With funding from the:

Federal Ministry
of Research, Technology
and Space

afs

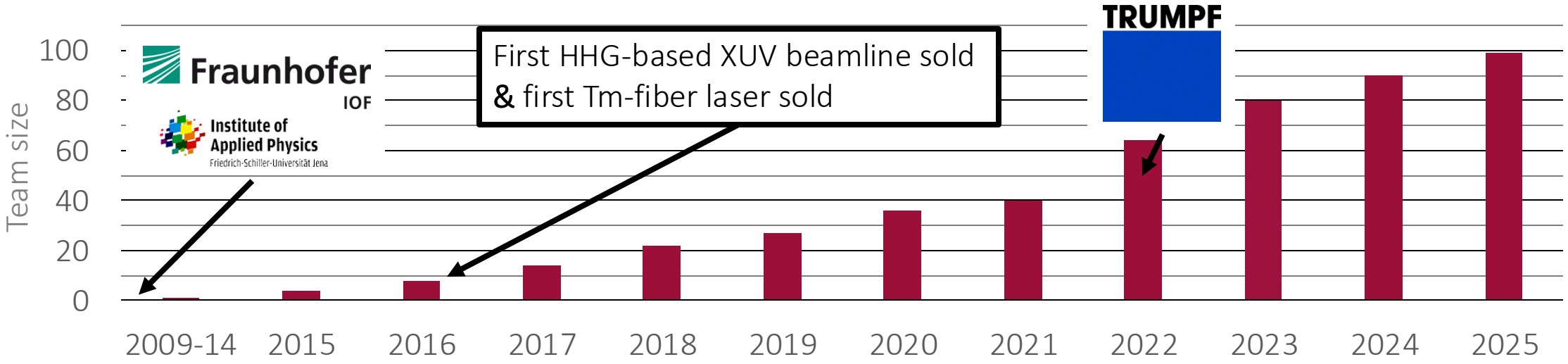
Member of the TRUMPF Group

High-power 2µm-wavelength fiber lasers

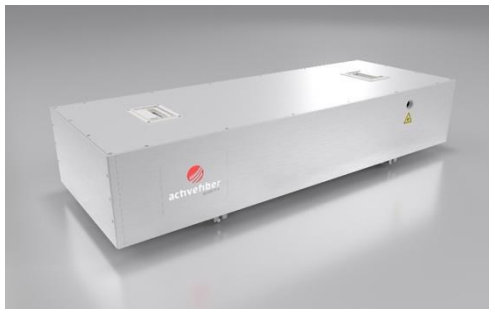
Tino Eidam

Visit us @ Booth
A3.327

Active Fiber Systems GmbH



Provider of laser sources

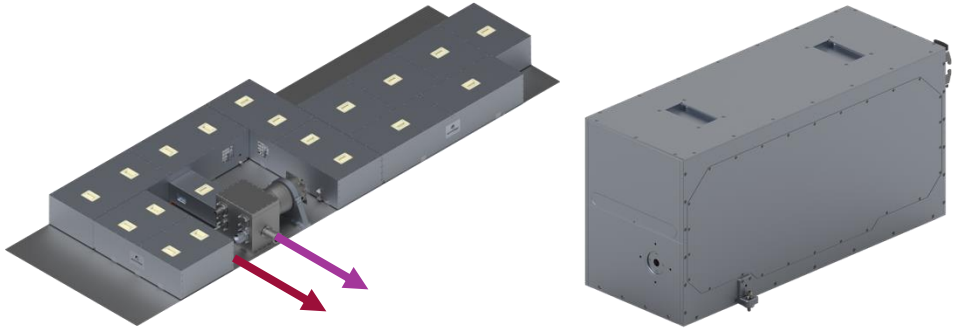


Yb-doped, F-CPA,
Oscillators & MOPA

Provider of complex systems

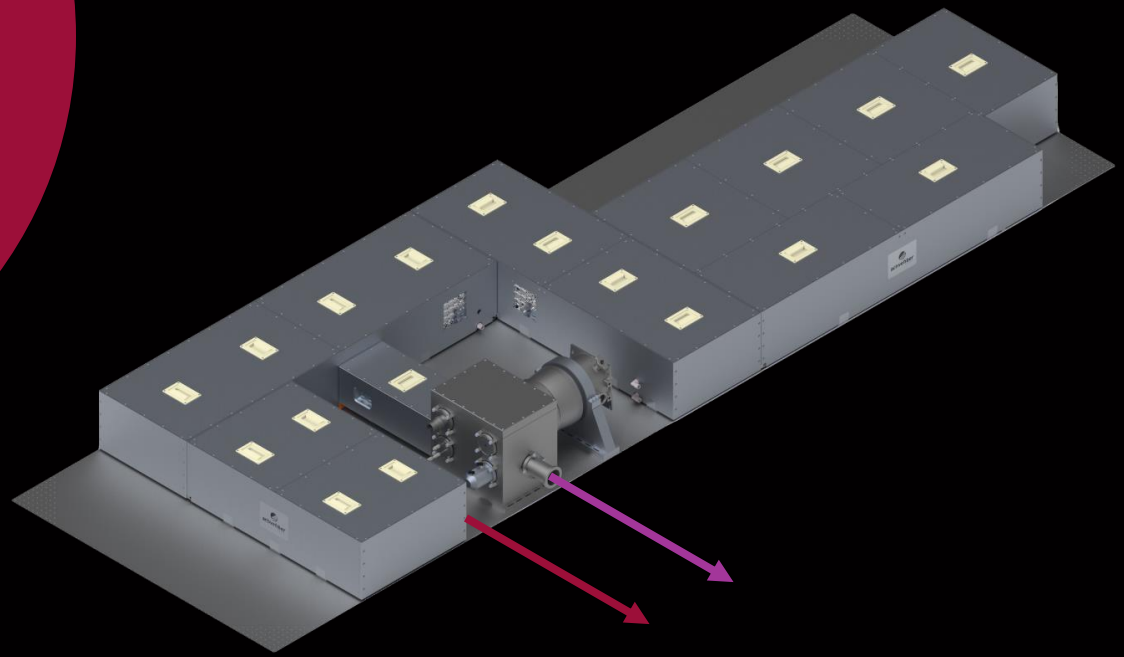
+ Coherent combining,
Tm-doped (2µm),
HHG (XUV), MIR, OPA

Provider of scientific beamlines & industrial solutions & medical devices



Scientific market

- Fully customizable lasers & Addons
  - Frequency conversion
  - Pulse compression
- Unparalleled specs
- Short time to market
- Multiple ultrafast outputs (MIR to XUV)

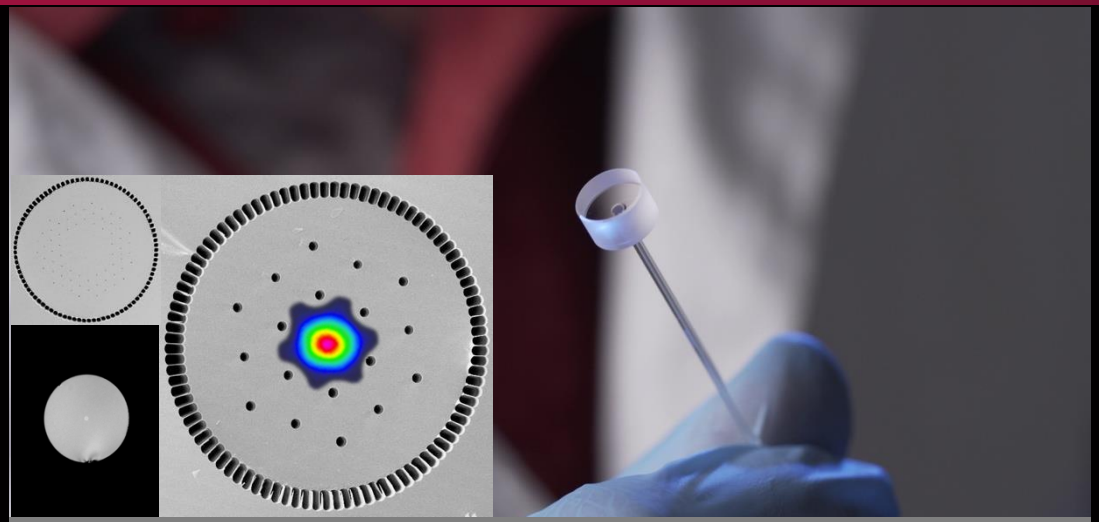


Industrial market

activeTwo-15

- Industrial-grade 2µm laser
- Ideal for silicon processing
- 400fs – 1ns | 100µJ | 15W | 1980nm

