Institute of Applied Physics

Friedrich-Schiller-Universität Jena

Laser physics SS 2023

Seminar 1

www.iap.uni-jena.de

Singularities of the timetable

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KW15		...	KW18		...	KW22	
*Mon 10.04**	*Wed 12.04*		*Mon 01.05**	*Wed 03.05*		*Mon 29.05**	*Wed 31.05*
	1st Seminar 14:00-15:30			Seminar during tutorial time 16:00-17:30			Seminar during tutorial time 16:00-17:30

*Public holidays

Hints for online students

- Lecture streaming
  - https://www.uni-jena.de/livestreams

Veranstaltungsort	Links
Albert-Einstein-Straße 6	
Hörsaal ACP	Livestream Chat
ACP Raum e001	Livestream Chat

  - Recorded videos in Moodle
- Seminar
  - Zoom

All seminar dates for the students

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KW	Date	Day	Seminar
15	12.04	Wednesday	Introduction
16	17.04	Monday	Discussion of problem sheet
17	24.04	Monday	Discussion of problem sheet
18	03.05	Wednesday	Discussion of problem sheet
19	08.05	Monday	Discussion of problem sheet
20	15.05	Monday	Discussion of problem sheet
21	22.05	Monday	Discussion of problem sheet
22	31.05	Wednesday	Discussion of problem sheet
23	05.06	Monday	Discussion of problem sheet
24	12.06	Monday	Discussion of problem sheet
25	19.06	Monday	Discussion of problem sheet
26	28.06	Wednesday	Exam

Group	Tutor	Location
1	Benjamin Yildiz (benjamin.yildiz@uni-jena.de)	Computer pool ACP
2	Yiming Tu (yiming.tu@uni-jena.de)	ACP Auditorium
3	Mehran Bahri (mehran.bahri@uni-jena.de)	SR1 ACP
4	Maximilian Benner (maximilian.benner@uni-jena.de)	SR2 ACP

- On **17.04** and **22.05**, **students in group 3** (Mehran) please come to **ACP auditorium** for your seminar

How does a homework look like:

Problem set X

Your Name
Name of tutor
Problem 1:

- A neat and tidy solution with text/ figures

…

- Please name your submitted pdf files including your seminar number and full name

Rule for the late submission

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- Please submit your homework in time

Problem Sheet 1

Opened: Monday, 3 April 2023, 12:00 PM
Due: Tuesday, 11 April 2023, 8:00 AM

Laser Physics SS23 Sheet 1.pdf 28 March 2023, 4:18 PM

- points will be given for exercises, which will count as additional points in the written exam according to the following table:
>90% correctly solved -> +5 points
>80% correctly solved -> +4 points
>70% correctly solved -> +3 points
>60% correctly solved -> +2 points
>50% correctly solved -> +1 point
(typical overall points of the written exam are in the range of 35-40)

- In case of late submission
  - You can submit it to **your seminar tutor** via **email** and we will correct it
  - For the **first** time, you will get **half** of your deserved points
  - From the second time on, **no point** will be given

Teamwork: presentation

- 15 topics, 4-6 persons / topic
- Presentations:
  - 8 min + 4 min discussion
  - The begin of June (Wednesday tutorial time)
  - **Mandatory**
- Topic released on through Moodle
- Sign in a topic after the release

Example:

Topic: Lasers in medicine

Possible content:

What kinds of lasers are used for (and why)?

- Surgery
- Ophtalmology
- Laser hair/tattoo removal
- Dentistry
- Medical imaging (e.g. OCT)
- …

	Topics of last year
(1)	Laser applications in material processing
(2)	Applications of lasers in art
(3)	The role of lasers in gravitational wave detection
(4)	Optical data storage/holography
(5)	Free-electron lasers and their applications
(6)	Laser-induced fusion
(7)	Lasers in space applications
(8)	Lasers in metrology
(9)	LIDAR
(10)	Lasers in medical applications
(11)	Lasers in manufacturing
(12)	Manipulation of matter with light (e.g. optical tweezers)
(13)	Lasers in communications
(14)	Lasers in quantum techniques
(15)	Laser applications in imaging

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Lasers

Laser physics SS23 seminar 1

Mehran Bahri

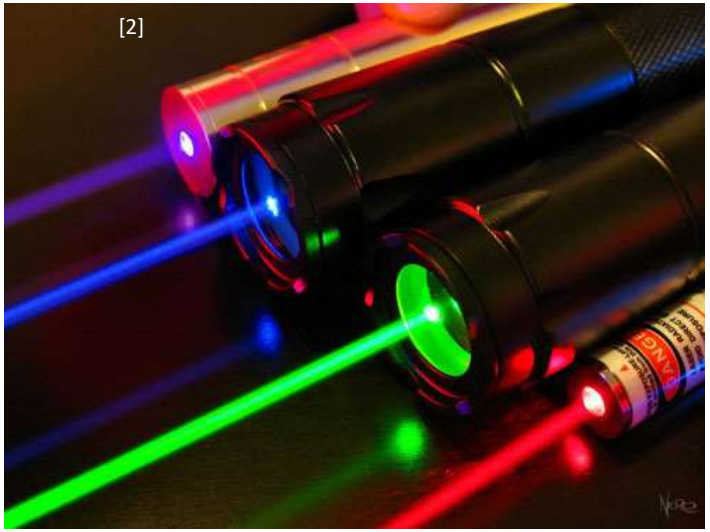
Everything from this slide on is not relevant for the exam

Why laser?


[1]

- Poly-chromatic
- Divergent
- Incoherent
- Spontaneous emission

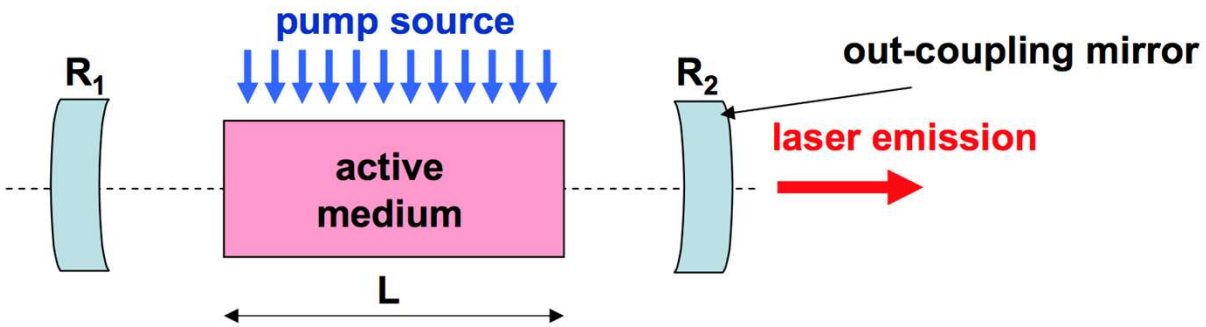
WHY?

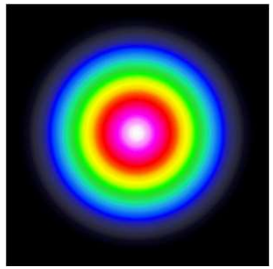

[2]

- Mono-chromatic
- Directional
- Coherent
- Stimulated emission

[1] http://www.blockheizkraftwerk-bhkw.net/wp-content/uploads/Gluehbirne-285x300.jpg
[2] http://www.laserfest.org/lasers/images/nero1.jpg

Light Amplification by Stimulated Emission of Radiation



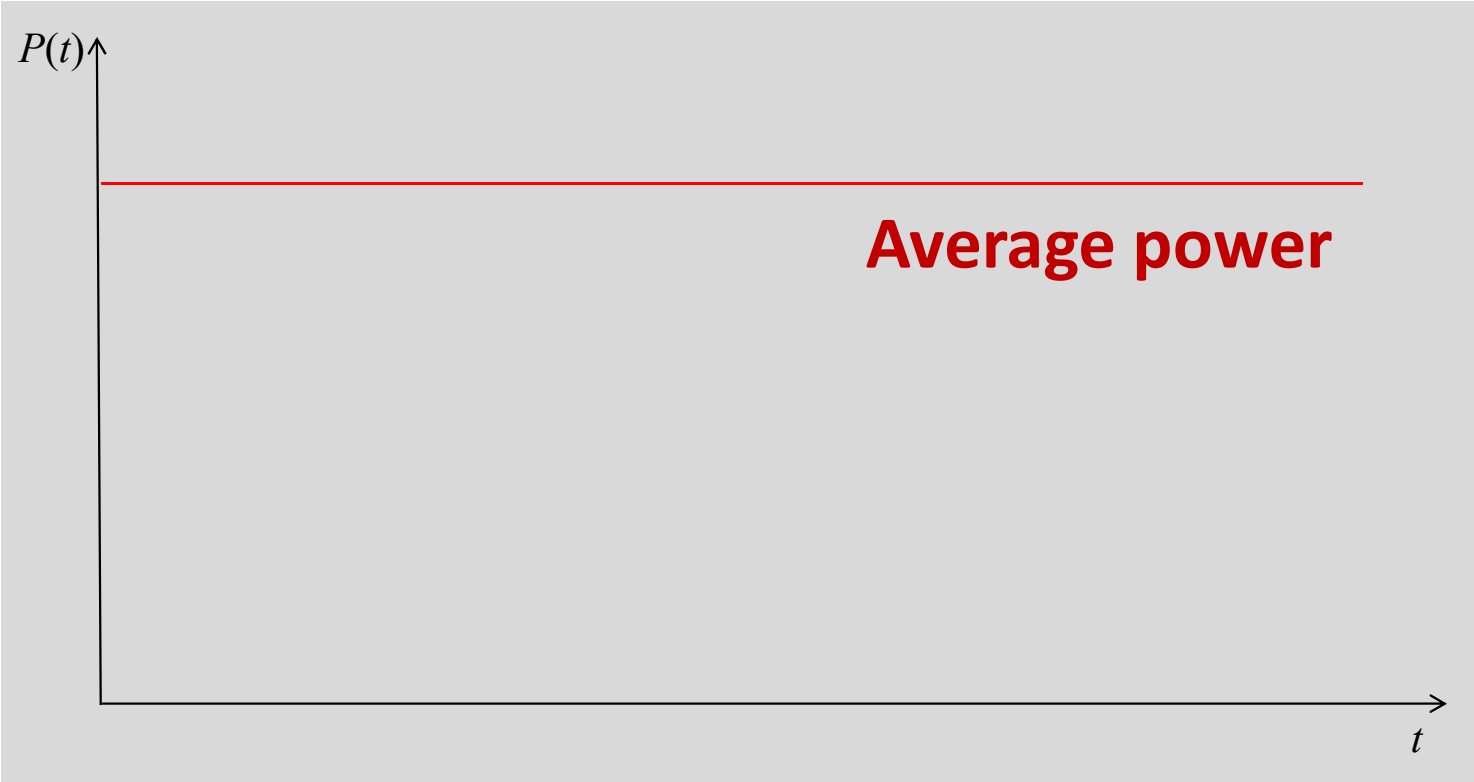


How does the output look like?

