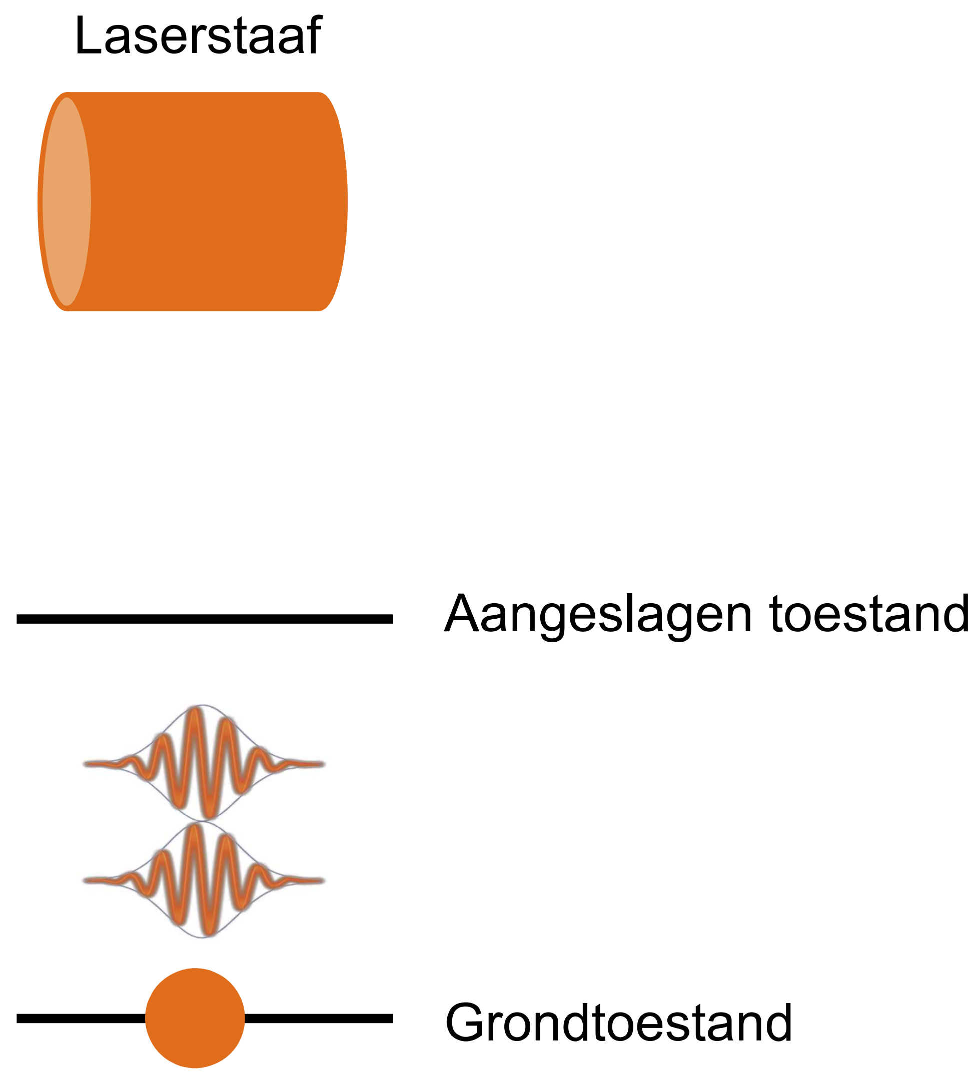

Gestimuleerde emissie

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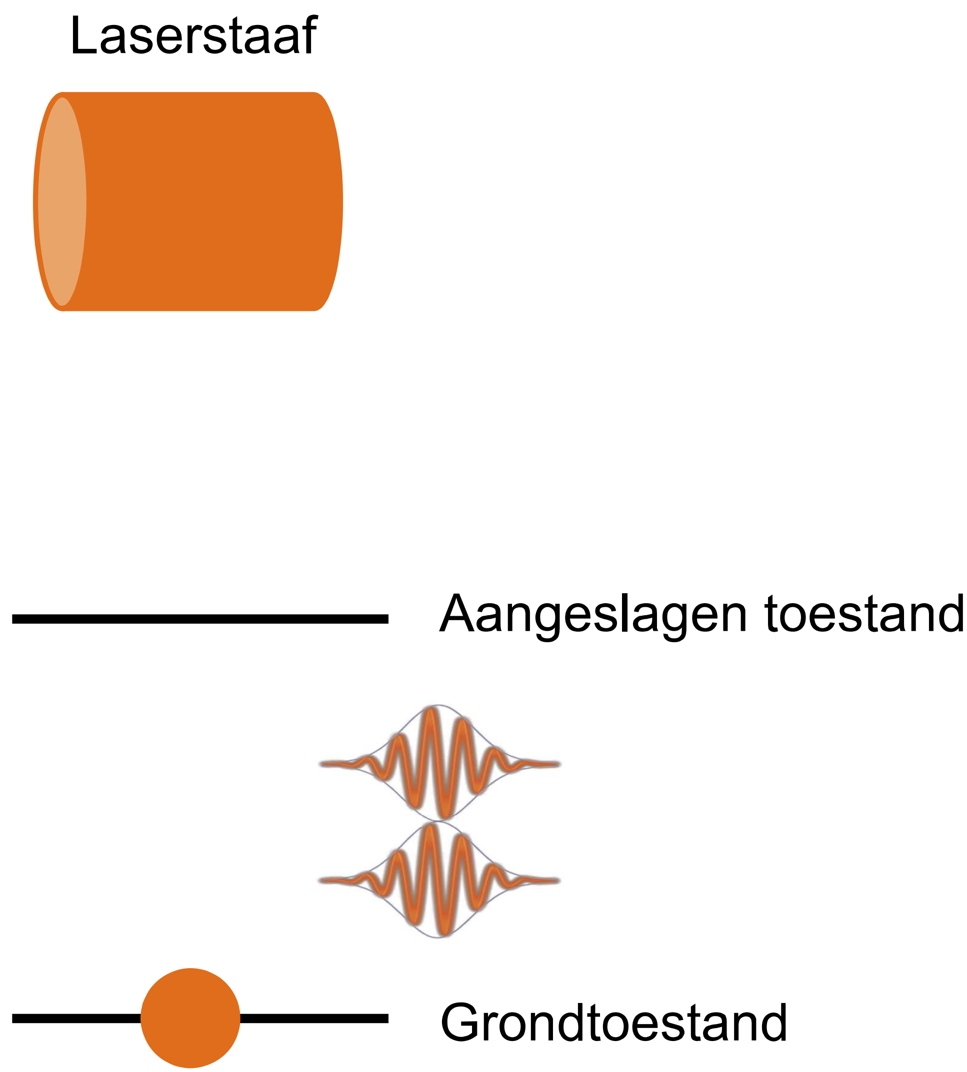
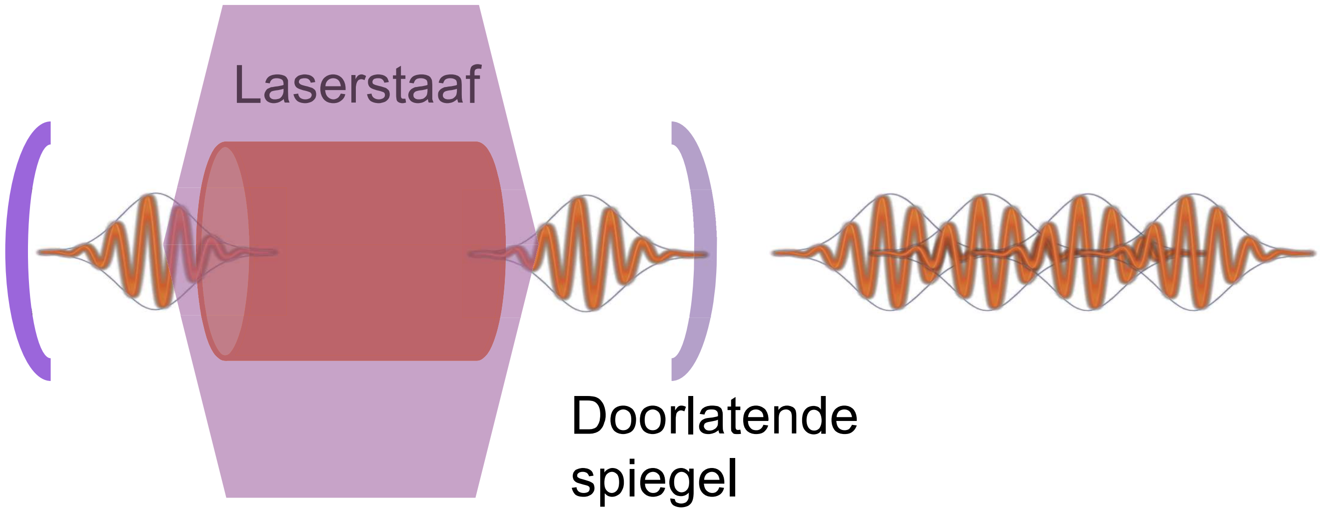
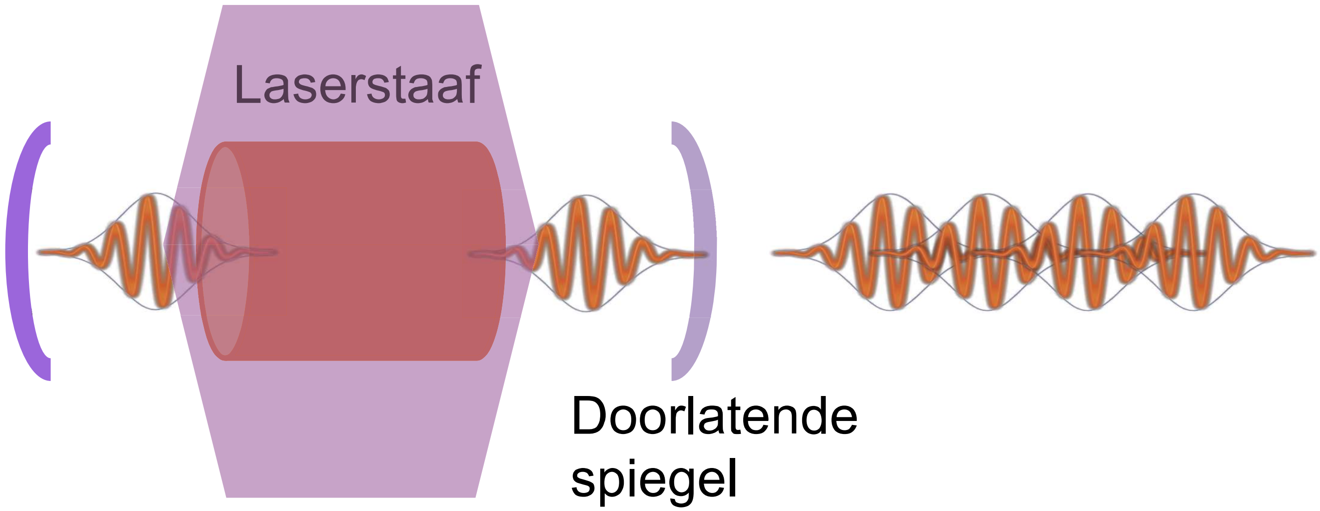