AFS core technologies



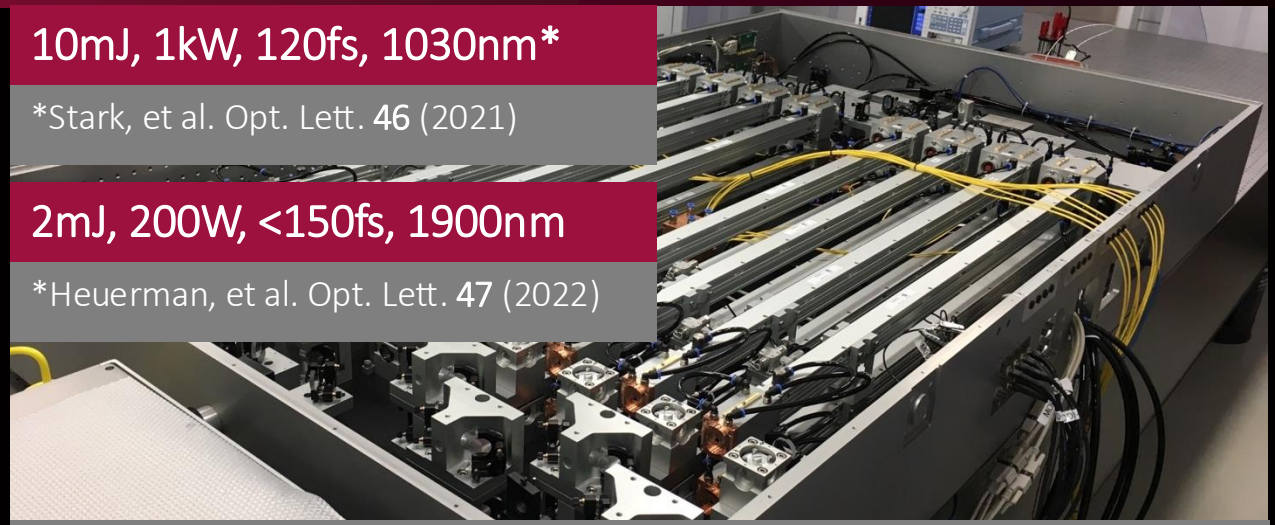
Large pitch fibers (Yb/Tm)

10mJ, 1kW, 120fs, 1030nm*

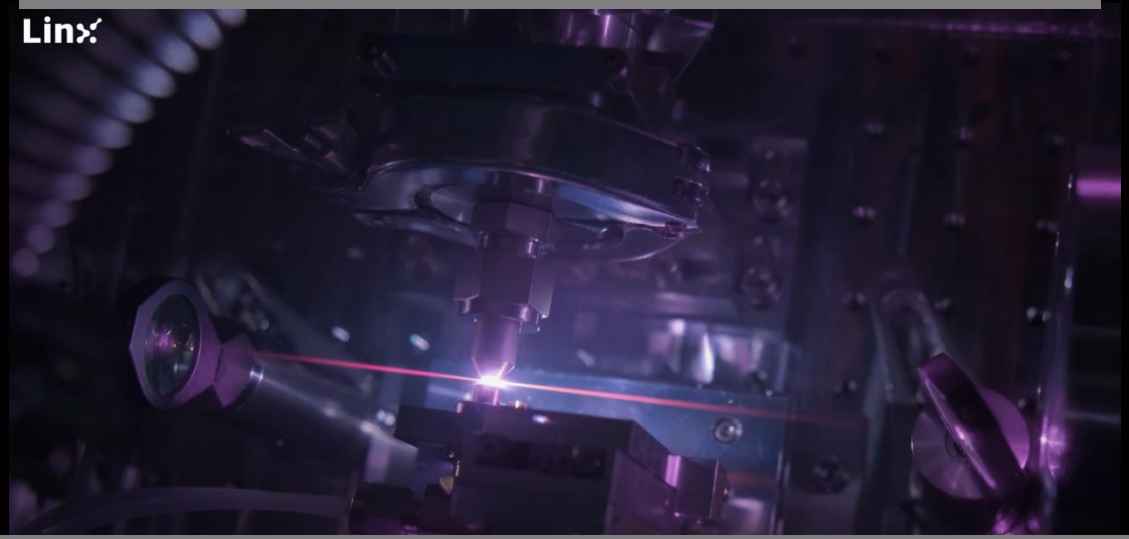
*Stark, et al. Opt. Lett. **46** (2021)

2mJ, 200W, <150fs, 1900nm

*Heuerman, et al. Opt. Lett. **47** (2022)



Coherent combining



High harmonic generation

6mJ, 600W, 35fs, 1030nm (commercial)

1mJ, 100W, 6fs, 1030nm, CEP-stable* (commercial)

*Hädrich, et al. Opt. Lett. 47 (2022).

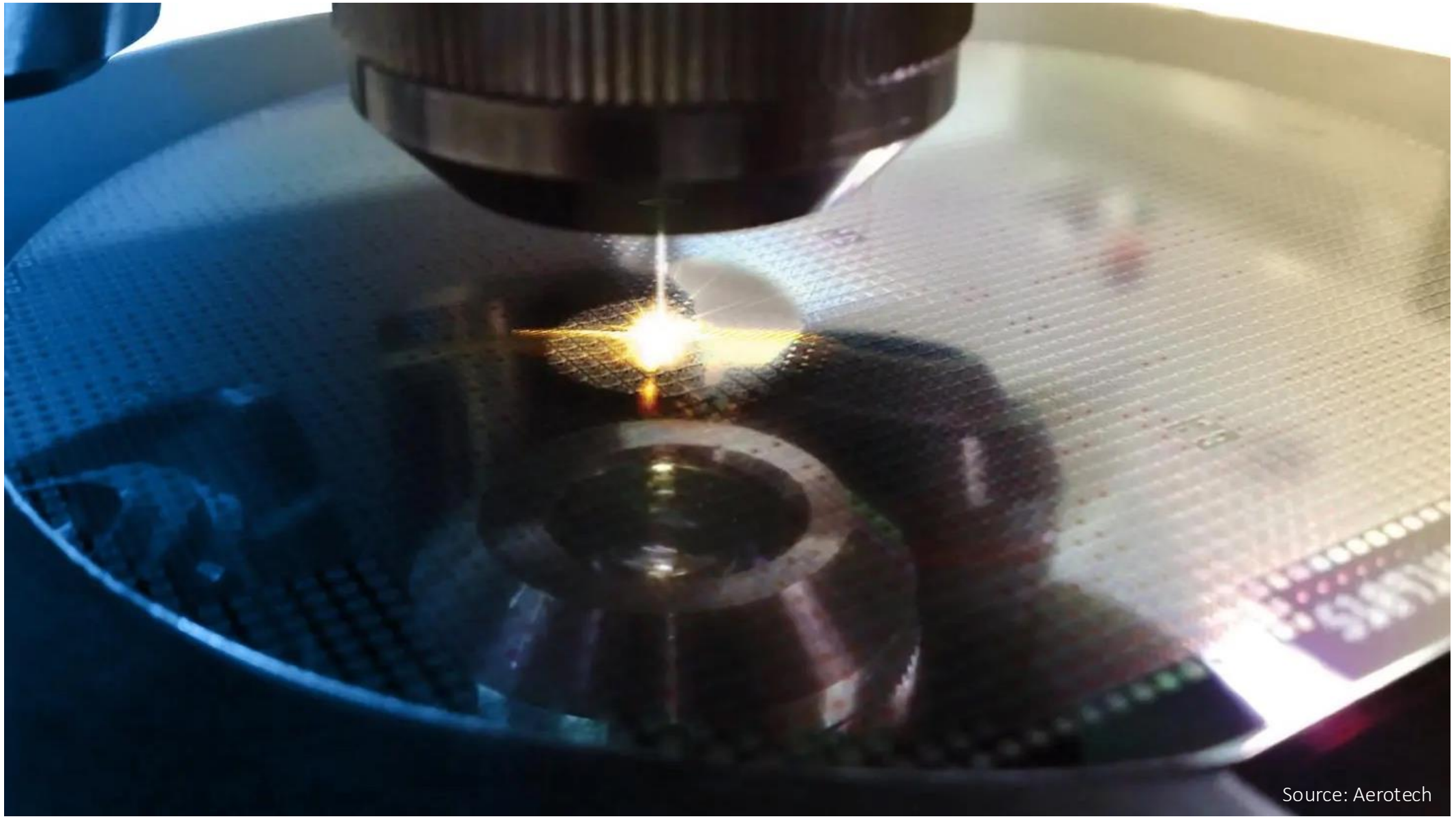
1.3 mJ, 130W, <11fs, 1900nm

*Wang, et al. Opt. Lett. 48 (2023).