- Spatially
- Temporally
- Spectrally

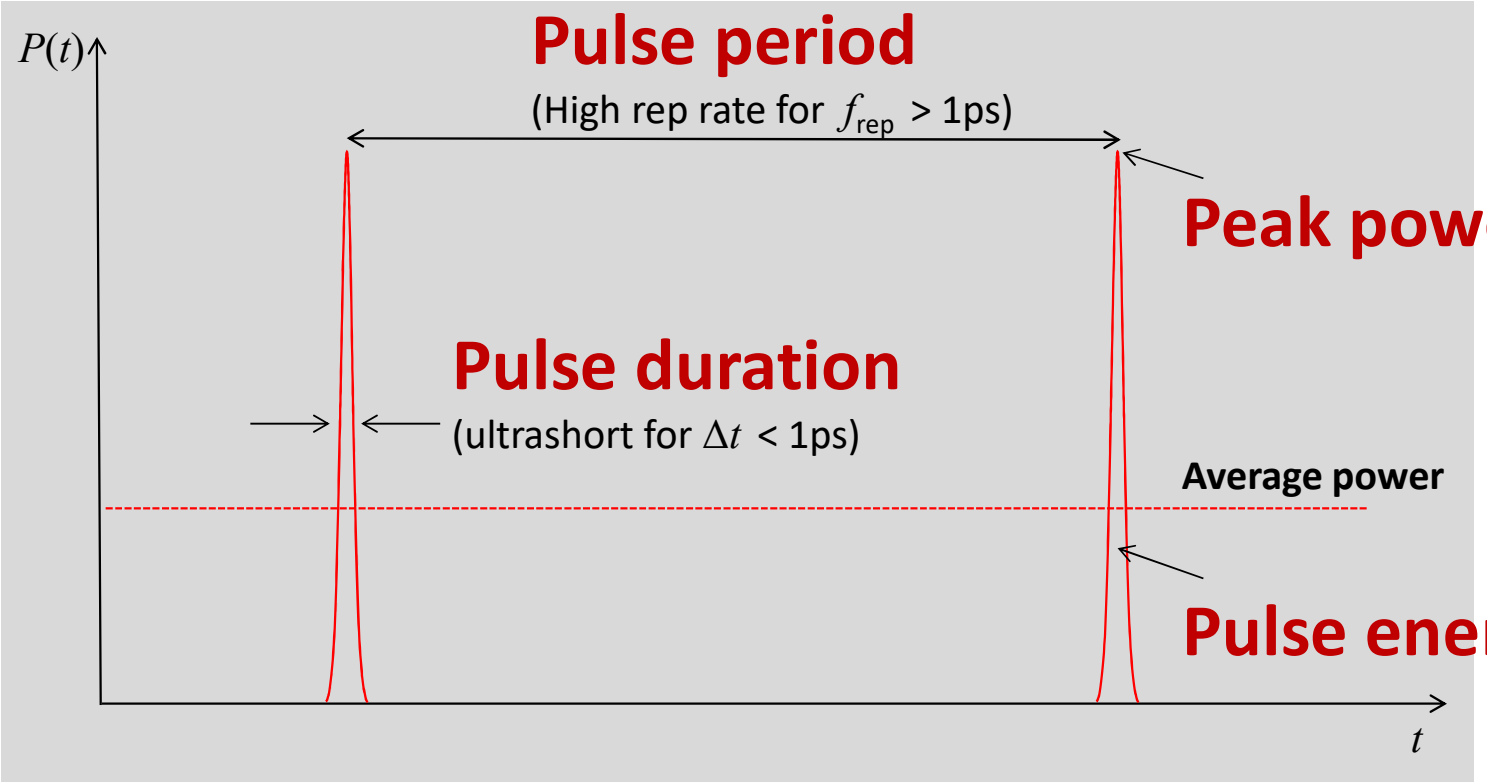
CW versus Pulse regime

Important parameters



Continuous wave (cw) operation

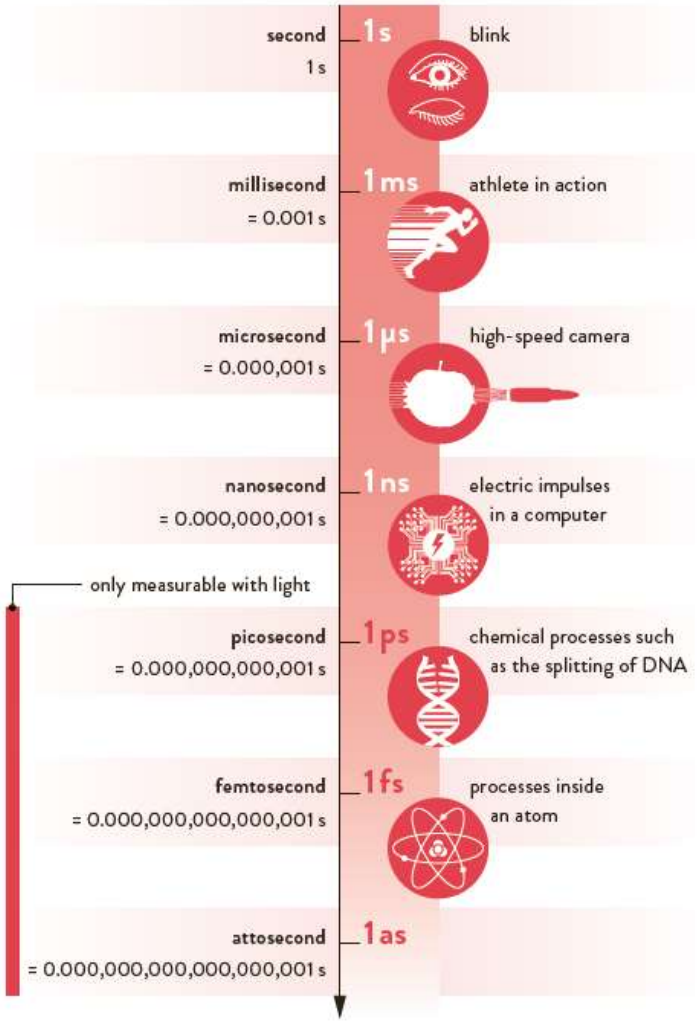
Important parameters



Pulsed operation

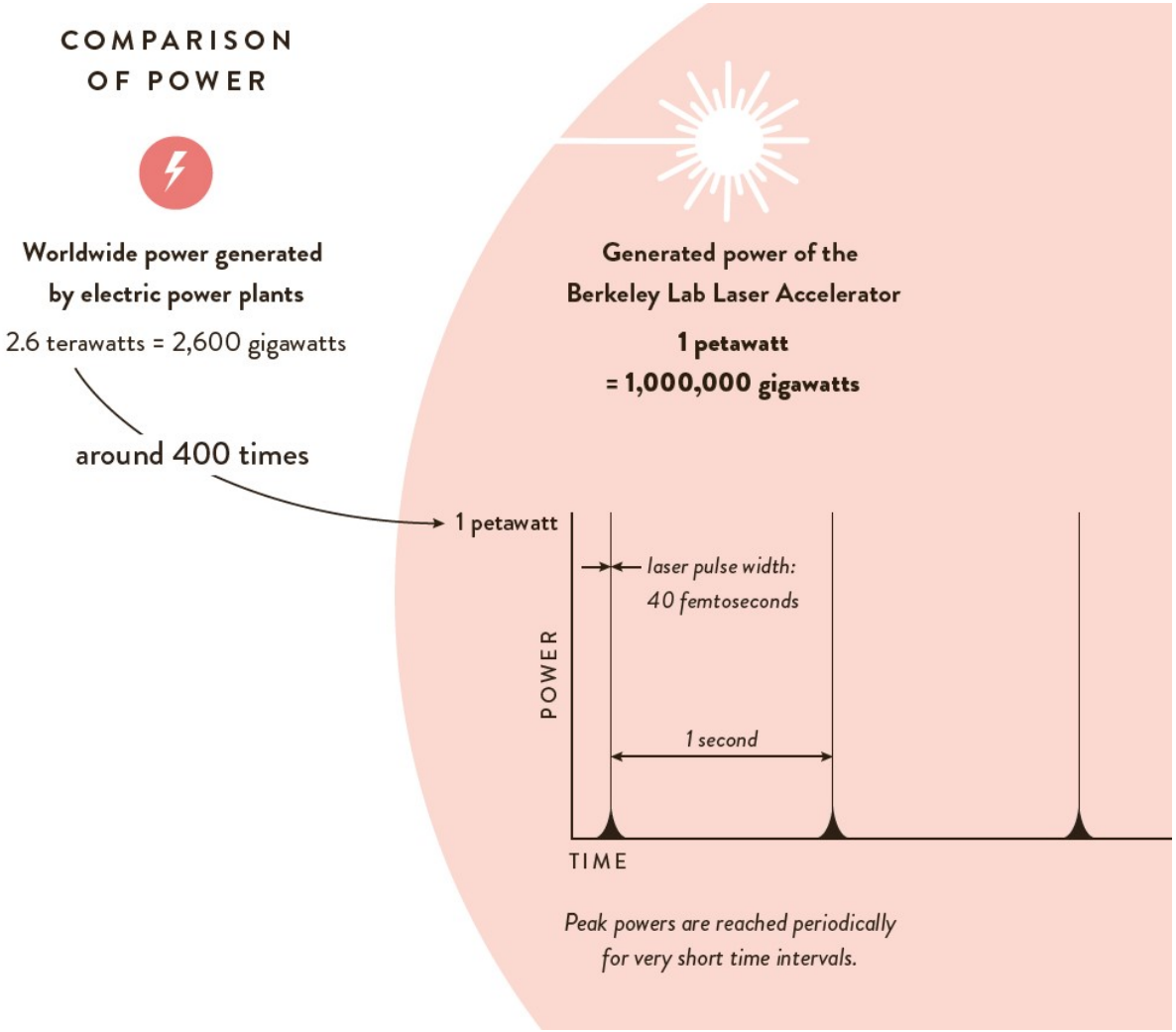
Why do we need to go to pulse regime?