Met spiegels: een laser!



Met spiegels: een laser!



Maar hoe maak je superkorte pulsen hiermee?

Gewone laser: een zooitje!

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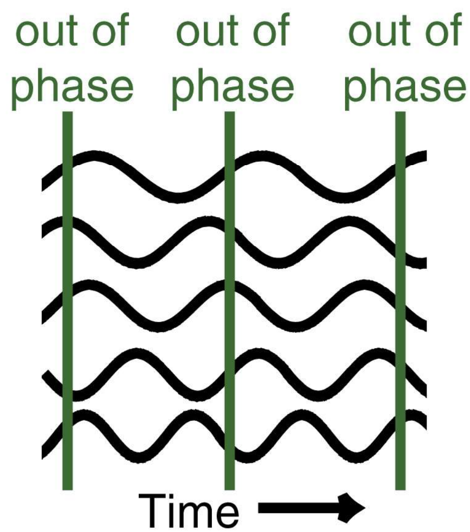
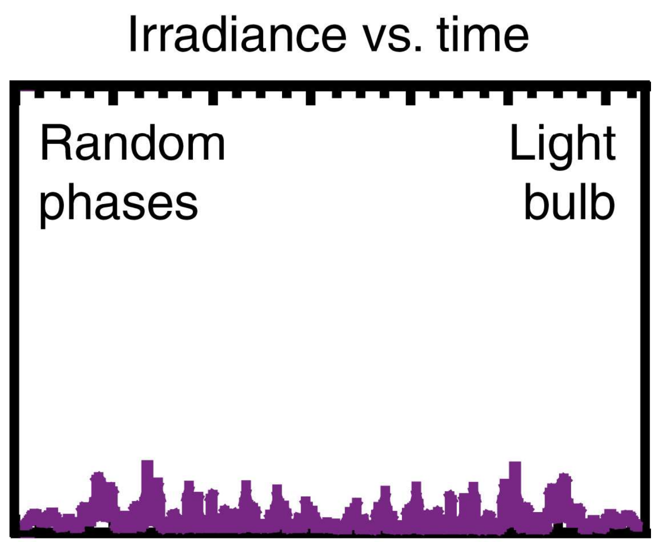
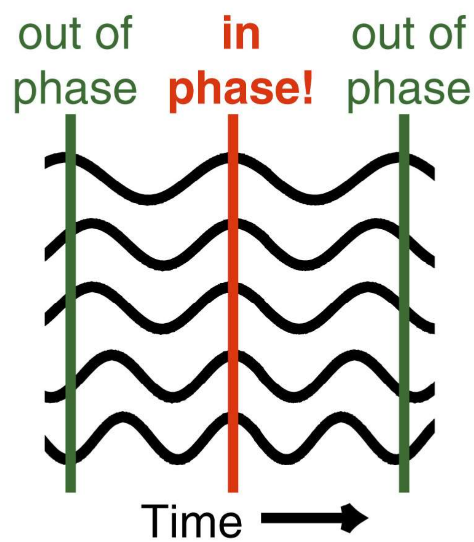
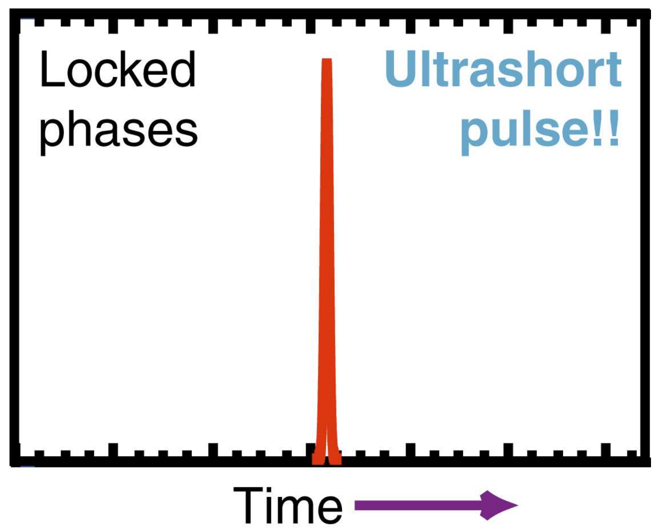
Random phases of all laser modes