Post compression

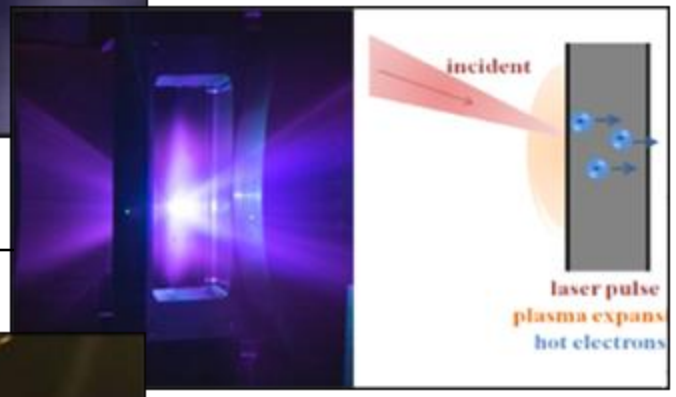
Why 2µm?

Semiconductor Processing

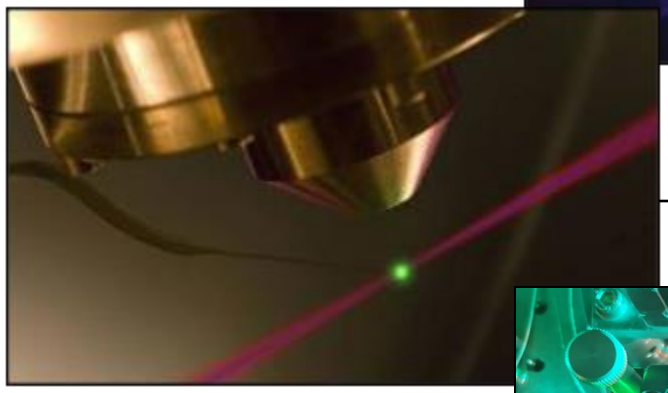


Secondary sources

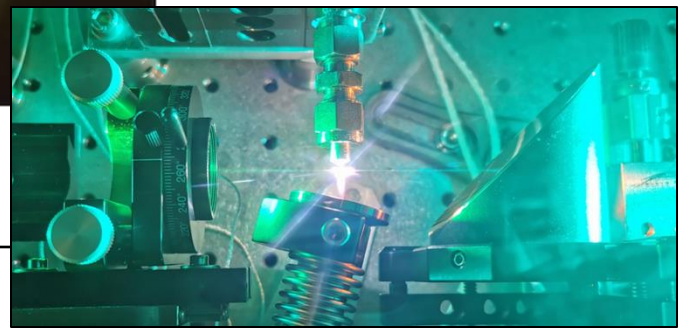
EUV Generation
~10^{11} W/cm^2



X-Ray Generation
~10^{17} W/cm^2

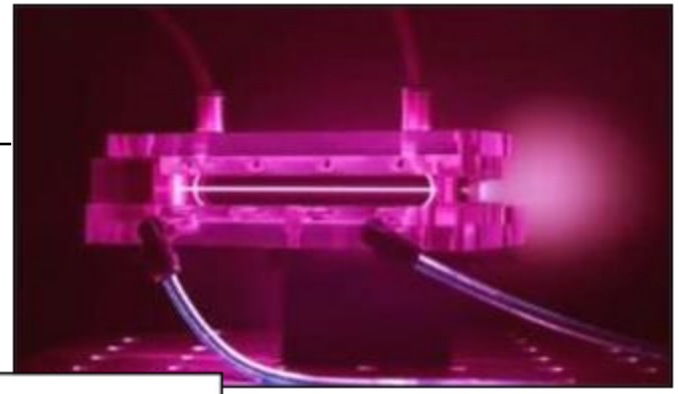


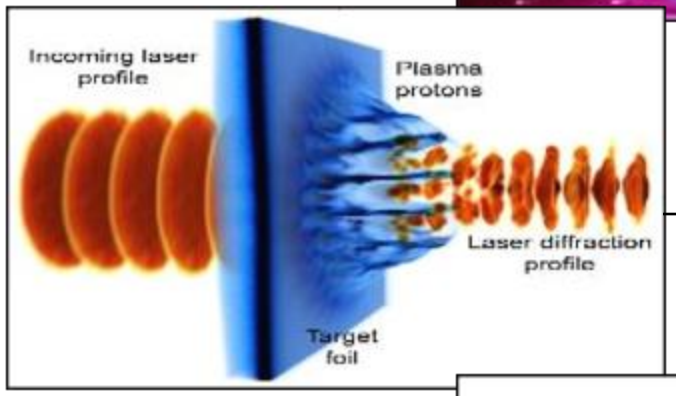
High-Harmonic Generation
~10^{14} W/cm^2



THz Generation
~10^{15} W/cm^2

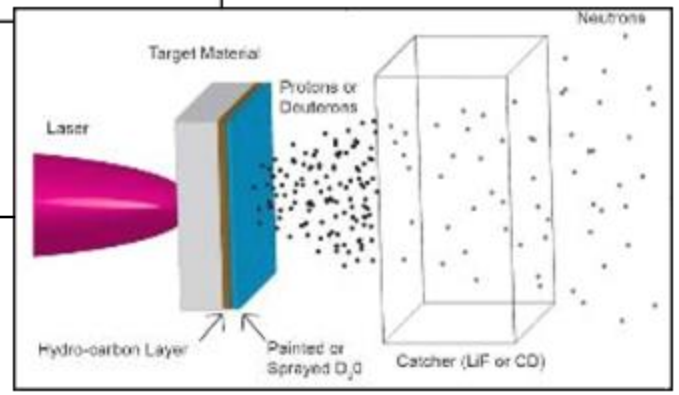
Electron Acceleration
~10^{18} W/cm^2





Proton Acceleration
~10^{18} W/cm^2

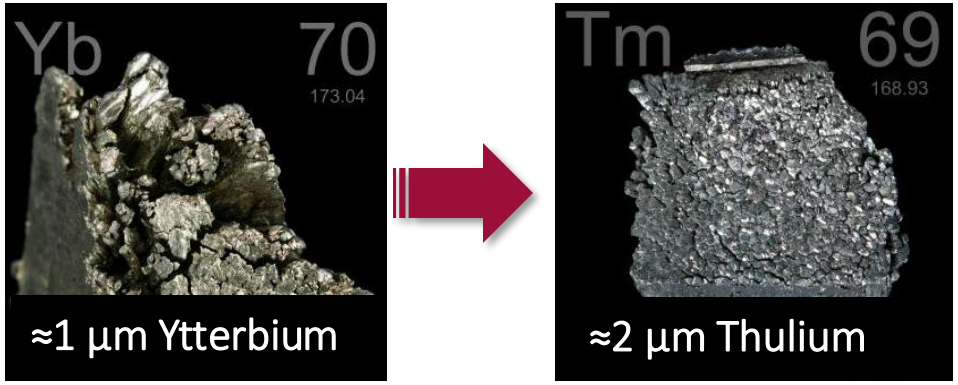
Neutron Generation
~10^{18} W/cm^2

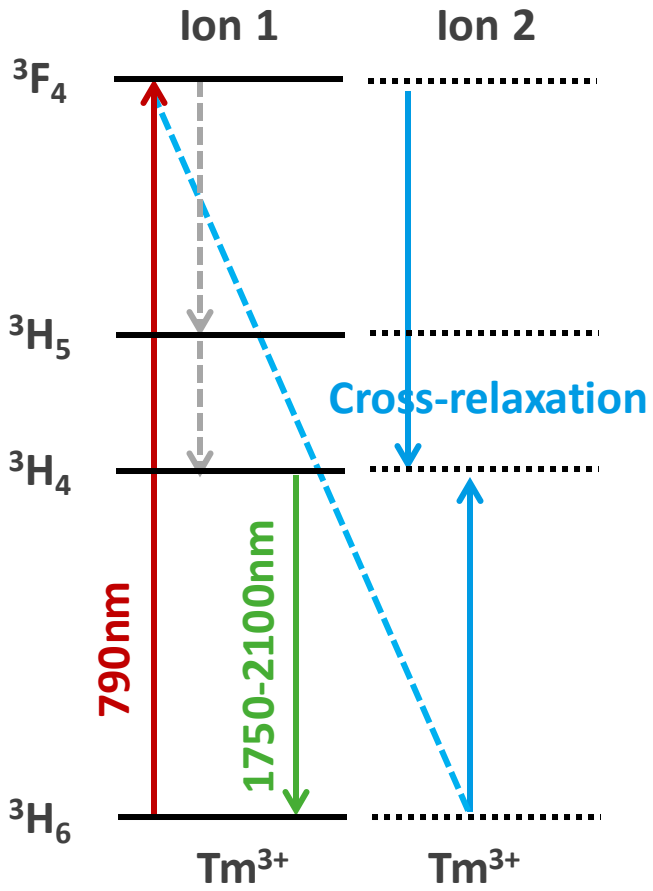


Thulium-Doped Fiber Laser

Ultrafast Tm-doped fiber lasers (TDFL)