Pulse duration



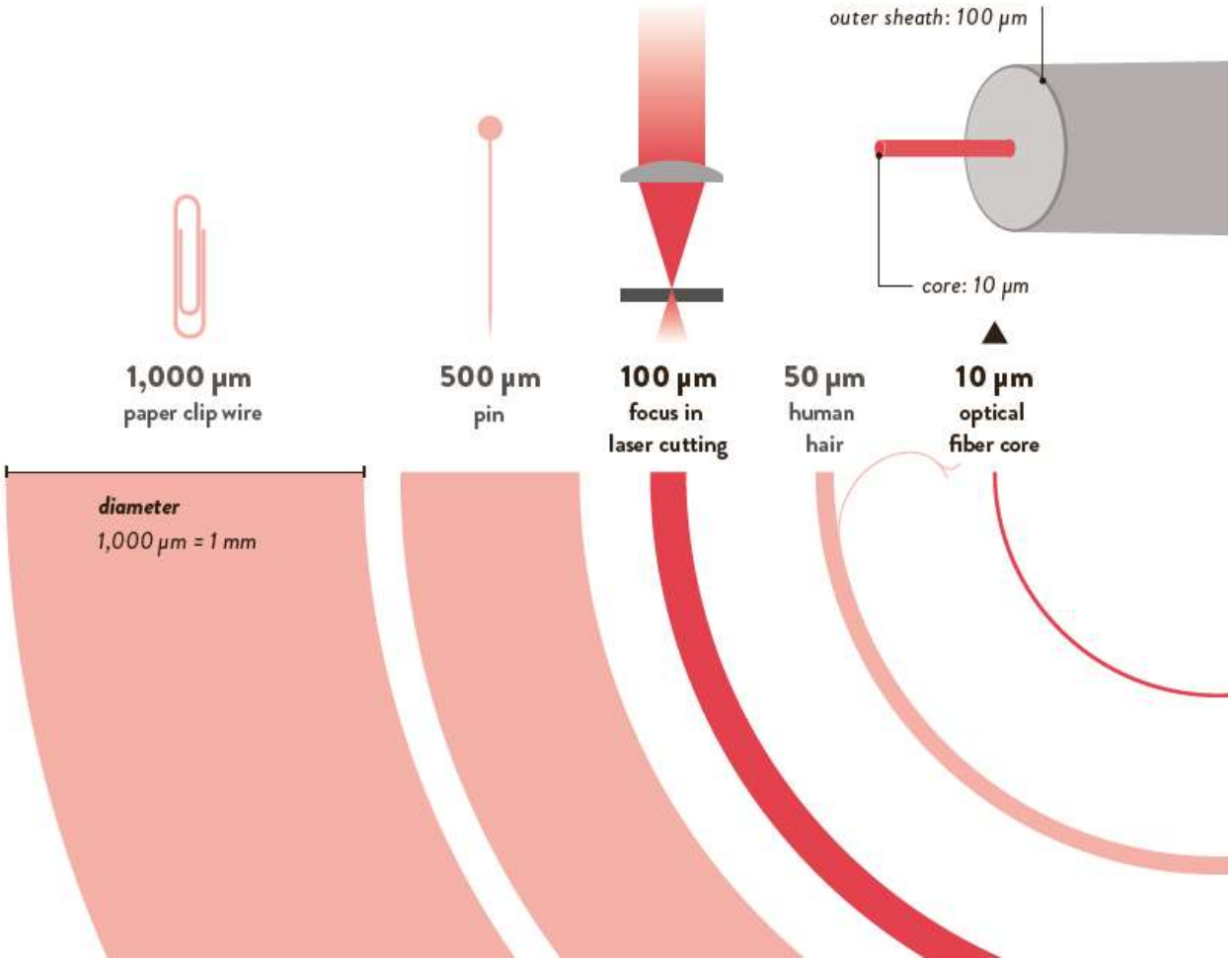
https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf

Peak power



https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf

Spot size



https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf

Future applications

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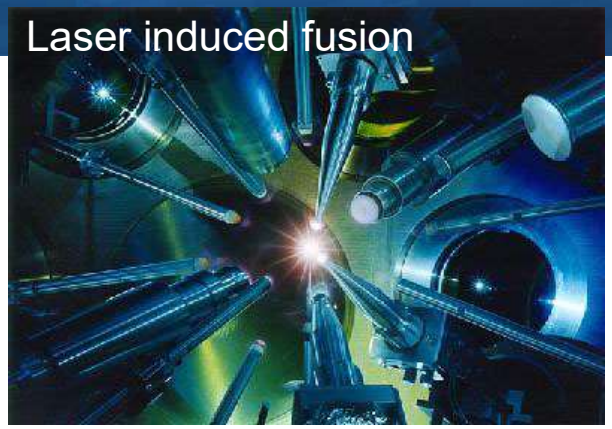

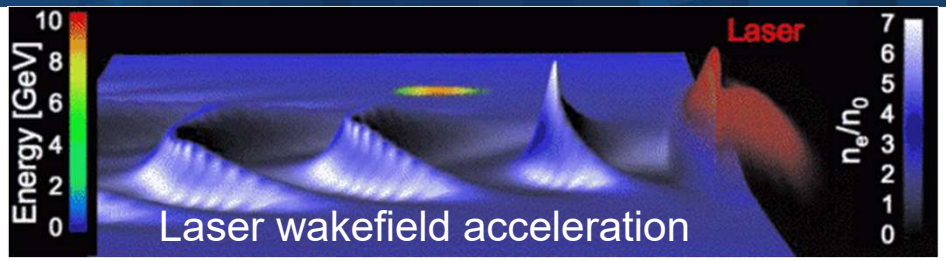

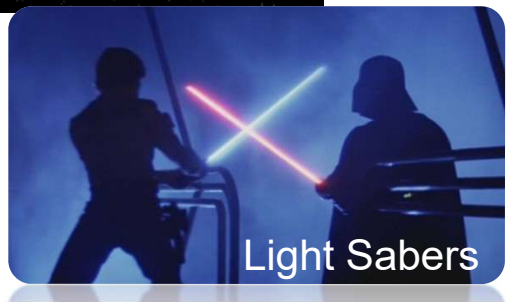

Problems with light sabers…

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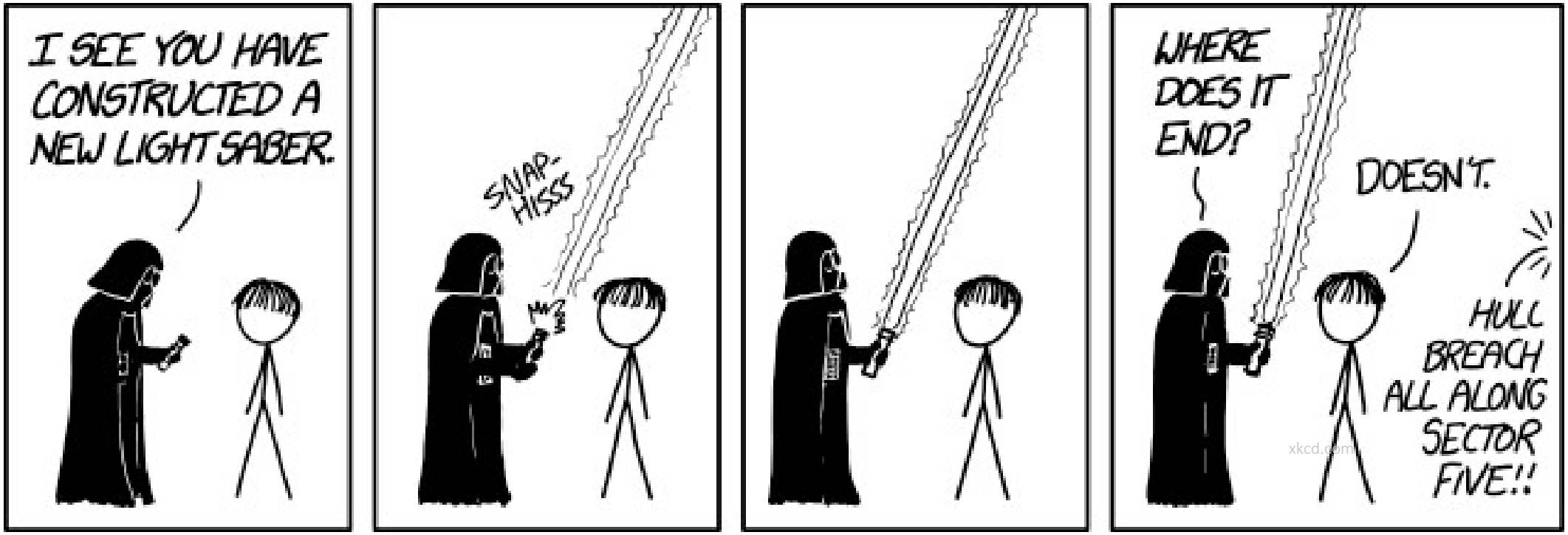