Locked phases of all laser modes





From R. Trebino

Optellen van golven tot pulsen

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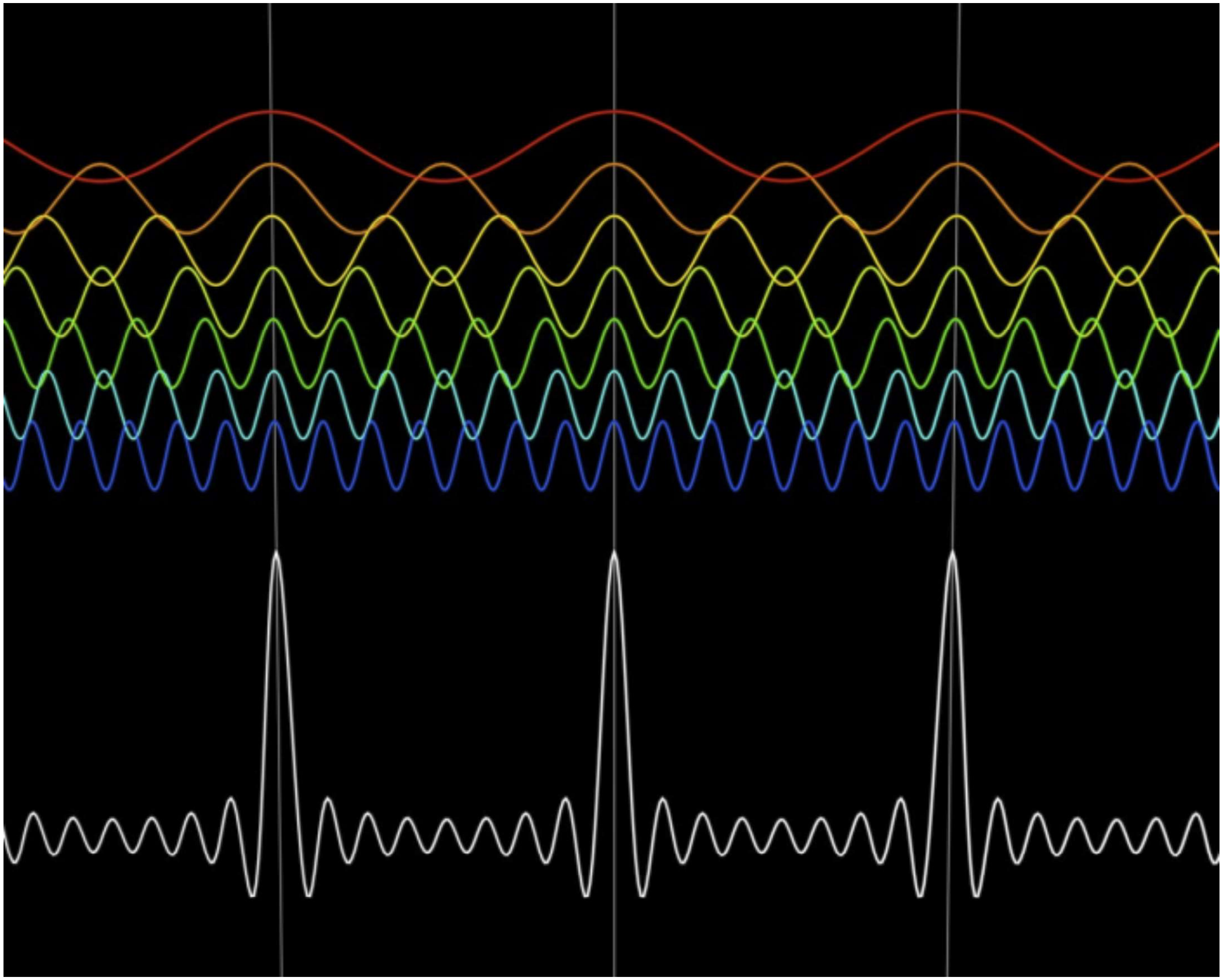
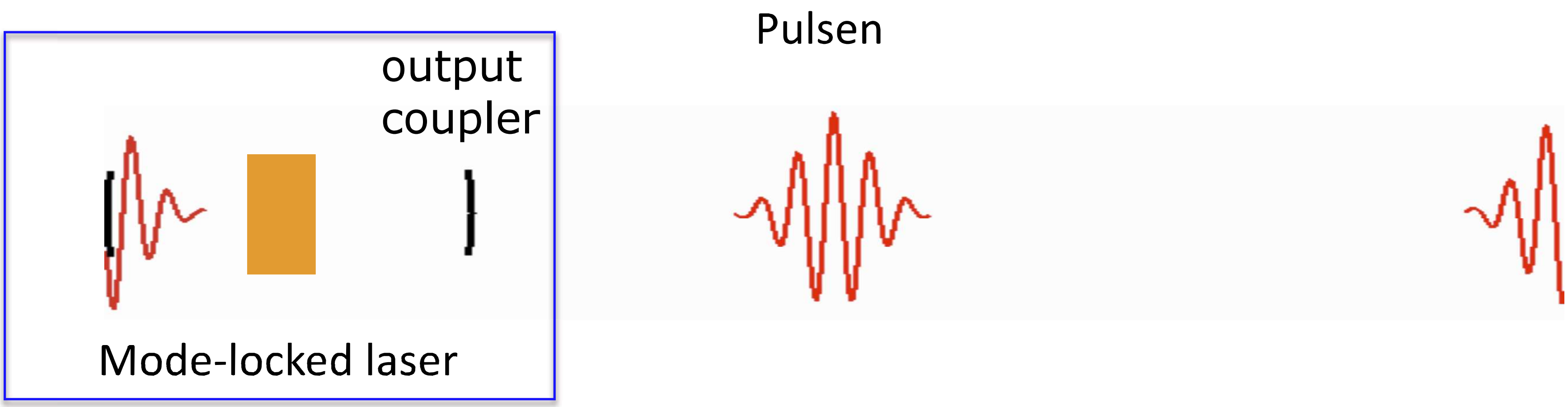
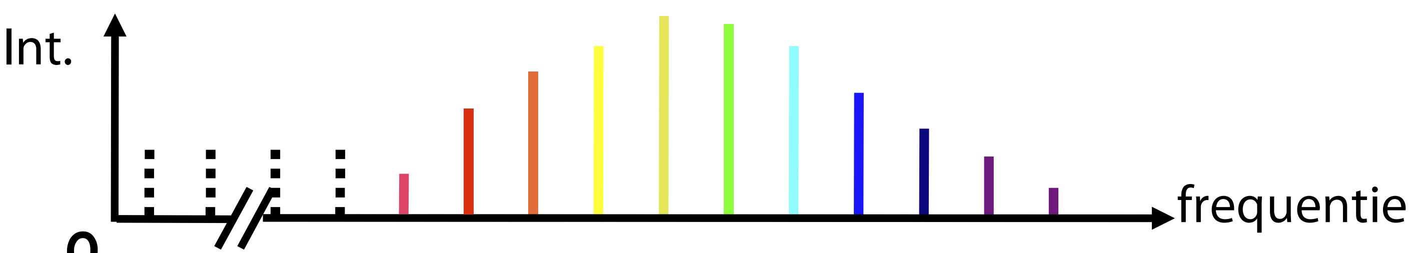


Ultrasnelle ‘gemodelockte’ lasers

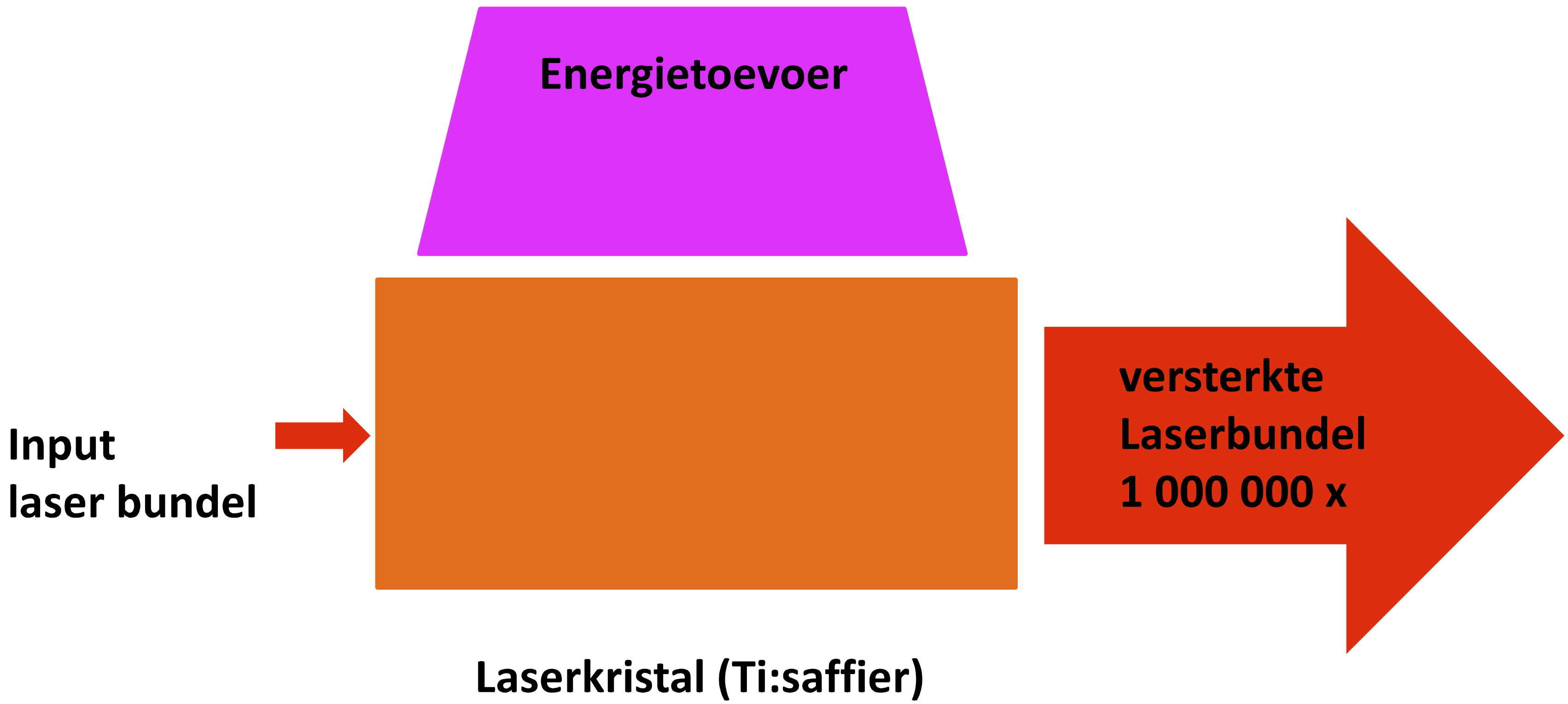


Laser modes (= frequenties = kleuren)



Duizenden tot miljoenen kleuren

Laserpulsen versterken, 1 MW tot ...