Different signal-core doping





Properties of Tm-doped fuses silica:

- Broad amplification bandwidth (<100 fs)
- Large quantum-defect (QD) when pumping at 790nm
  - → Typically strong QD-heating
  - → Cross-relaxation allows for up to >70% efficiency[1]

[1] S. D. Jackson and S. Mossman, "Efficiency dependence on the Tm3+ and Al3+ concentrations for Tm3+-doped silica double-clad fiber lasers.," Appl. Opt. 42, 2702–2707 (2003).

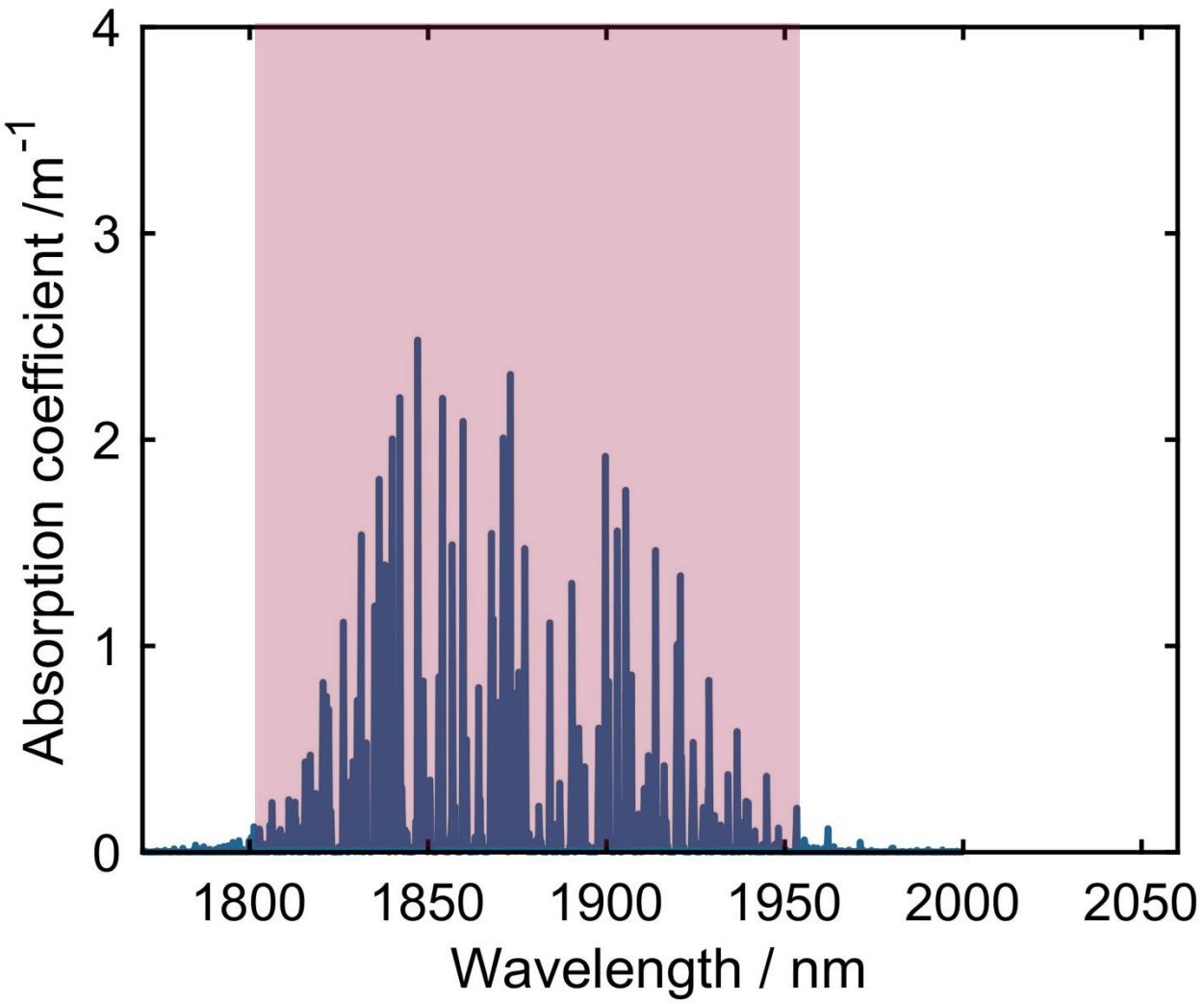
Challenges

Atmospheric water-vapor absorption

- Overlap of absorption lines with gain bandwidth of Tm-doped fused silica

→ spatial and temporal effects[1]

→ enhanced impact of nonlinearity (e.g. SPM)