Military

Laser Pointer for Aim Assistance

Laser Weapons

Military

Laser weapons

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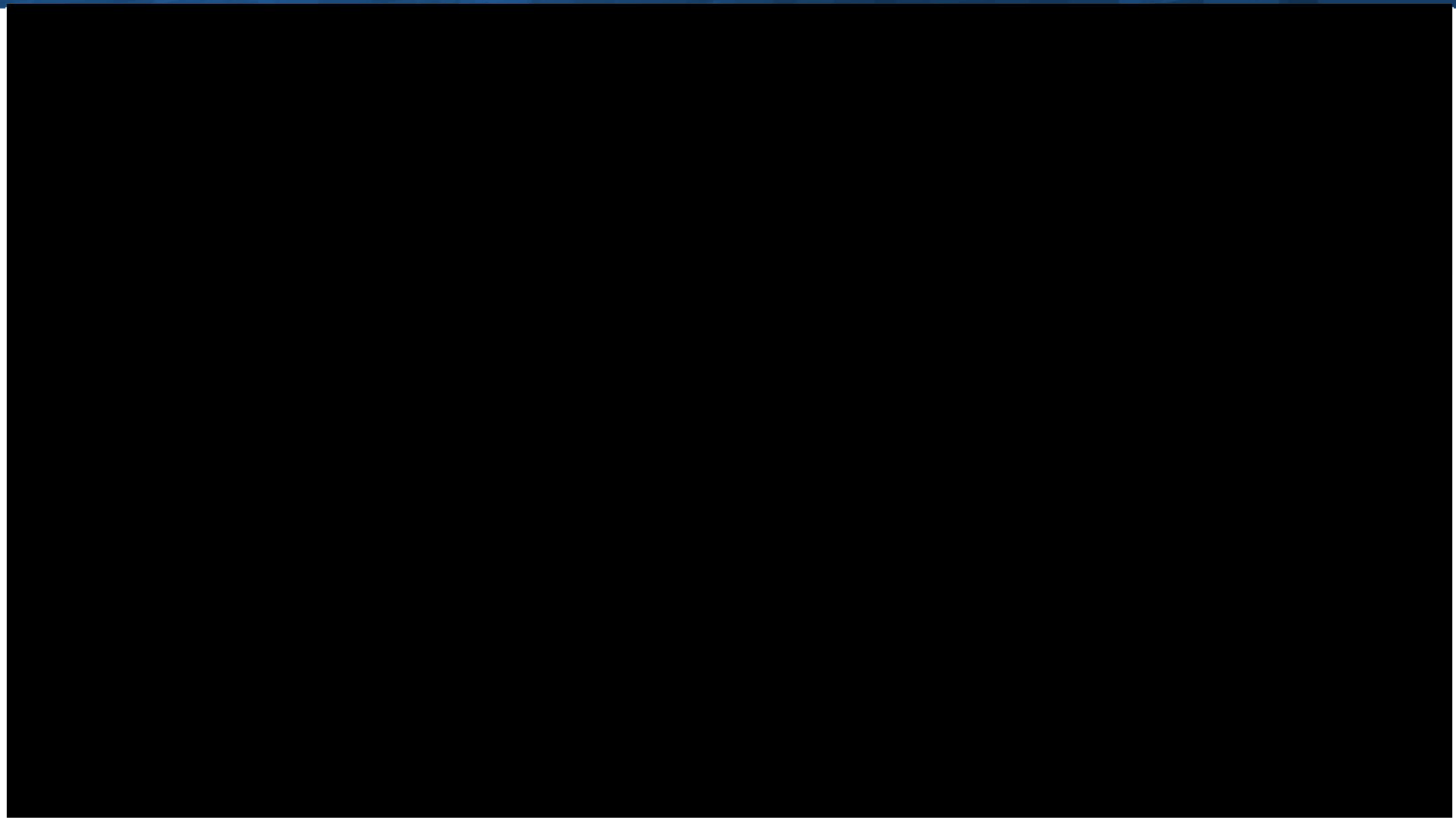

Futural applications

Space debris removal

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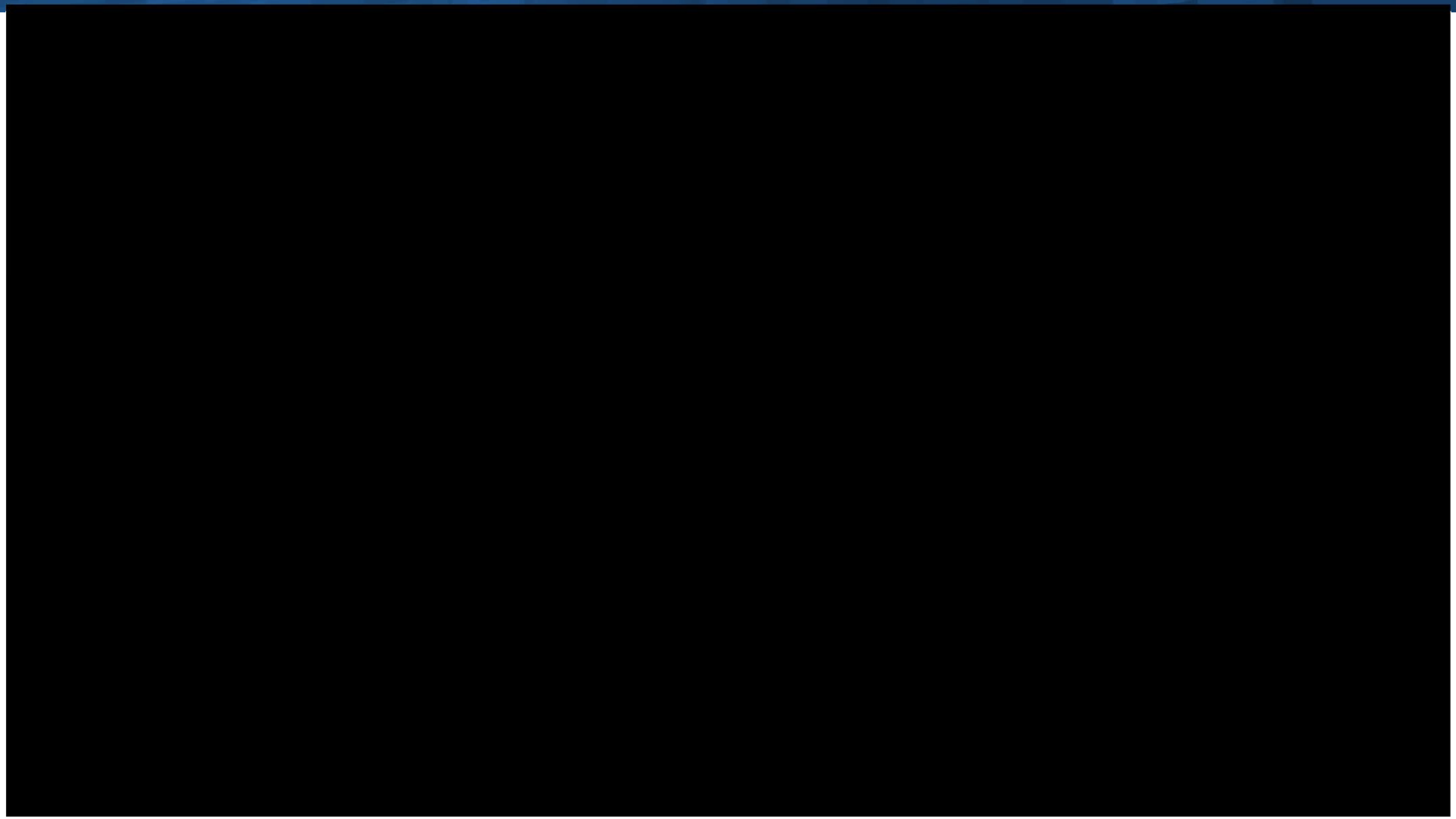

Close Future Application

Laser induced fusion (National Ignition Facility NIF)

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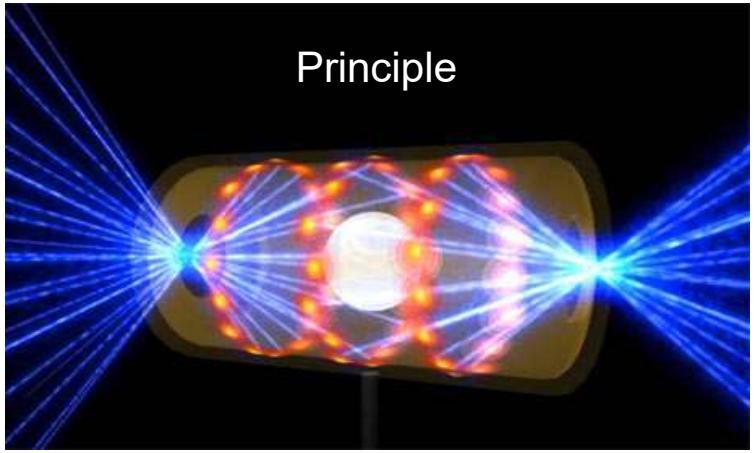
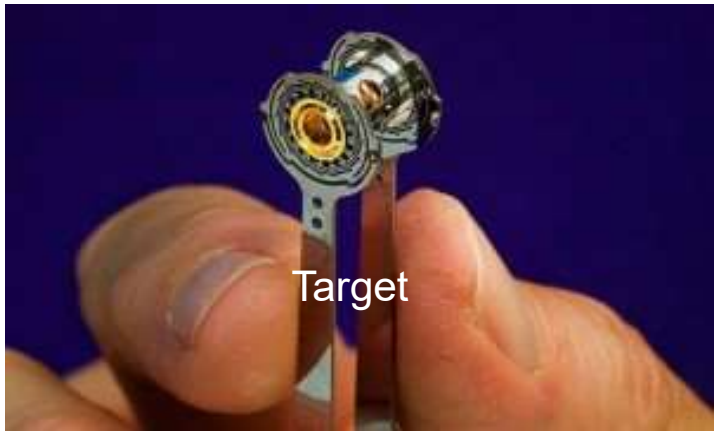
When the temperature and density of that small spot are raised high enough, fusion reactions will occur and release energy.