Probleem... laserintensiteit wordt te hoog

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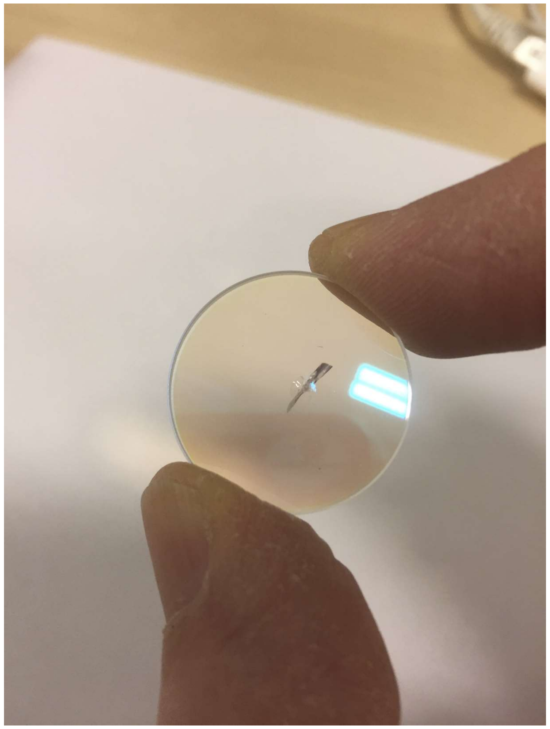
$$\text{Piek-}\textbf{intensiteit} = \frac{\text{Piekvermogen}}{\text{Oppervlakte van bundel}}$$

Optiek en laserstaven gaan kapot bij $>10^{11}$ W/cm^2



Maak de laserpuls dus langer en de bundel groter

Optellen van golven tot pulsen

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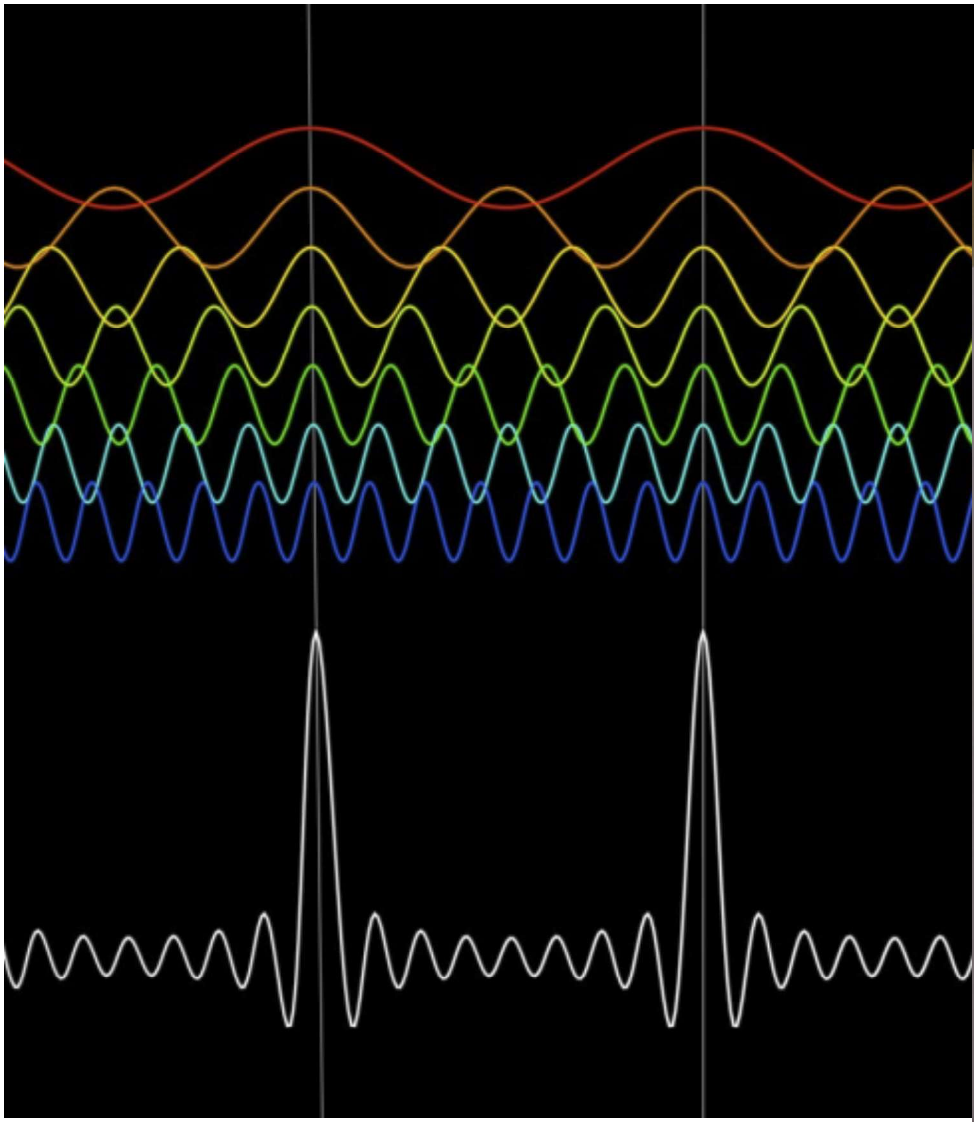