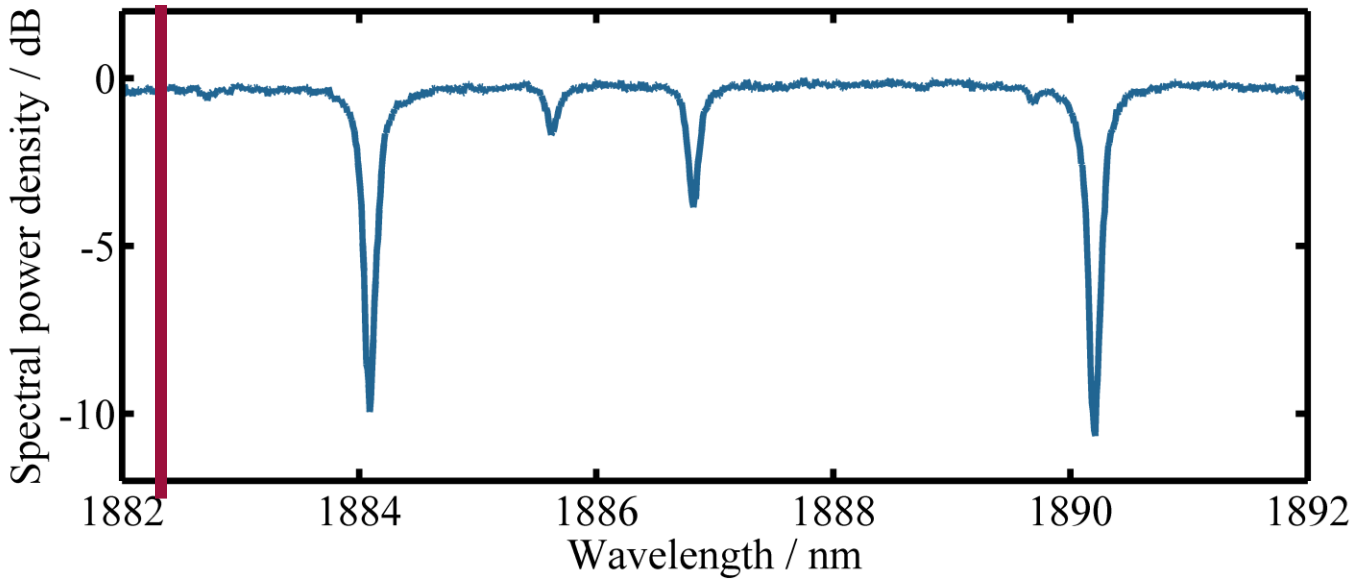


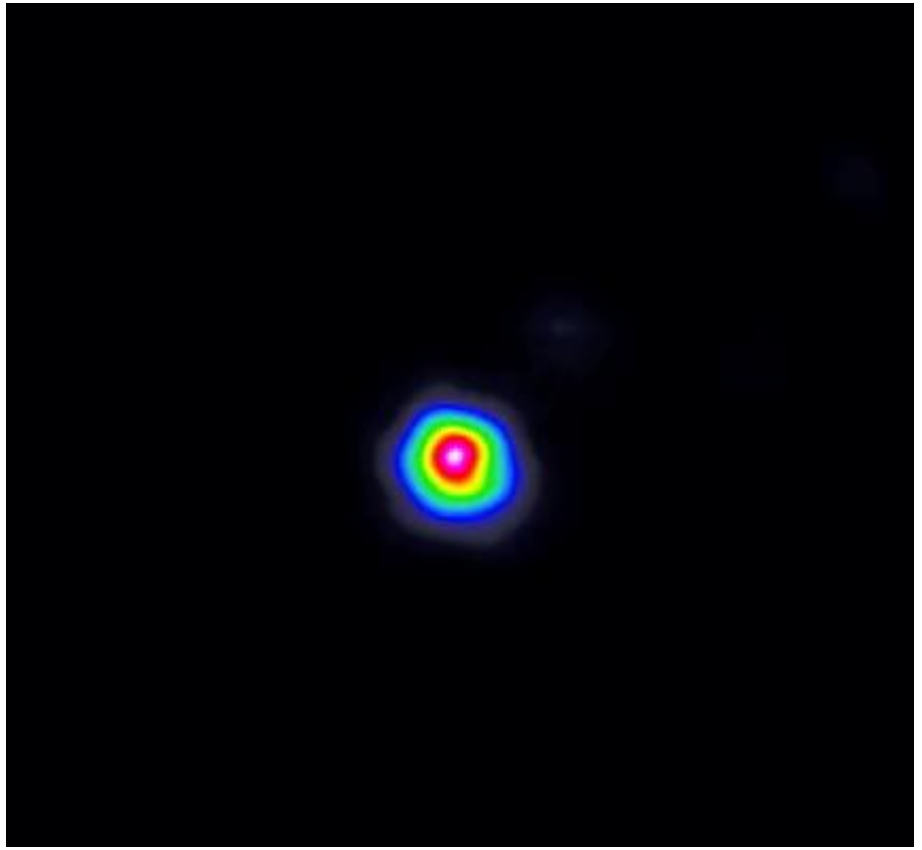
[1] M. Gebhardt, C. Gaida et al., "Impact of atmospheric molecular absorption on the temporal and spatial evolution of ultra-short optical pulses," Opt. Express **23**, 13776 (2015).

Challenges

Impact of water-vapor absoprtion[1] in the spatial domain

- Tunable cw-laser, wavelength sweep at 25W output power
- Beam image after 1m free-space propagation distance





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Challenges

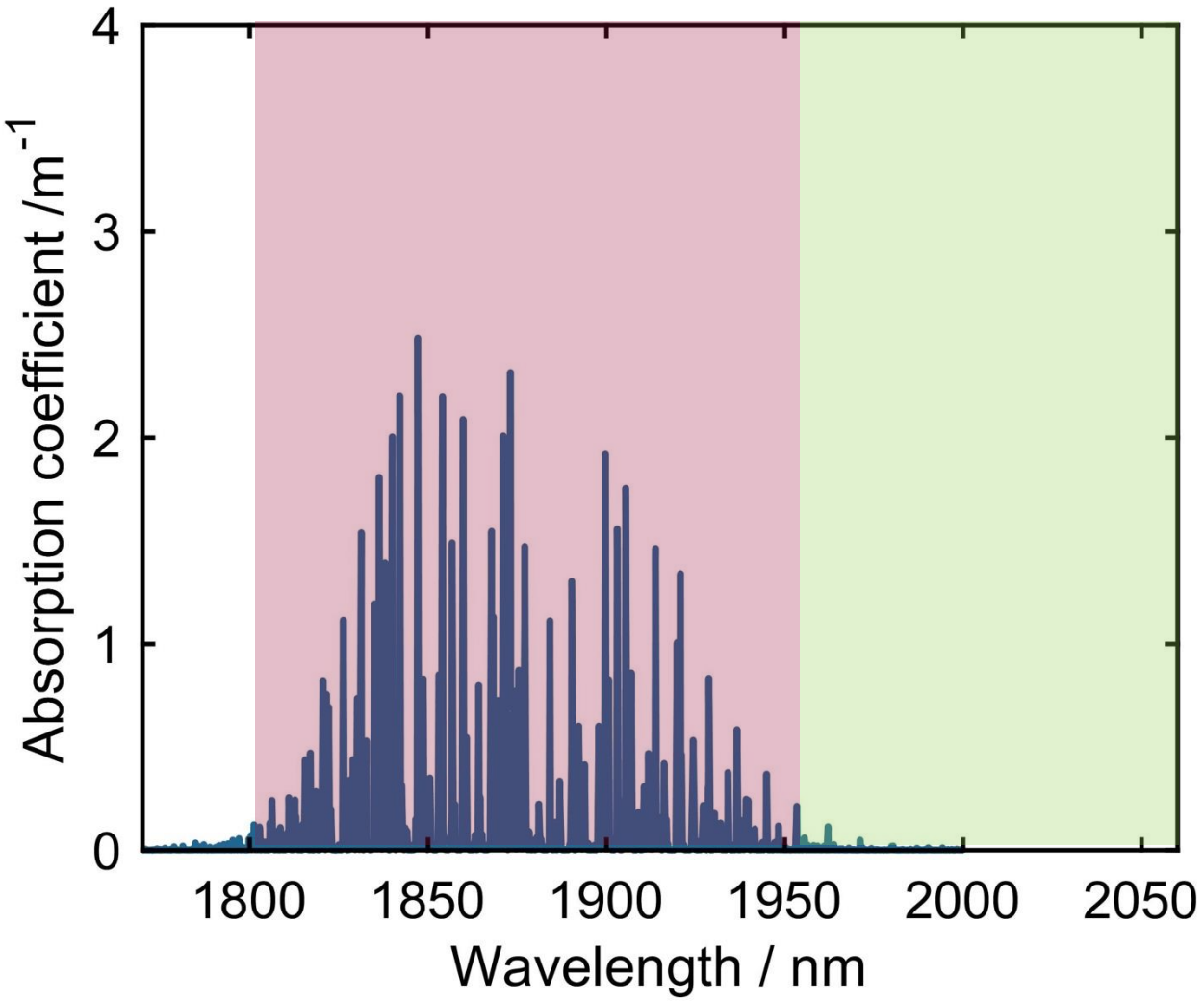
Atmospheric water-vapor absorption

- Overlap of absorption lines with gain bandwidth of Tm-doped fused silica

→ spatial and temporal effects[1]

→ enhanced impact of nonlinearity (e.g. SPM)

Vacuum not required for wavelength range >1950nm

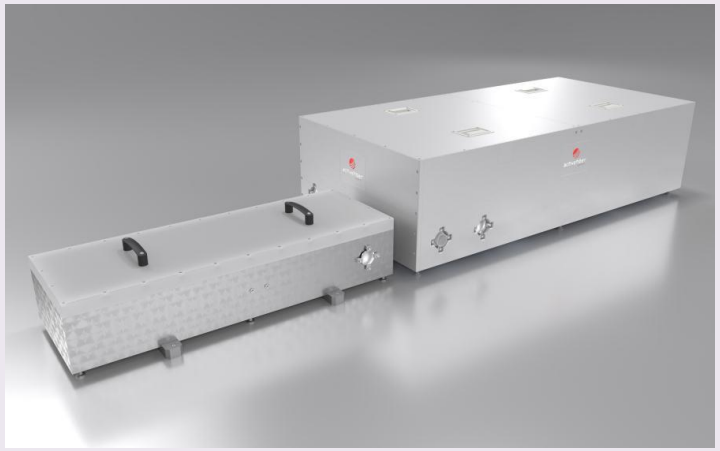


[1] M. Gebhardt, C. Gaida et al., "Impact of atmospheric molecular absorption on the temporal and spatial evolution of ultra-short optical pulses," Opt. Express **23**, 13776 (2015).