Specification:

- 15 ns, 192 beams, several MJ energy
- Target: hydrogen: Deuterium and Tritium
- Frequency tripled: 351 nm
- Pulsenergie per beam: 18,75 kJ
- Efficiency (pump -- UV): 0,7%



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Applications

Laser physics SS23 seminar 1

LIDAR

Light detection and ranging

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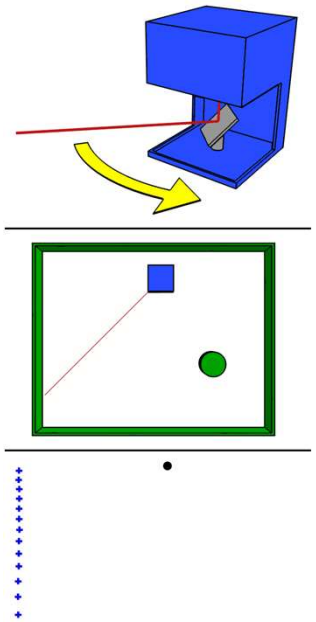
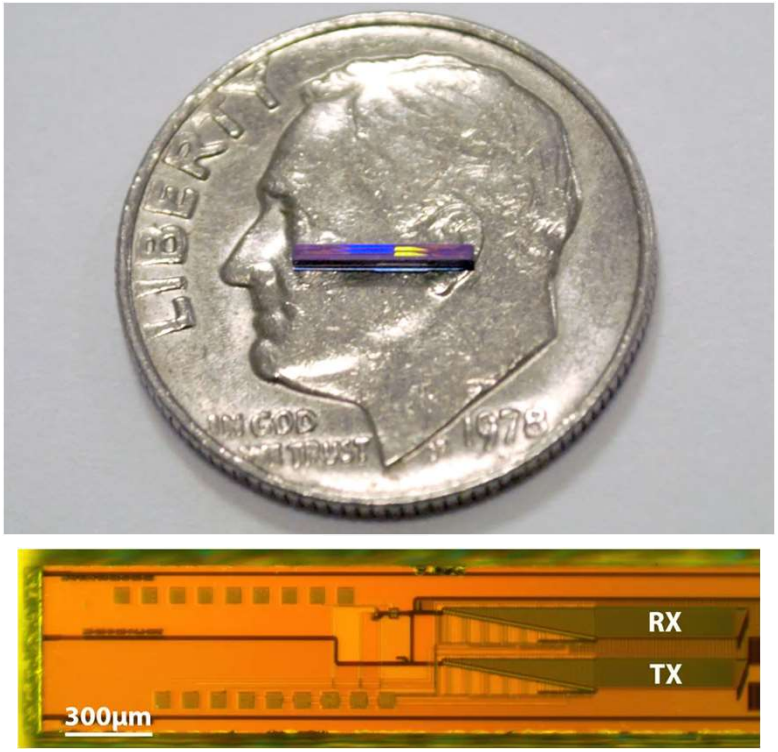
Working principle



Then

Now



https://en.wikipedia.org/wiki/Lidar; https://www.theneweconomy.com/technology/googles-driverless-cars-hit-roads-tomorrow-despite-flaws;
https://spectrum.ieee.org/mit-lidar-on-a-chip, MIT and DARPA Pack Lidar Sensor Onto Single Chip

LIDAR

Light detection and ranging

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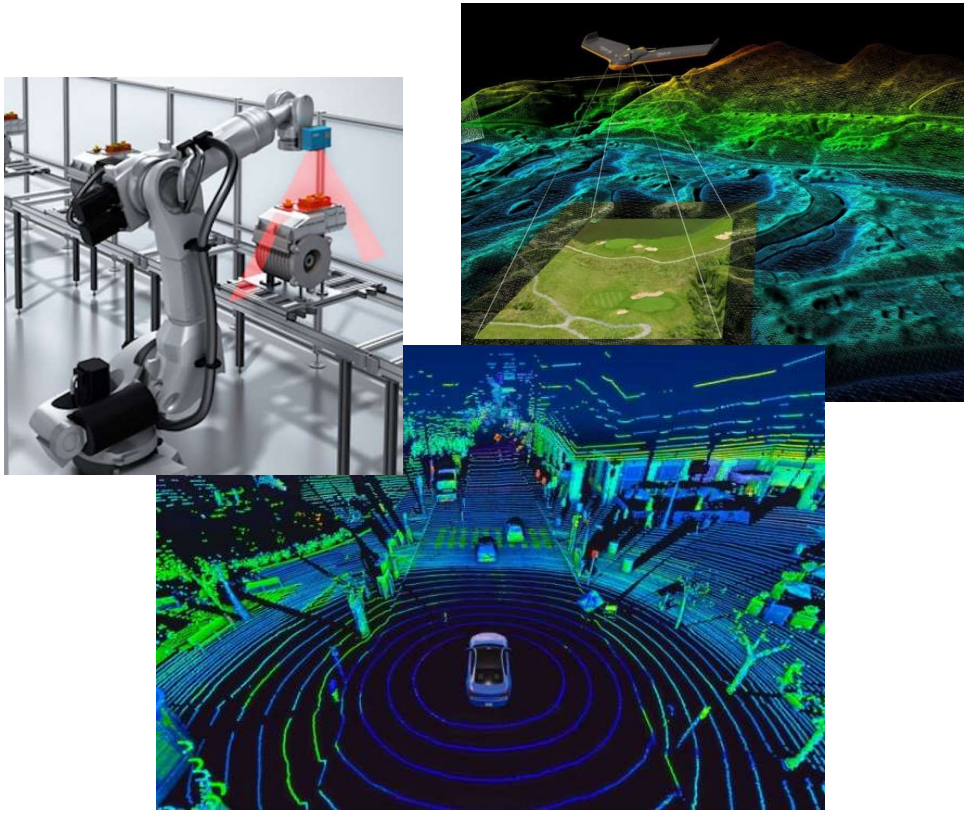
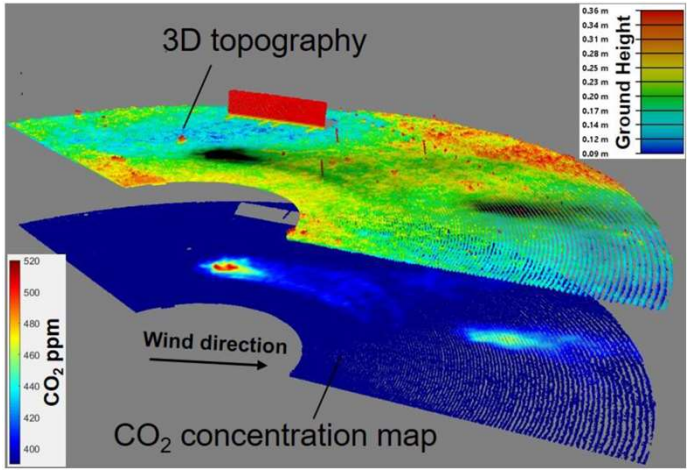
Automation & 3D Mapping



https://www.gim-international.com/content/article/multibeam-lidar-for-mobile-mapping-systems; https://www.sick.com/gb/en/industries/automotive-and-parts-suppliers/powertrain/palletizing-station/robot-guidance-with-2d-lidar-sensor/c/p333676; https://xcytemedia.co.uk/3d-mapping/

Gas sensing



M. J. Thorpe *et al.*, "Gas mapping LiDAR for large-area leak detection and emissions monitoring applications," *2017 Conference on Lasers and Electro-Optics (CLEO)*, San Jose, CA, USA, 2017, pp. 1-2.

Adding functionality to everyday items

Communication

Fiber based

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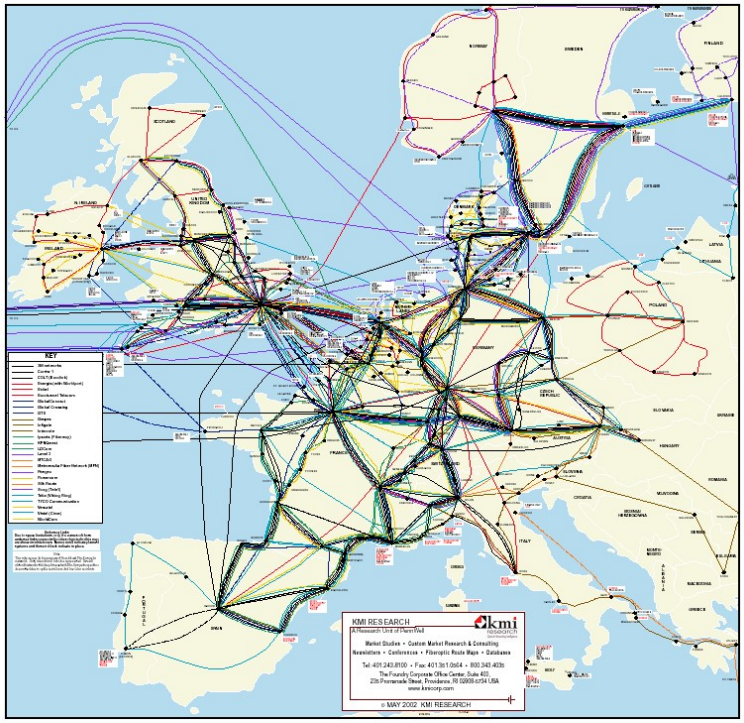
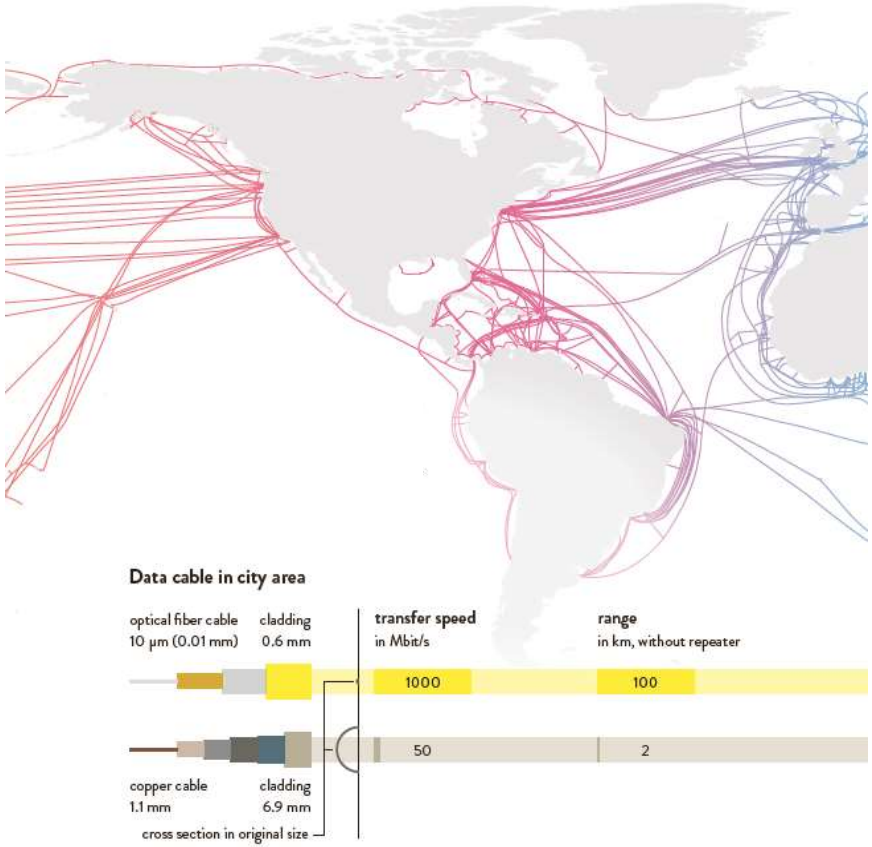