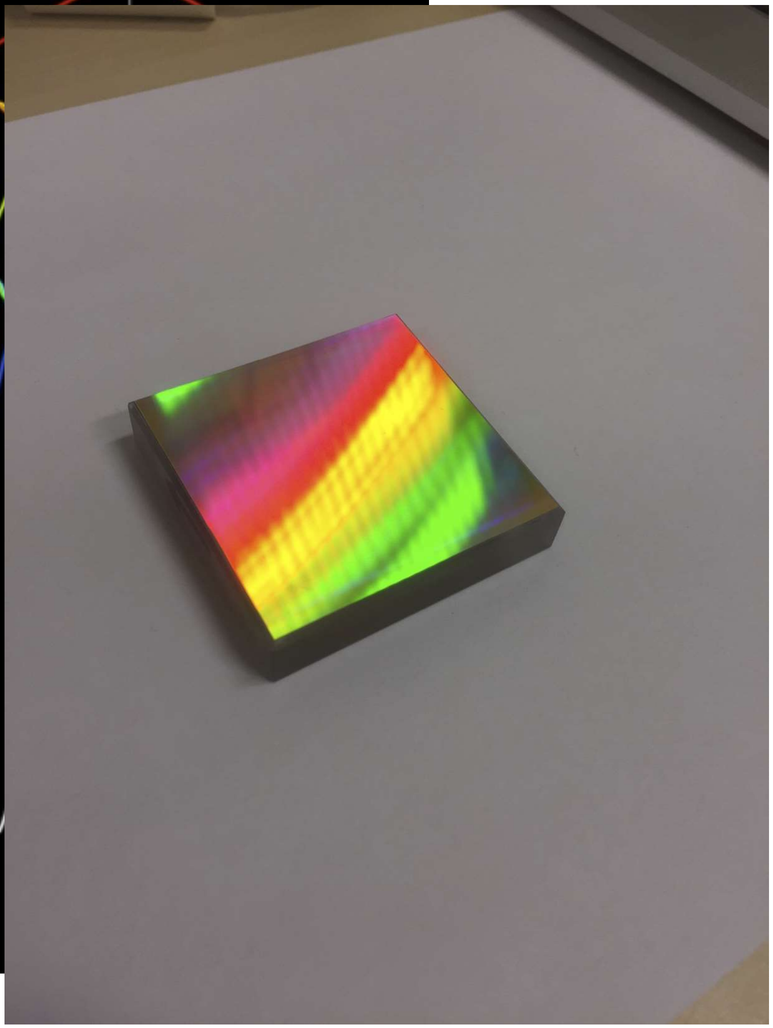

Oprekken pulsen door dispersie

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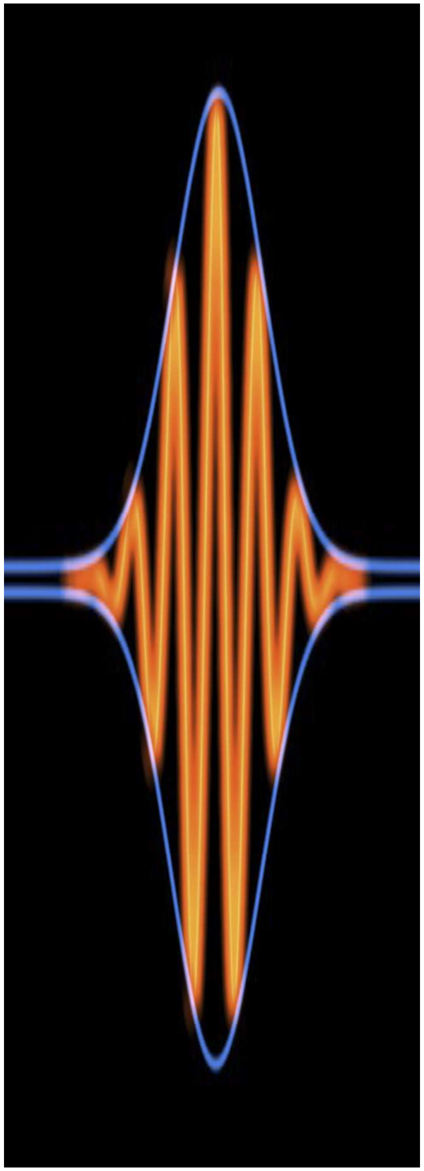
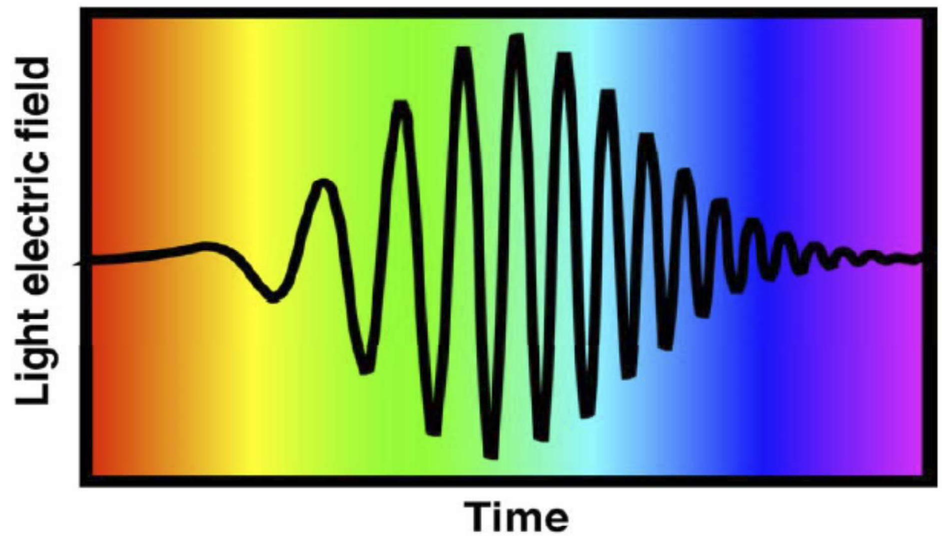


‘Dispersie’ maakt de puls langer en minder intens



“Chirped pulse amplification”

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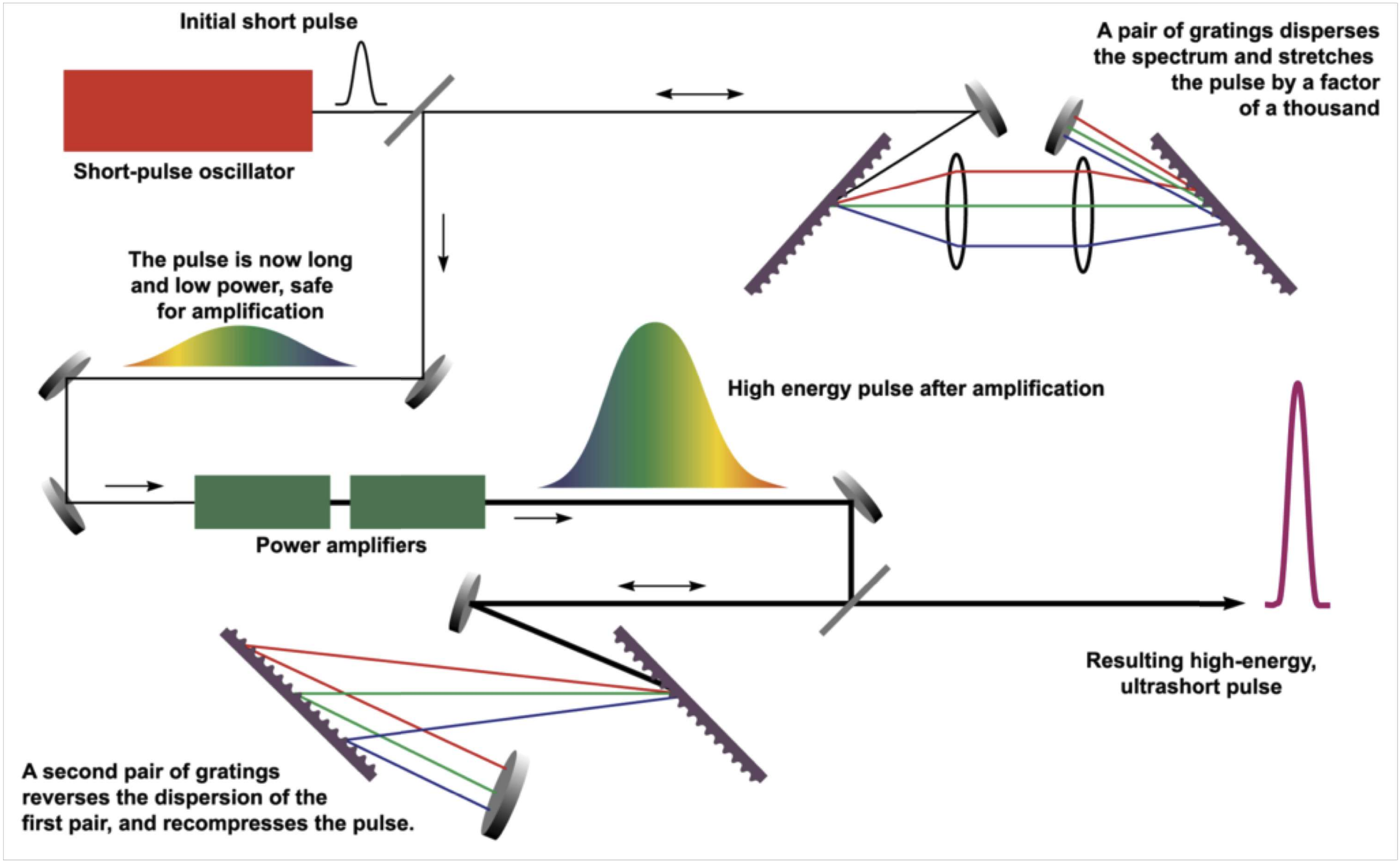

Het artikel uit 1985

Volume 56, number 3 OPTICS COMMUNICATIONS 1 December 1985

COMPRESSION OF AMPLIFIED CHIRPED OPTICAL PULSES ☆

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

We have demonstrated the amplification and subsequent recompression of optical chirped pulses. A system which produces 1.06 μm laser pulses with pulse widths of 2 ps and energies at the millijoule level is presented.

The onset of self-focusing of intense light pulses limits the amplification of ultra-short laser pulses. A similar problem arises in radar because of the need for short, yet energetic pulses, without having circuits

pulse would be free from gain saturation effects, because the frequency varies along the pulsewidth and each frequency component sees gain independently.

A schematic diagram of the amplifier and compres-

De ‘stretched’ en gecomprimeerde puls

Factor 200 in pulslengte

spacing was optimized for maximum compression of the pulses directly from the fiber. The gratings were set at 65° angle of incidence and separated by 25 cm.