Product platforms: Thulium

- Coherent-combining-based & highly customizable. Capable of world-record power/energy for ultrafast sources

Thulium-300



1900nm | 2mJ | 200W | 150fs

- Unprecedented commercial specs at 2µm central wavelength
- Suitable for scientific environments

activeTwo-15

1980nm | 100µJ | 15W | 400fs

- Compact & affordable
- Industrial-grade reliability

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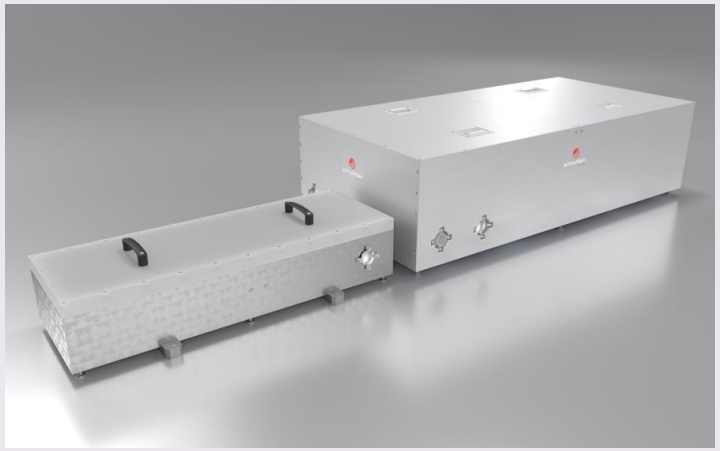
Thulium-300



1900nm | 2mJ | 200W | 150fs

- Unprecedented commercial specs at 2µm central wavelength
- Suitable for scientific environments

activeTwo-15

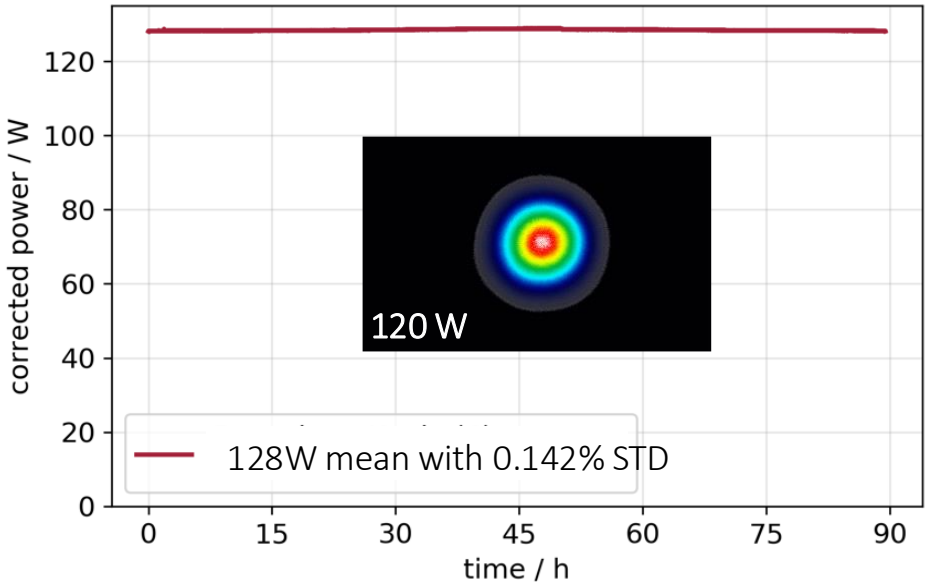
1980nm | 100µJ | 15W | 400fs

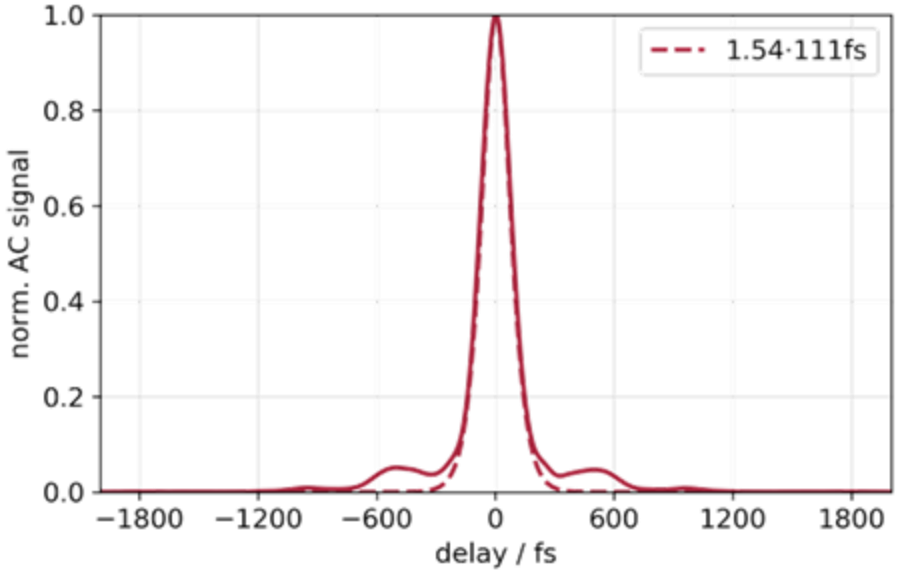
- Compact & affordable
- Industrial-grade reliability

Ultrafast TDFL for research (1. generation)

4-channel Tm-based system

- >120W average power long-term stable
- <5µrad beam-pointing stability (8h)
- >200µJ, <150fs pulses
- 1950nm center wavelength





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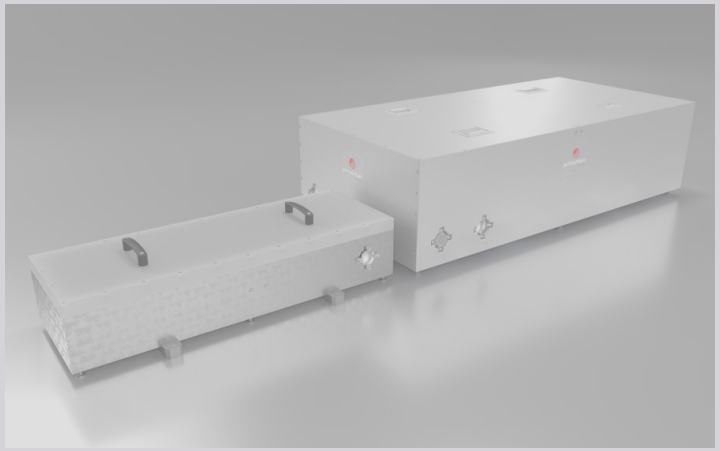


1950nm | 2mJ | 200W | 150fs

- Unprecedented commercial specs at 2µm central wavelength
- Suitable for scientific environments

activeTwo-15

1980nm | 100µJ | 15W | 400fs

- Compact & affordable
- Industrial-grade reliability

Industrial-grade ultrafast TDFL (2. generation)

Modular design

Supply units

Electrical drivers

Water-water Chiller

Optical engine + laser control

Oscillator

Frontend

Main Amplifier

Isolator and Acousto-optic modulator

Pulse Compressor

All-fiber

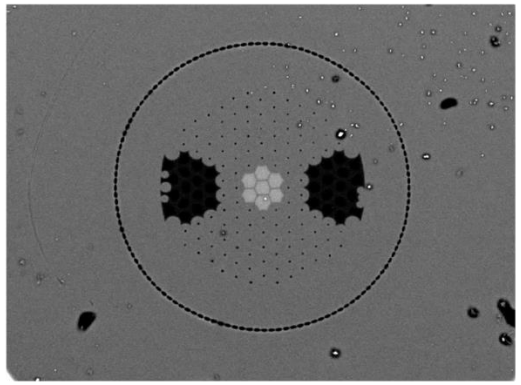
Free-space

Industrial-grade ultrafast TDFL (2. generation)