Schintler, Laura & Gorman, Sean & Reggiani, Aura & Patuelli, Roberto & Gillespie, Andy & Nijkamp, Peter & Rutherford, Jonathan. (2005). Complex Network Phenomena in Telecommunication Systems. Networks and Spatial Economics. 5. 351–70. 10.1007/s11067-005-6208-z.



https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf

Communication

Fiber based – speeding up the internet (increasing bandwidth)

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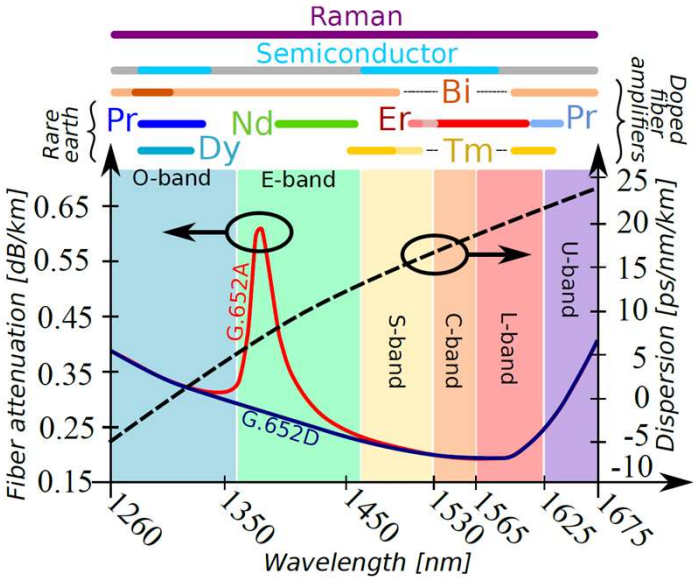
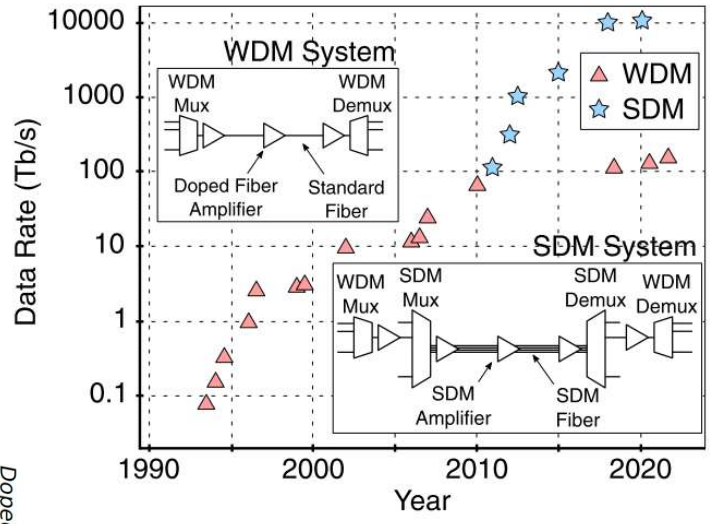
L. Rapp and M. Eiselt, "Optical Amplifiers for Multi–Band Optical Transmission Systems," in *Journal of Lightwave Technology*, vol. 40, no. 6, pp. 1579-1589, 15 March15, 2022, doi: 10.1109/JLT.2021.3120944.





WDM: Wavelength Division Multiplexing

Using more wavelength channels

Using more spatial channels

Puttnam, B. J., Rademacher, G. and Luís, R. S., "Space-division multiplexing for optical fiber communications," Optica 8(9), 1186 (2021).

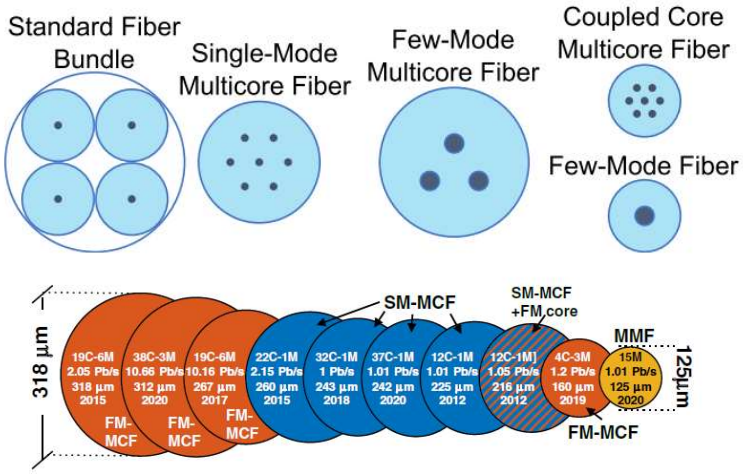


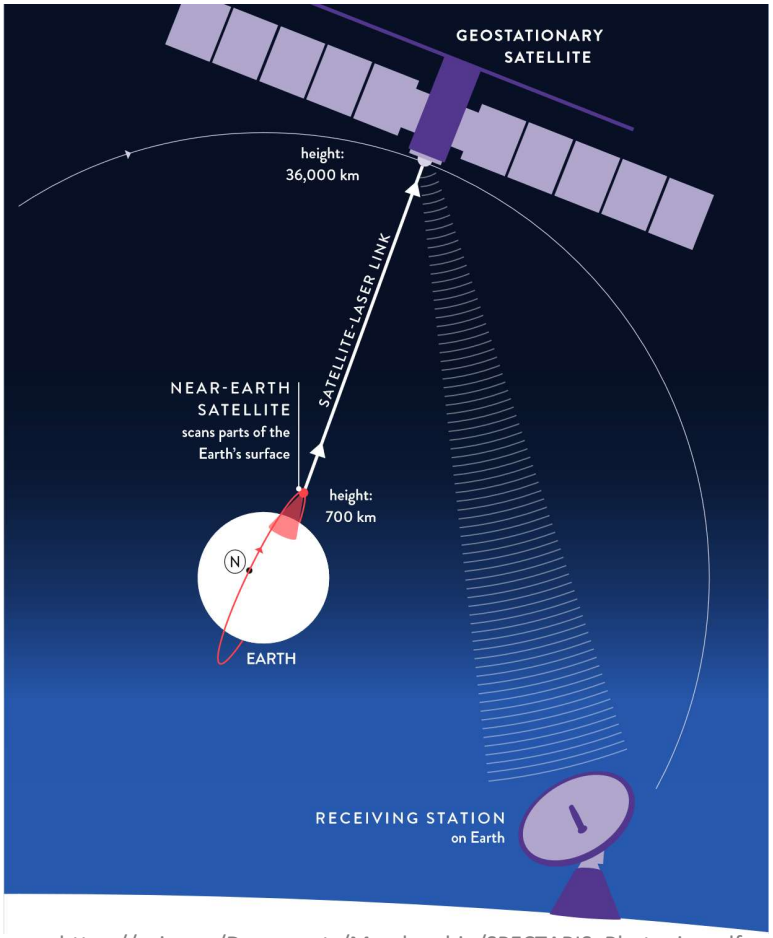
Fig. 10. Cladding diameters of fibers used in >1 Pb/s transmission experiments [12–15,141,179,229–231,247].

Communication

Free space

Why are lasers also used for non terrestrial communication?

- Long distance:
  - Needs *power* (to counteract loses)
  - Needs good *beam quality*
- *Lightweight* and *robust* (fiber lasers as prime example)
- Energy *efficient*:
  - Is good in itself
  - Less waste heat (= less cooling → less total system weight)
- All so far discussed advantages:
  - Low latency (speed of light)
  - Great bandwidth (WDM & SDM)



https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf

Special applications

Laser lightning rod (left) & laser guide star (right)