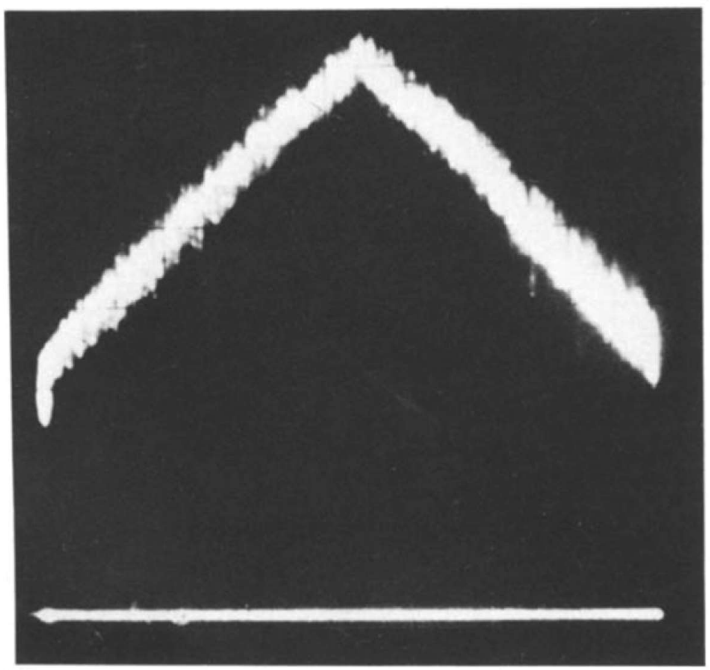

Fig. 2. Autocorrelation of stretched pulse at output of fiber. The pulse is rectangular in shape with a 300 ps pulsewidth.

In previous compression experiments of 1.06 μm pulses, shorter fiber lengths were used because maximum power output was desired [6]. In this case, the pulses are amplified in a regenerative amplifier and therefore the losses in the fiber are immaterial. The

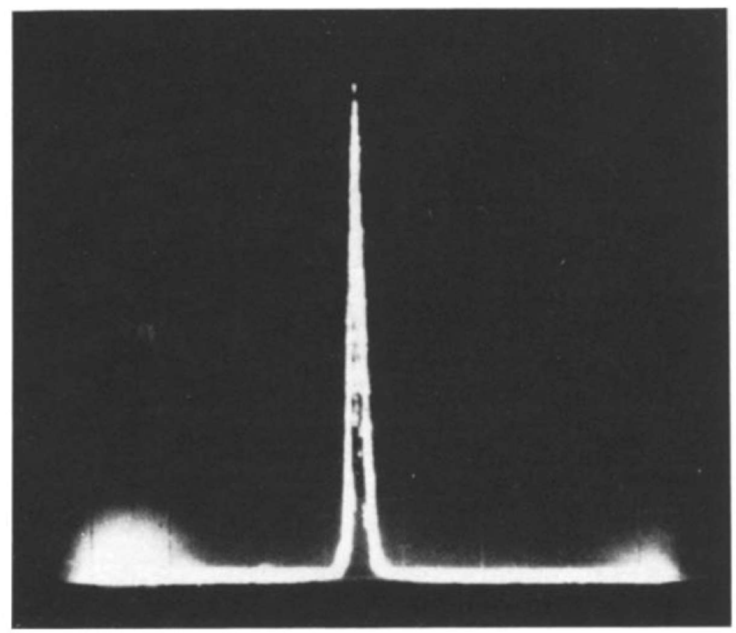

Fig. 3. Autocorrelation of 1.5 ps compressed pulse.

Gefocusseerde laserbundel in lucht ...

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Gefocusseerde laserbundel in lucht ...

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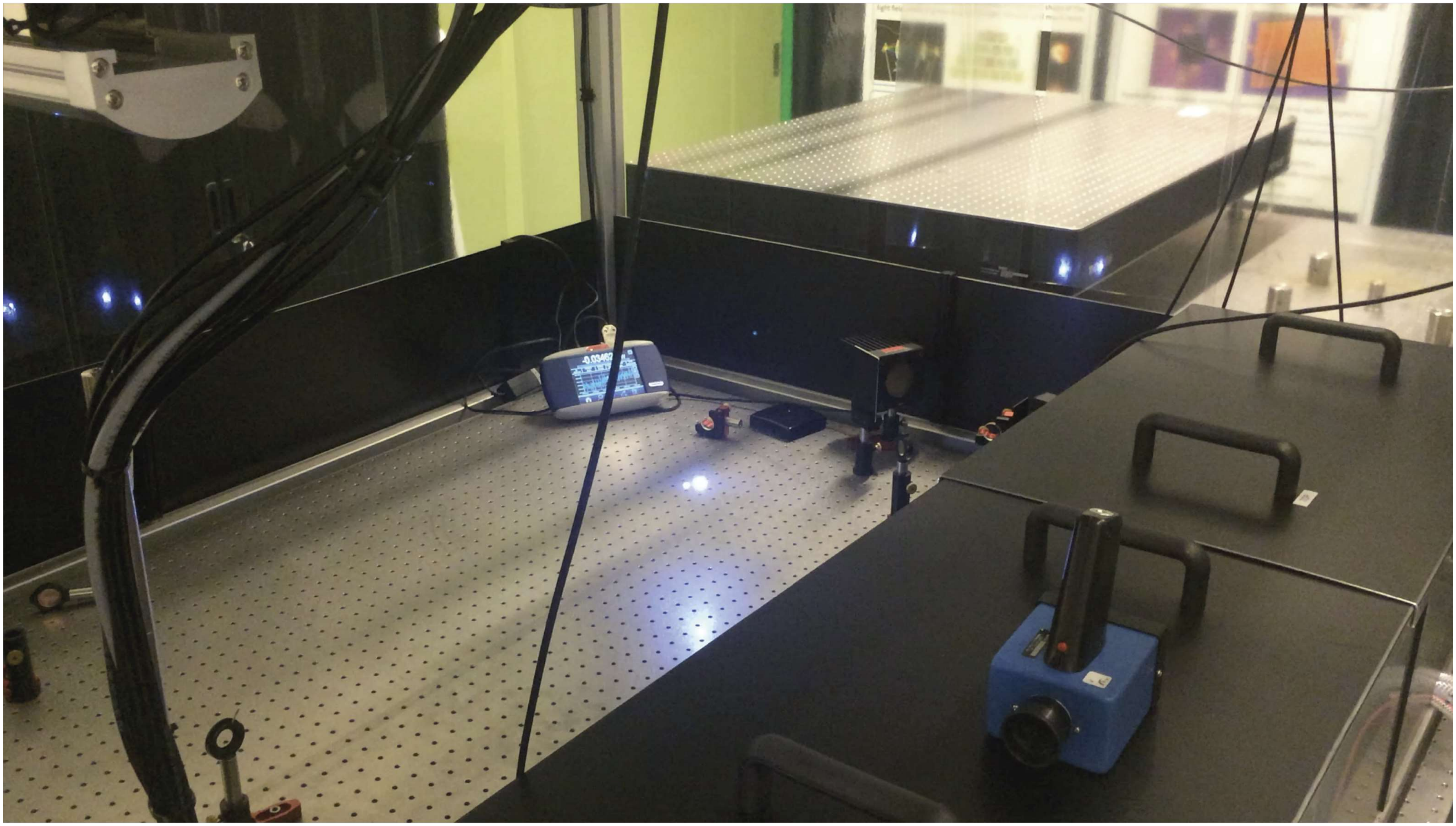
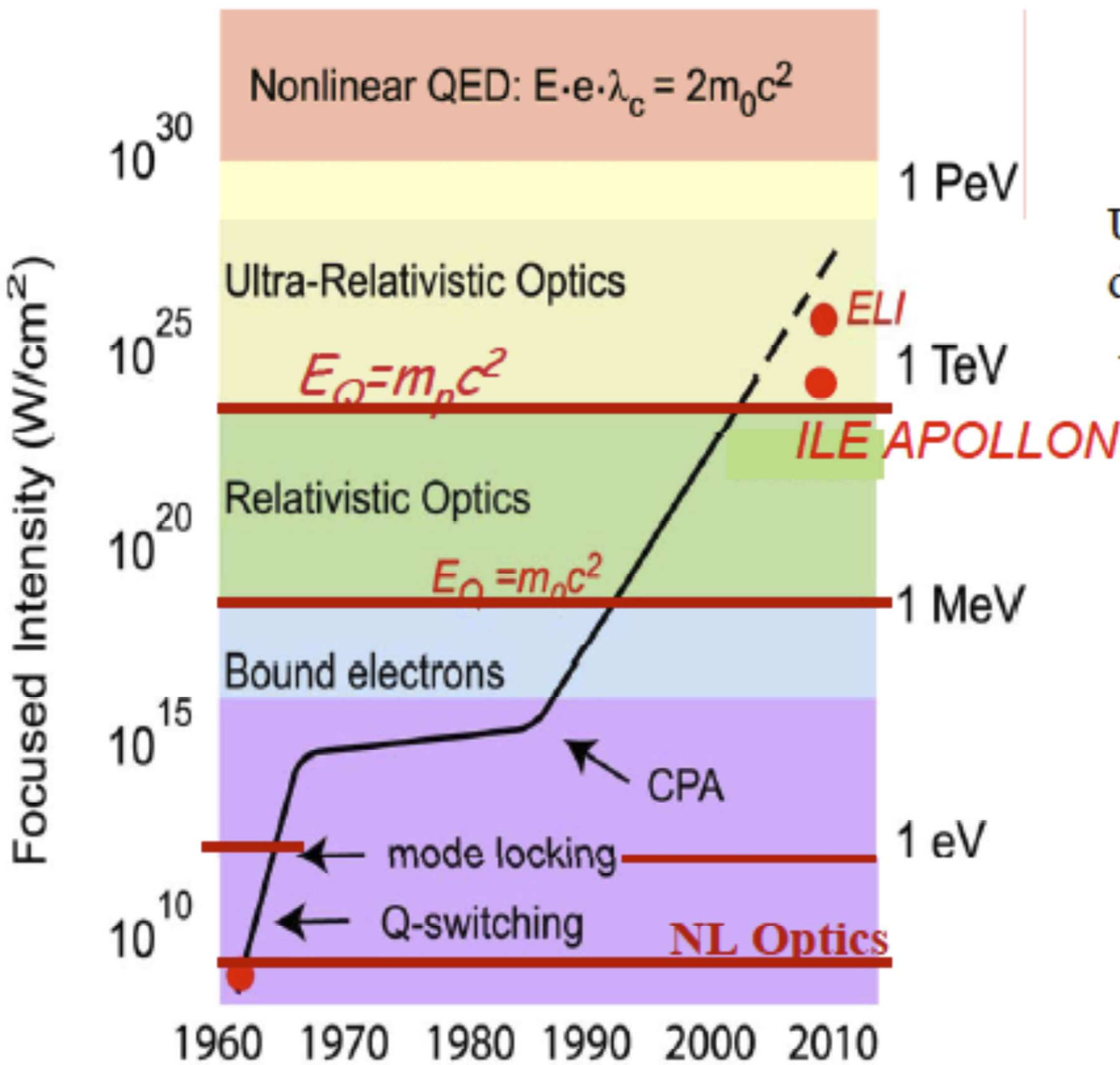