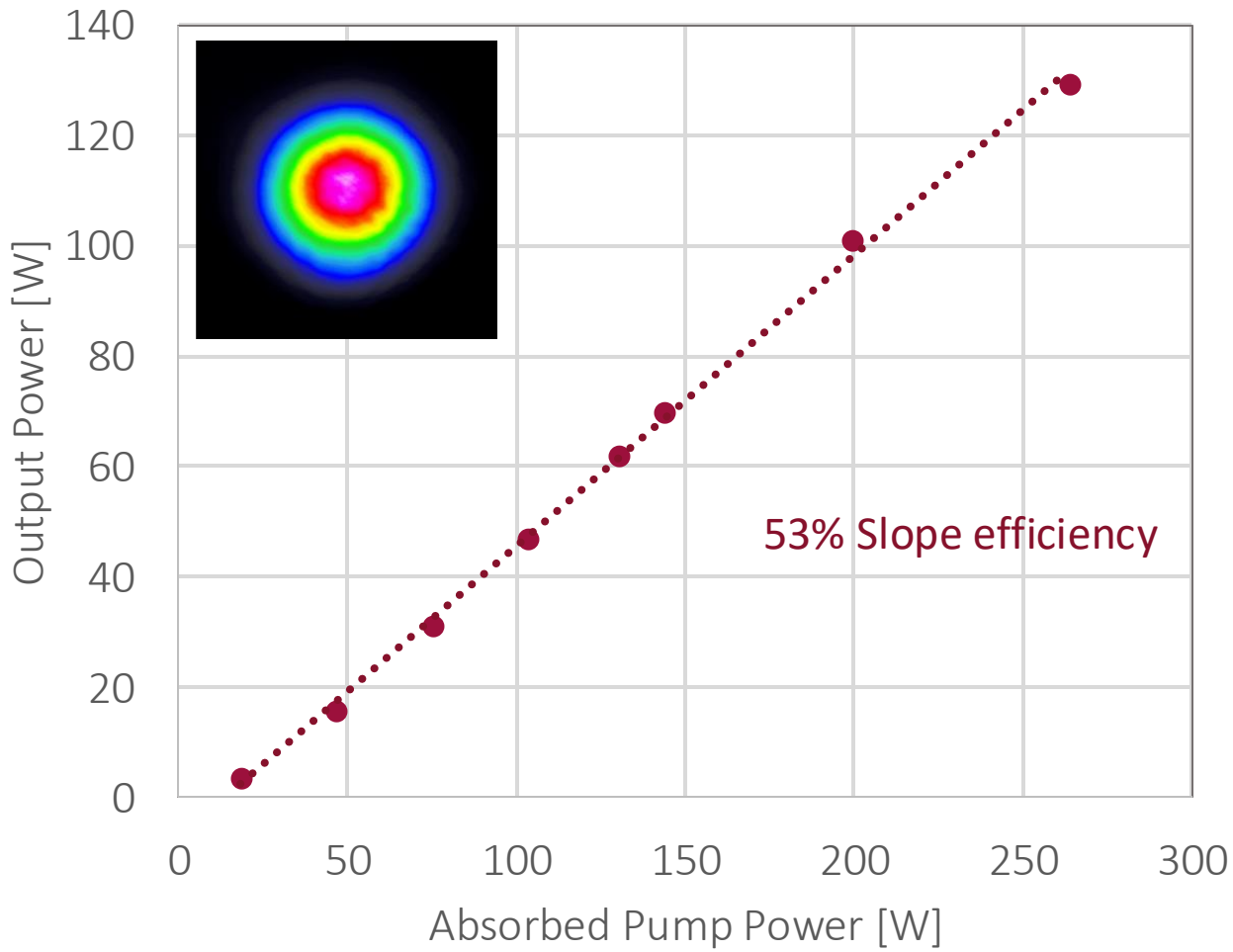
Main-amp module

High-power fiber-amplifier (>40W)

Tm-doped photonic crystal fiber



- Advanced cooling concept
  → high efficiency of >50% (cross-relaxation)
  → excellent long-term stability
- >120W and diffraction-limited beam quality

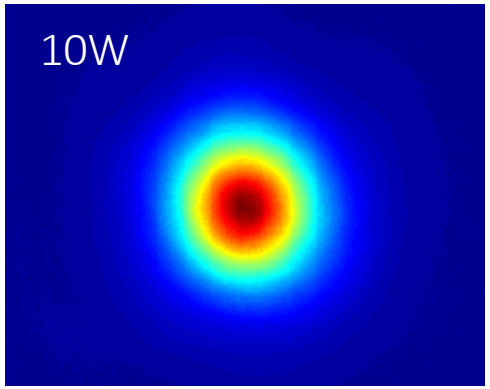


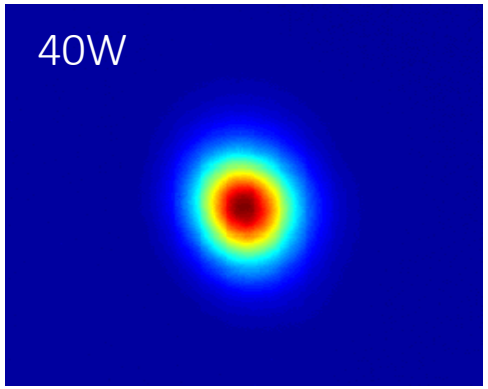
Industrial-grade ultrafast TDFL (2. generation)

Free-space module

Isolation

Free-space isolator

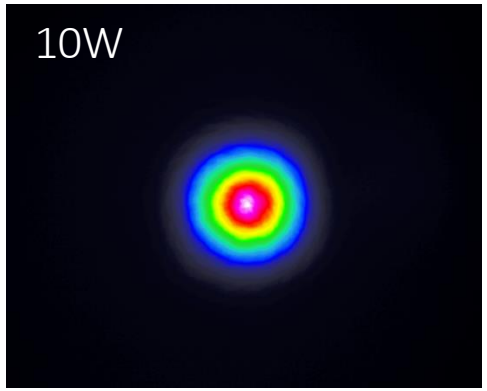


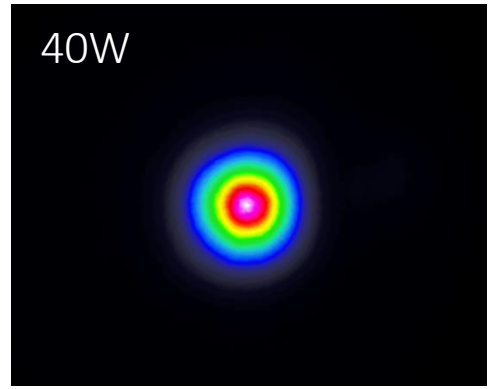


- 40W average power tested
- Static thermal lens
- >25dB isolation

Pulse-on-demand

Free-space AOM





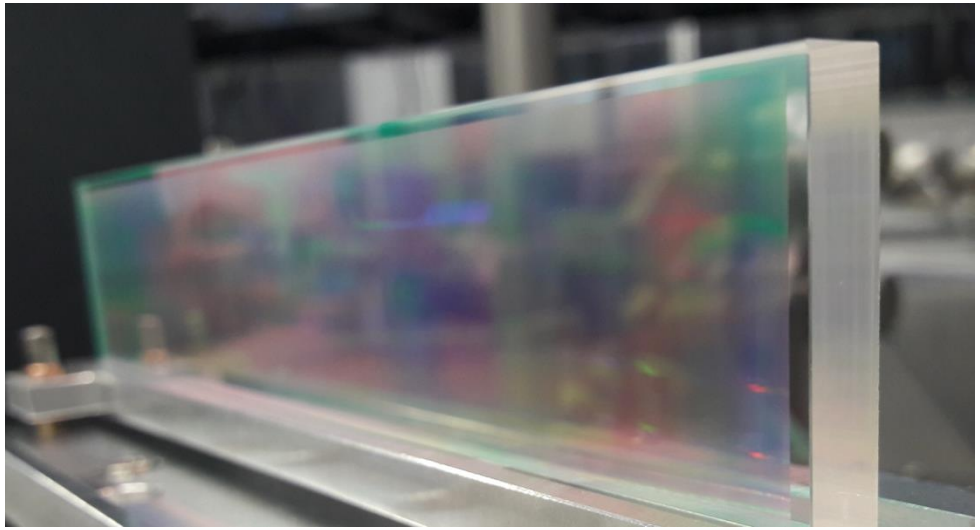
- 40W average power tested
- No thermal beam degradation

Industrial-grade ultrafast TDFL (2. generation)