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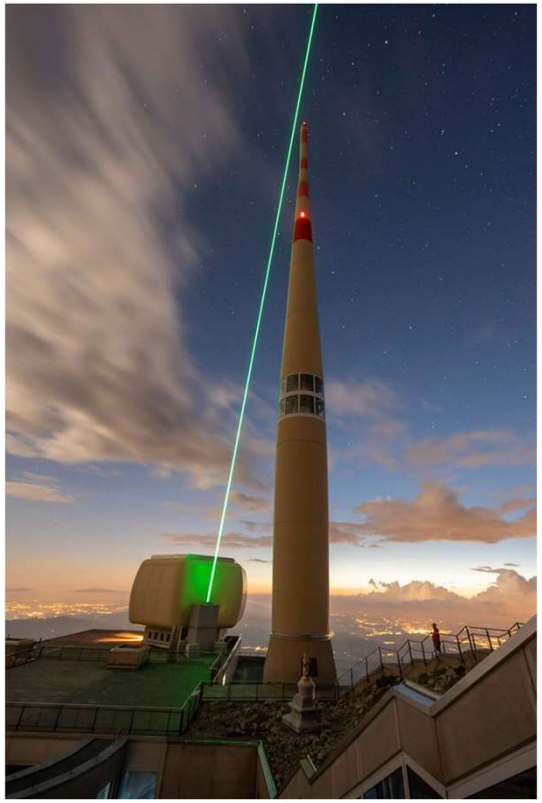
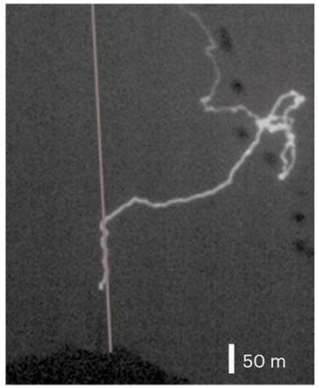
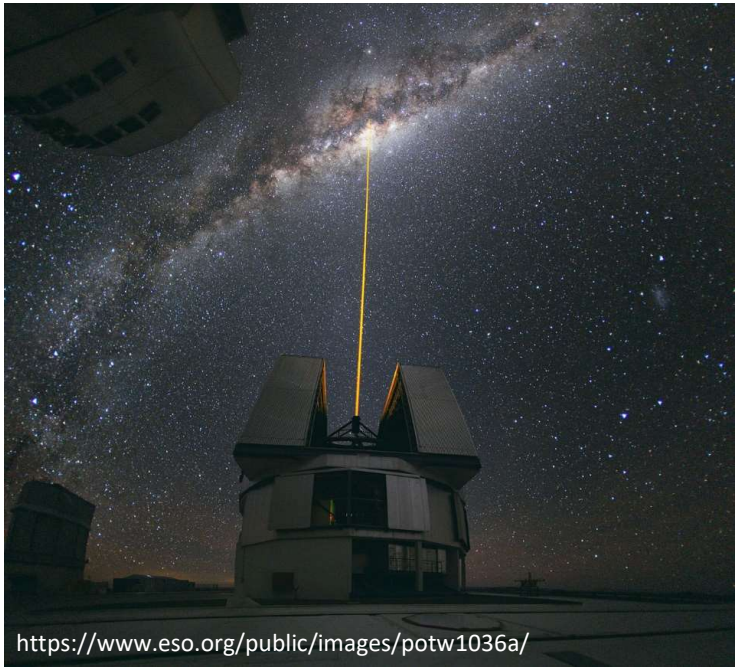
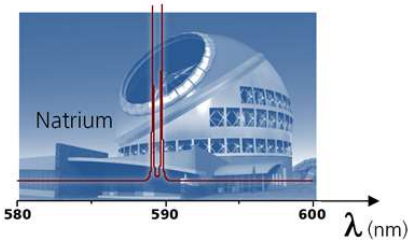
Houard, A., Walch, P., Produit, T. *et al.* Laser-guided lightning. *Nat. Photon.* **17**, 231–235 (2023). https://doi.org/10.1038/s41566-022-01139-z

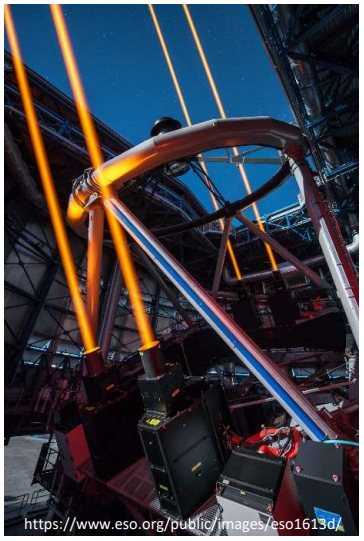




Laser for ionizing path in air
→ creating favorable path for lightning strike



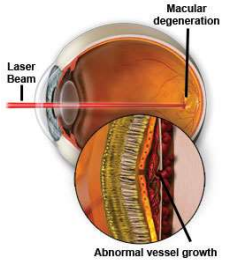


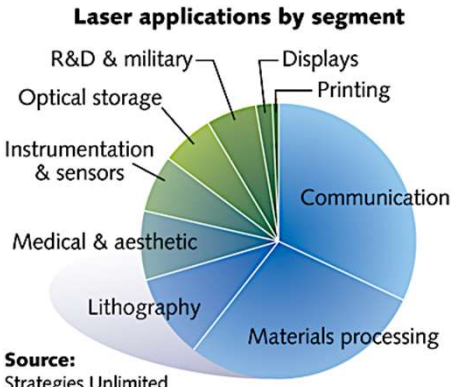


Laser (at 589nm*!) for sodium excitation in atmosphere
→ creating artificial lightsource used as reference in astronomy
(* Utilization of non-linear effects for creating l589nm laser light)

Where else are lasers used?

https://spie.org/Documents/Membership/SPECTARIS_Photonics.pdf





http://www.laserfocusworld.com/content/dam/lfw/print-articles/2015/01/1501LFW01f_2.jpg

Industry
E.g. drilling, cutting, welding, ...

Medicine
E.g. eye surgery, tattoo removal, ...

Research
E.g. atto science, particle acceleration, ...

LASER

Metrology
E.g. interferometry, spectroscopy, ...

Everyday life
E.g. Internet, optical drives, laser pointer, ...

Military
E.g. aim assistance, weapons, ...

http://www.lasershowservice.de/images/lasersymbol-bunt_animiert2.gif

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AG Fiber Laser

Laser physics SS23 seminar 1

AG Fiber Laser

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Fiber Laser

Performance of single fiber

- Fiber design
- Transverse mode instability
- 2-µm fiber laser

Performance of fiber laser system

- In/coherent beam combination
- Pulse compression

Secondary source and application

- Soft X-ray to THz
- XUV microscopy

AG Fiber laser: Fiber design

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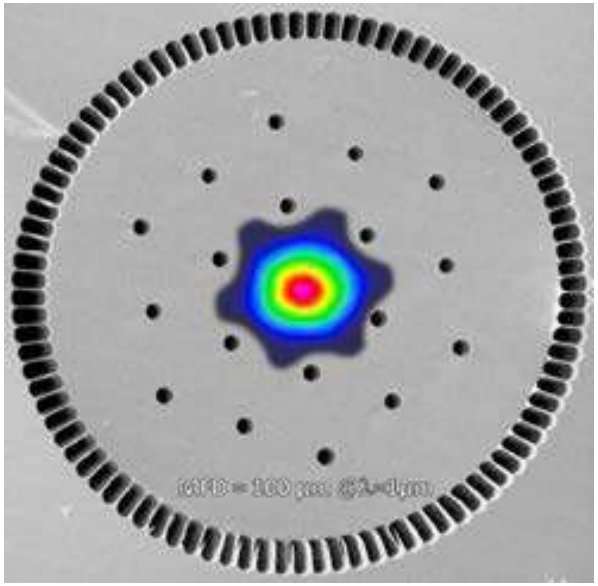

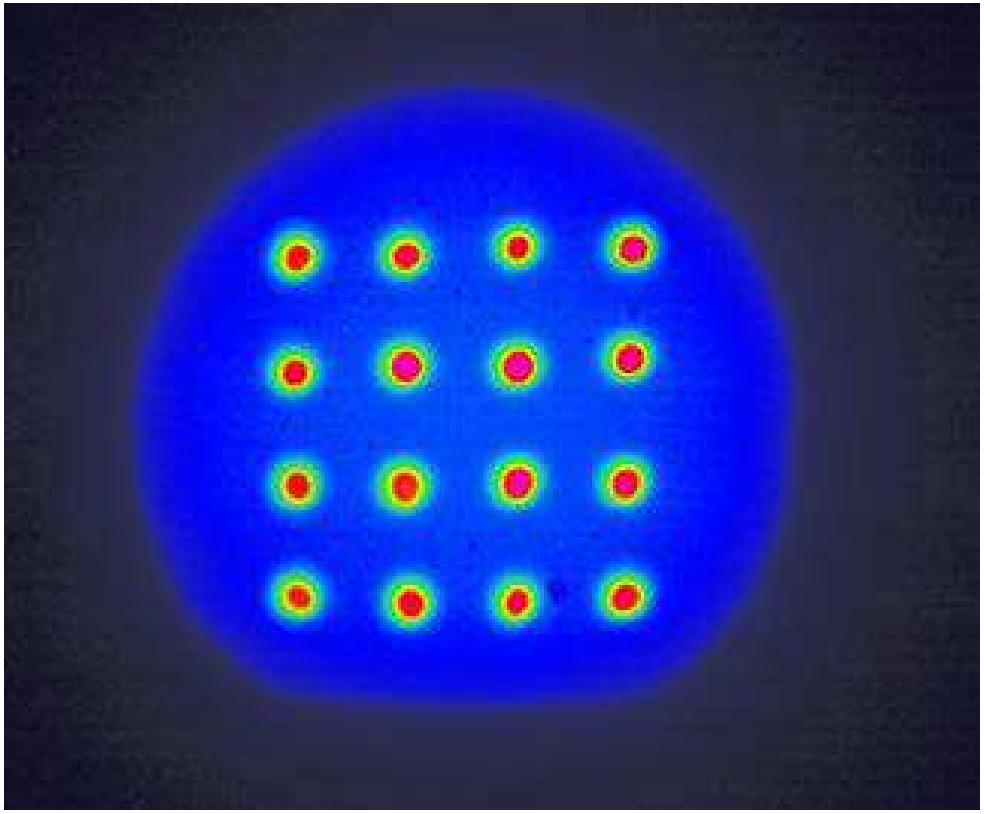

AG Fiber laser: Transverse mode instability

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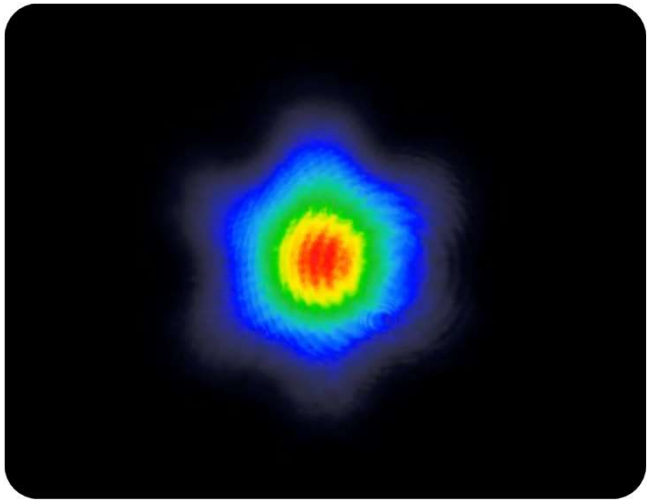
= nonlinear effect that occurs at a specific average output power with a threshold-like behavior



below threshold

- fundamental mode
- ⇨ good beam quality
- stable

above threshold

- dynamic energy transfer between different modes
- ⇨ decreased beam quality
- unstable (time & space)