Maximum intensiteit na compressie



Ultra-relativistic intensity is defined with respect to the proton $E_Q=m_pc^2$, intensity~10^{24}W/cm^2

Toepassingen

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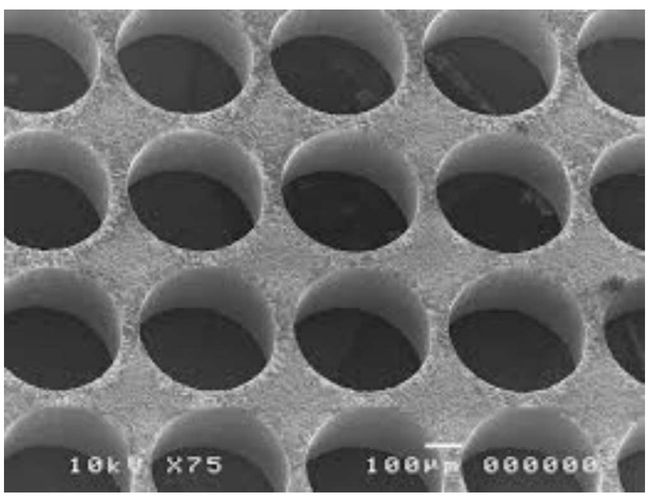
Lasersnijden: **oogchirurgie** of **precies lasersnijden**



Toepassingen

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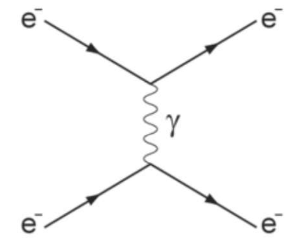
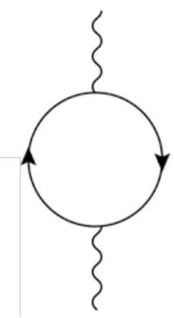
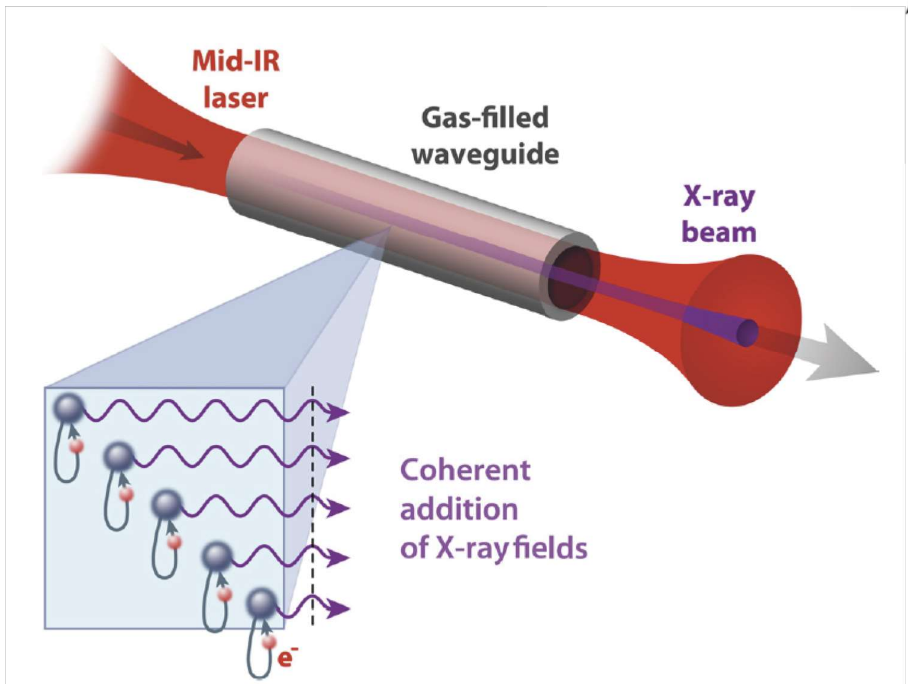
Fundamentele fysica, bijvoorbeeld:



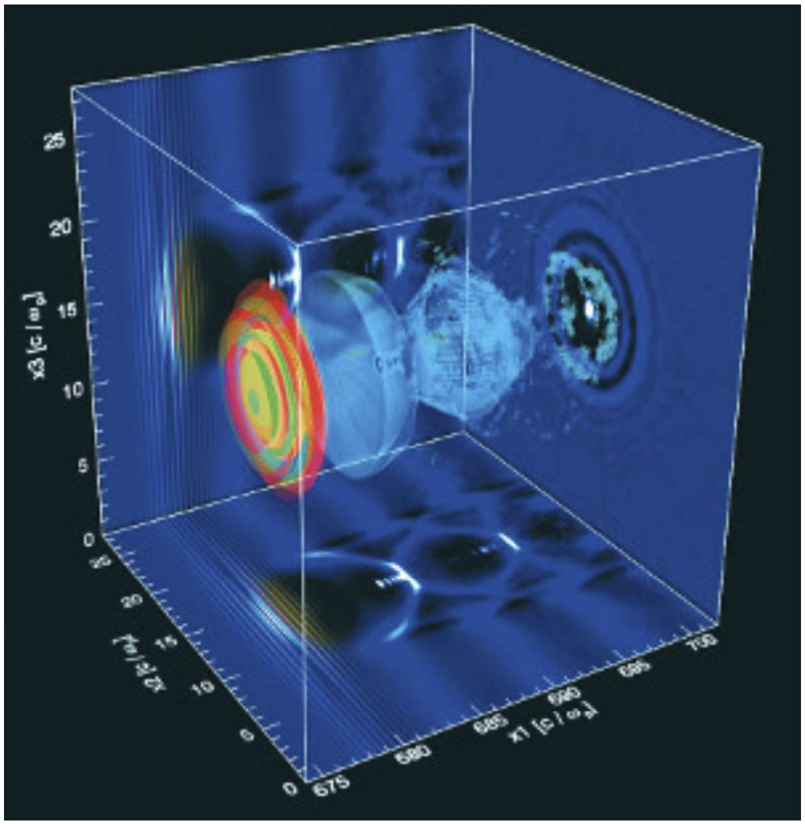
Maken van nieuwe golflengtes (extreem UV)
Testen atoom en molecuul energiestructuur
Testen van Quantum ElectroDynamica (QED)

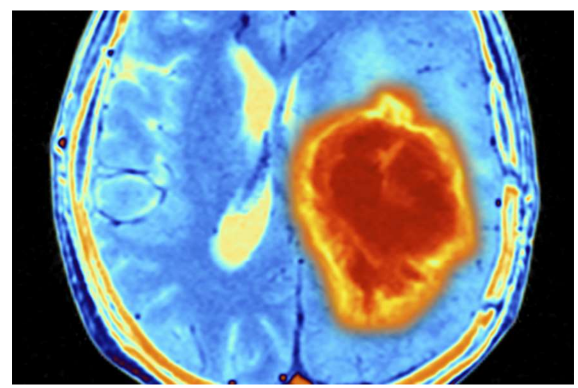


Attoseconden fysica
(10^{-18} seconde…)
En nog veel meer!