Free-space module

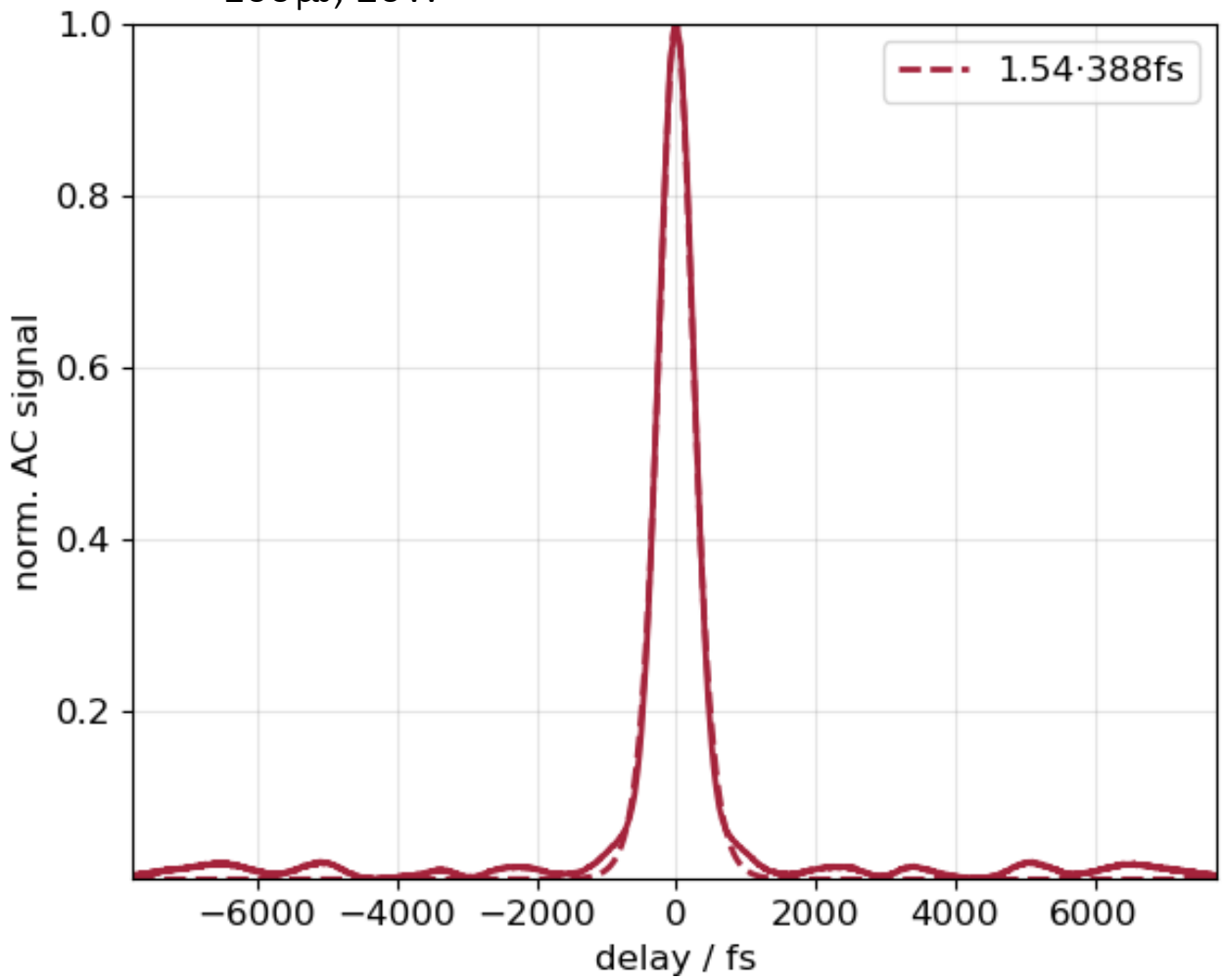
Treacy Compressor

Reflective dielectric gratings



- >90% compressor efficiency

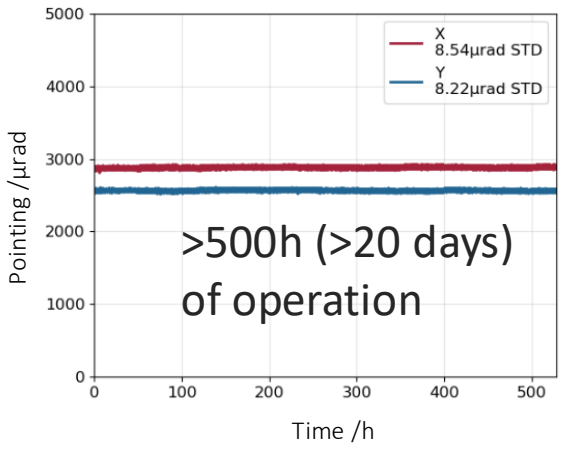
>100µJ, 20W

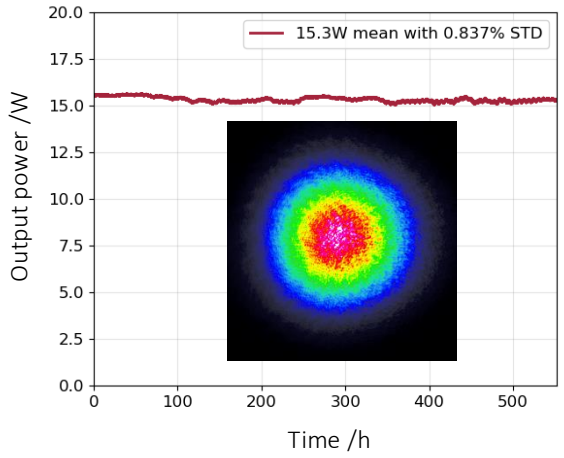


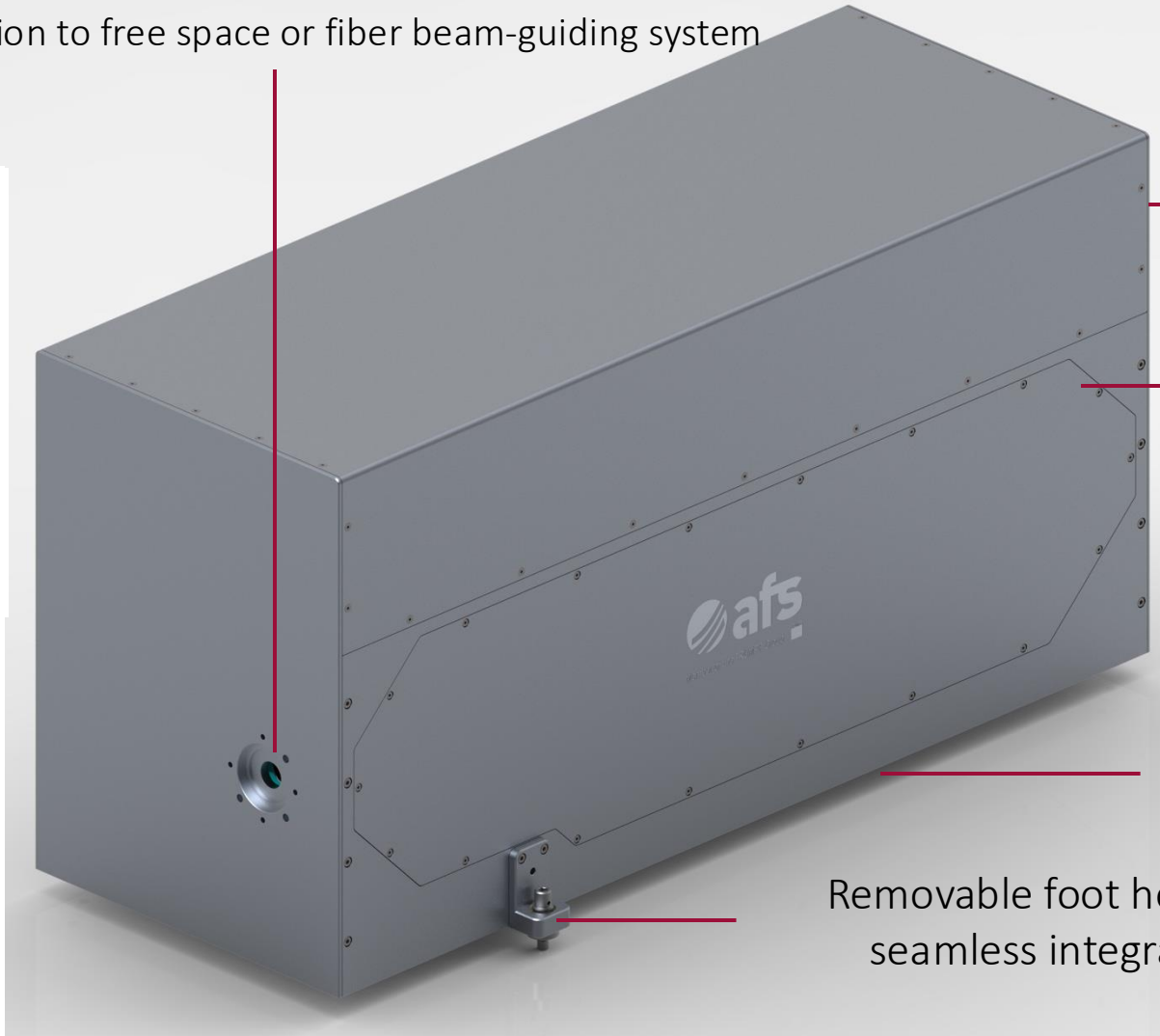
Industrial grade 2µm solution

15 W	1980 nm	100 µJ	<1Hz - 25MHz	400 fs – 1.5ns

- Output prepared for connection to free space or fiber beam-guiding system
- Safetey shutter included







RTC6 interface
Control via Software – API

Easy service access via side ports

Footprint: 0.24 m²
(2.6ft²)

Removable foot holds for seamless integration

With funding from the:

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and Space

afs

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Lasers beyond the state of the art

Active Fiber Systems GmbH

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