- Beam is not usable for applications anymore
- **TMI = main limitation for further power scaling of fiber lasers with good beam quality**

AG Fiber laser: Coherent beam combining

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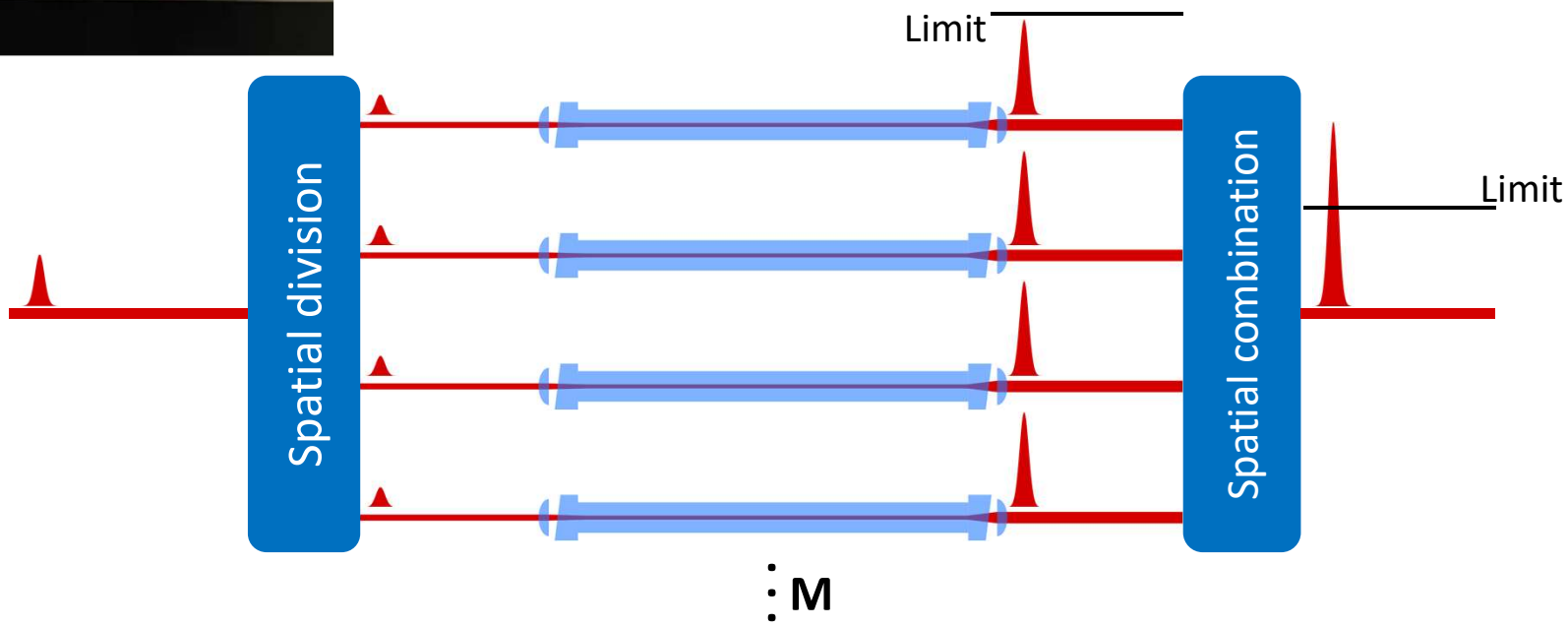

AG Fiber laser: Pulse compression

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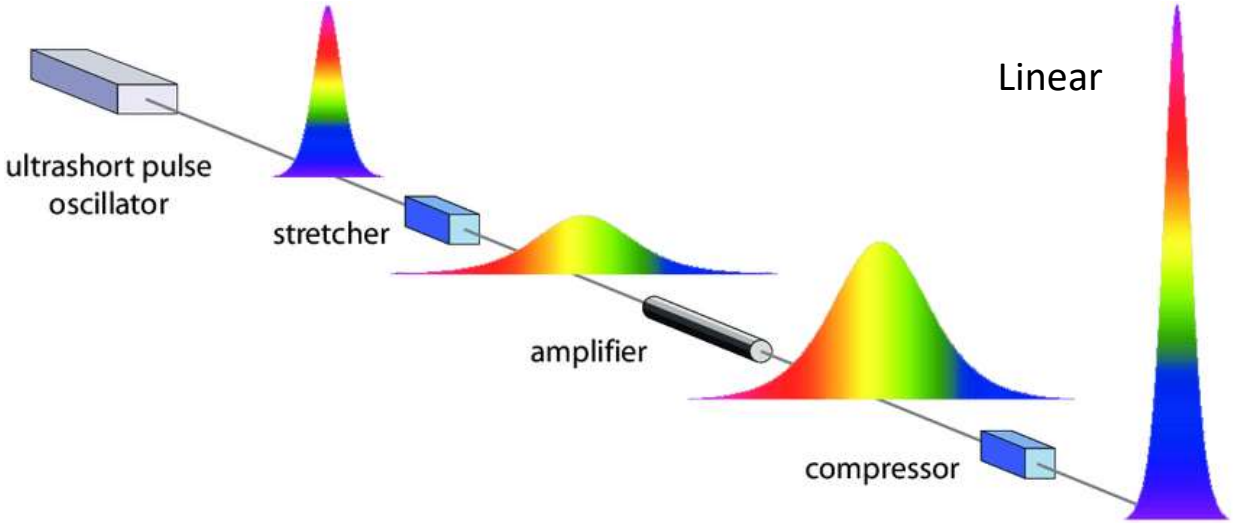

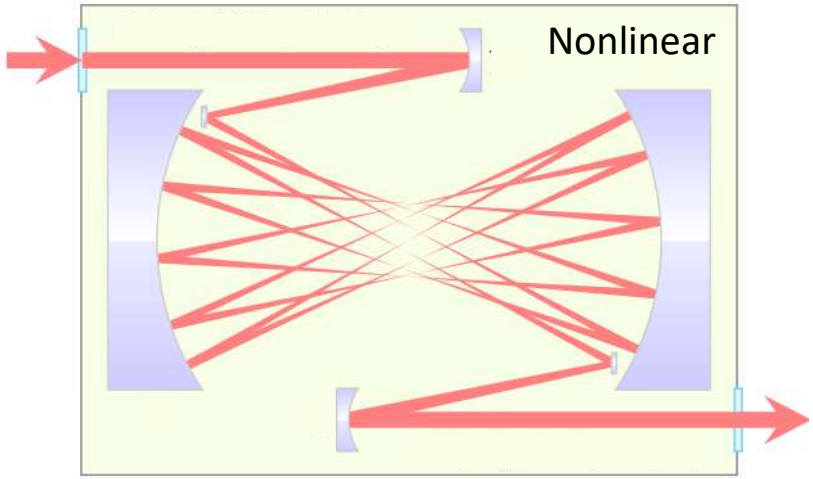

AG Fiber laser: Frequency conversion & applications

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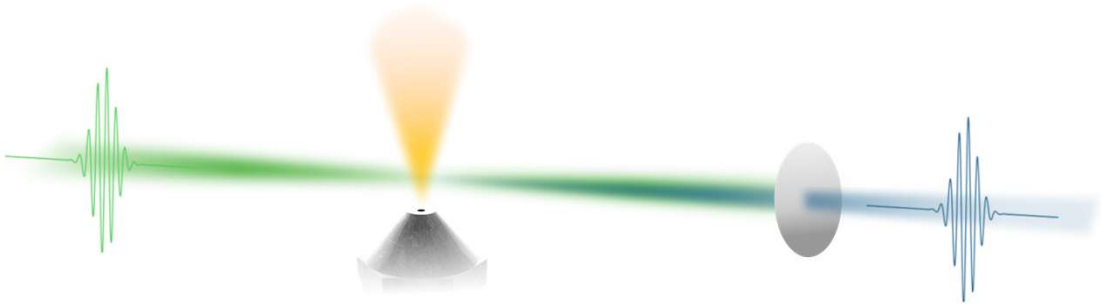

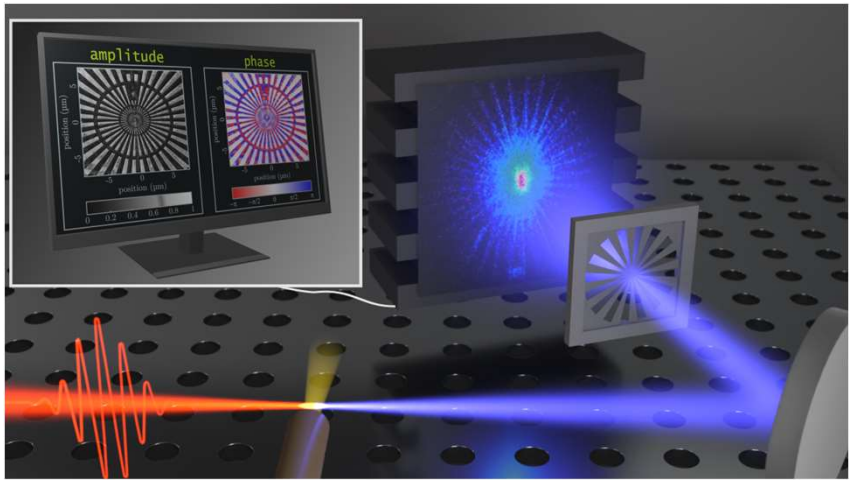

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Laser physics SS23 seminar 1