Deeltjesversnellers met licht – super kort

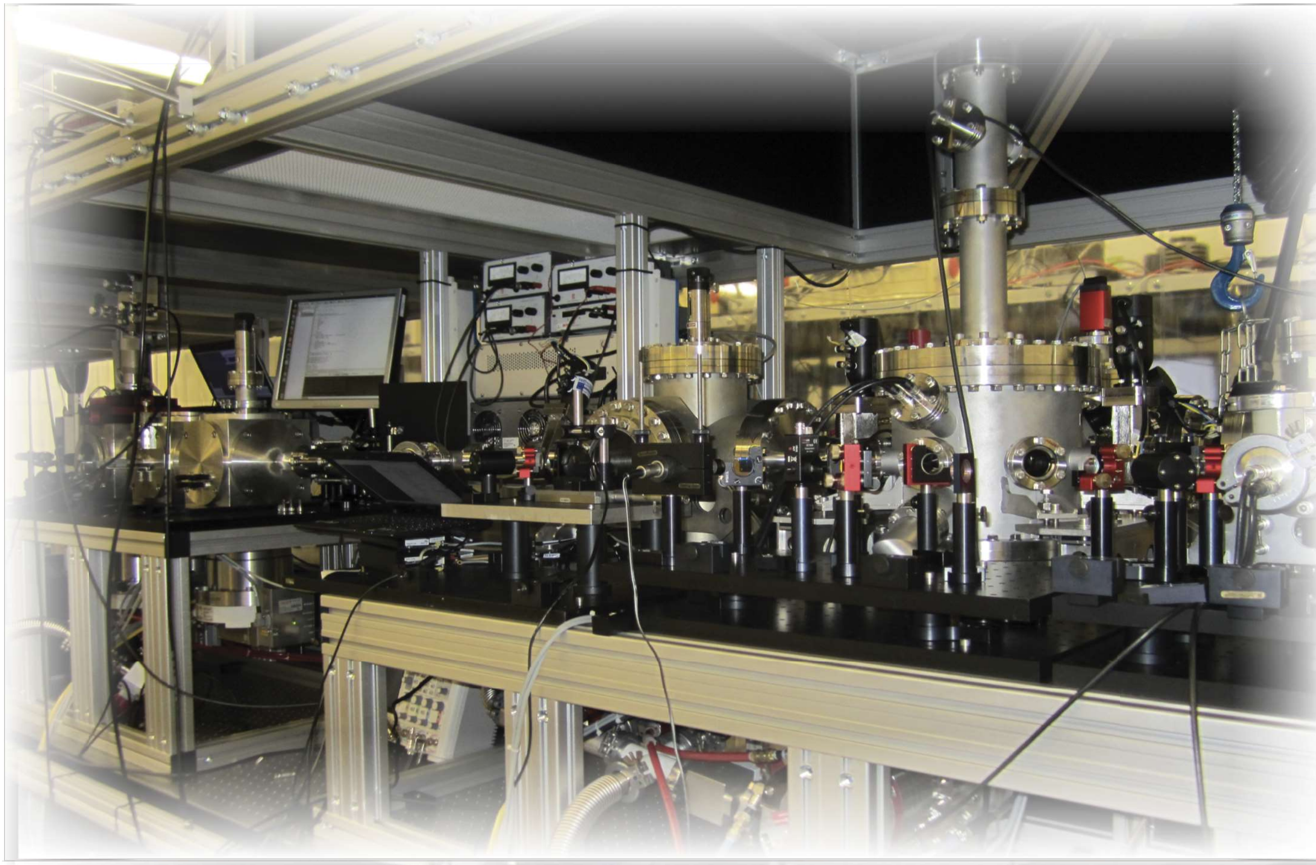


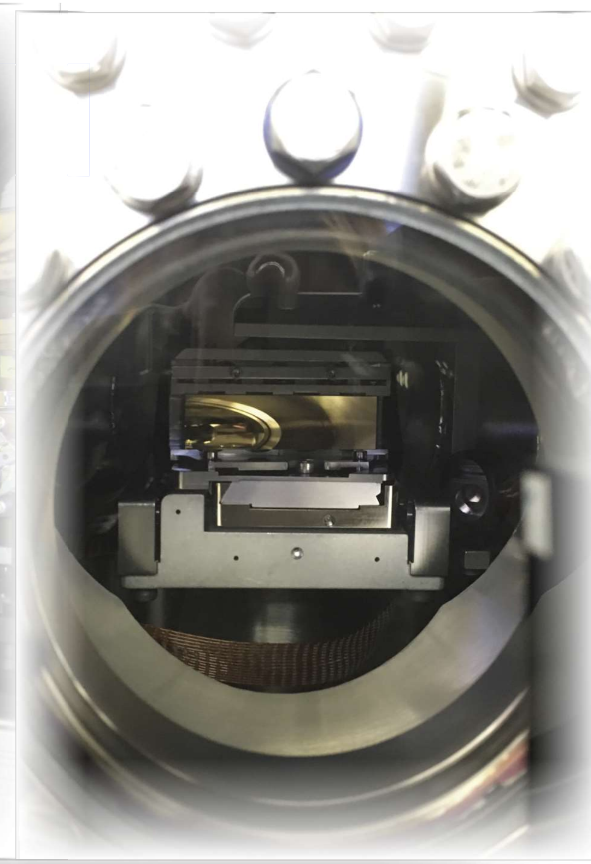


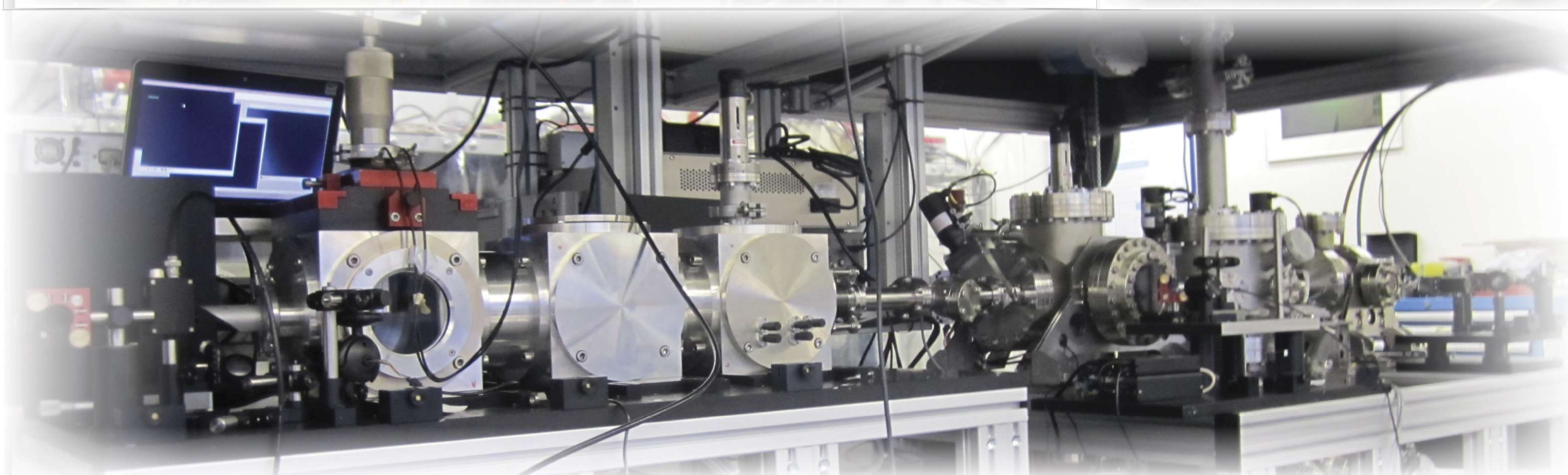
Bijvoorbeeld voor kankerterapie.

Etc etc…

Een van de chirped pulse amplifiers op de VU







Samenvatting

"Chirped pulse amplification" – CPA heeft ongelofelijke laserintensiteiten en korte pulsen mogelijk gemaakt

Er zijn heel veel toepassingen van CPA, van medisch tot fundamentele fysica

Het einde is nog niet in zicht: nu kan ~10 PW gemaakt worden, maar er zijn al plannen voor 100 PW en meer…

De fysica van ons universum maakt onwaarschijnlijk veel mogelijk: een geweldige speeltuin!