COLLEGE OF ENGINEERING
NUCLEAR ENGINEERING & RADIOLOGICAL SCIENCES
UNIVERSITY OF MICHIGAN

CENTER FOR ULTRAFAST OPTICAL SCIENCE

Solid-State Coherent Sources at Long Wavelengths

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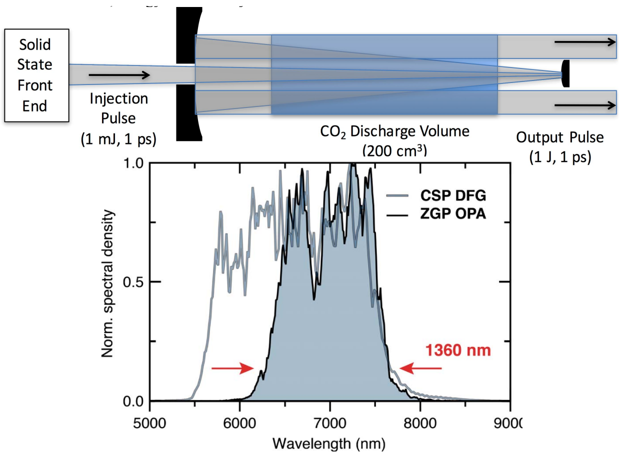
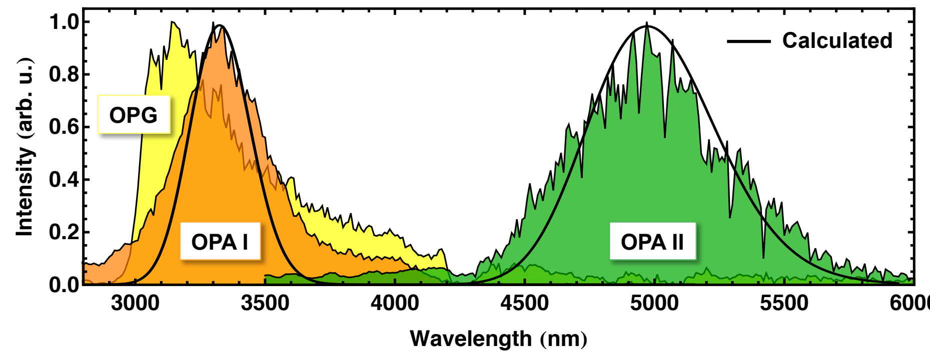
Overview

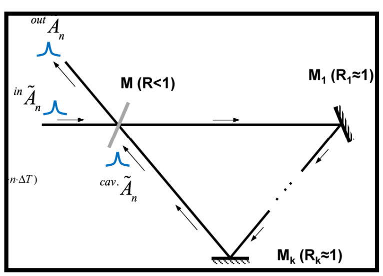
Current status of LWIR sources

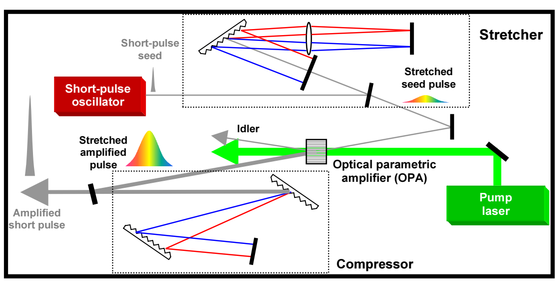


ZGP OPA at 5 μm at UMich

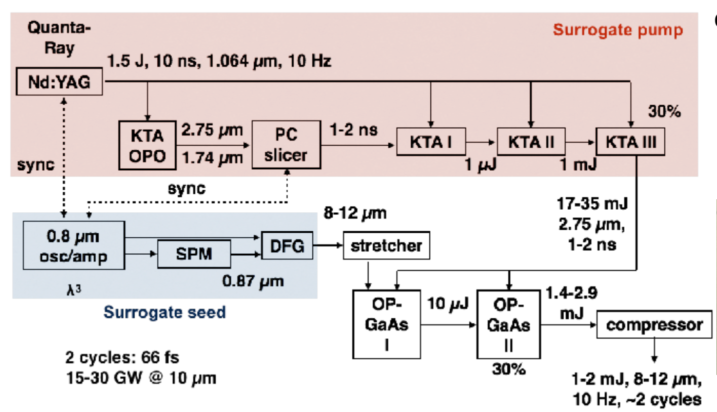


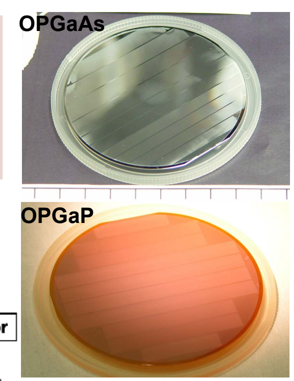
Our solid-state approach to LWIR production





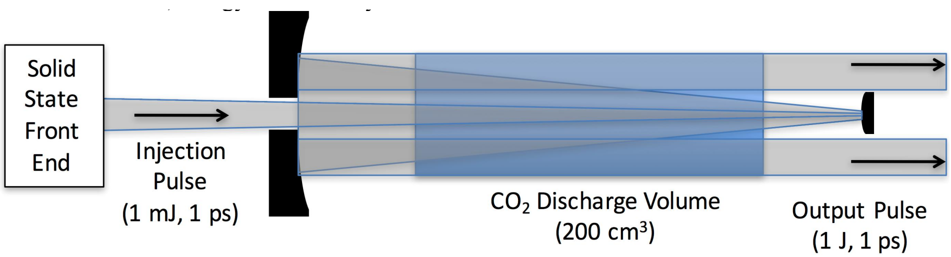
MURI plan of work



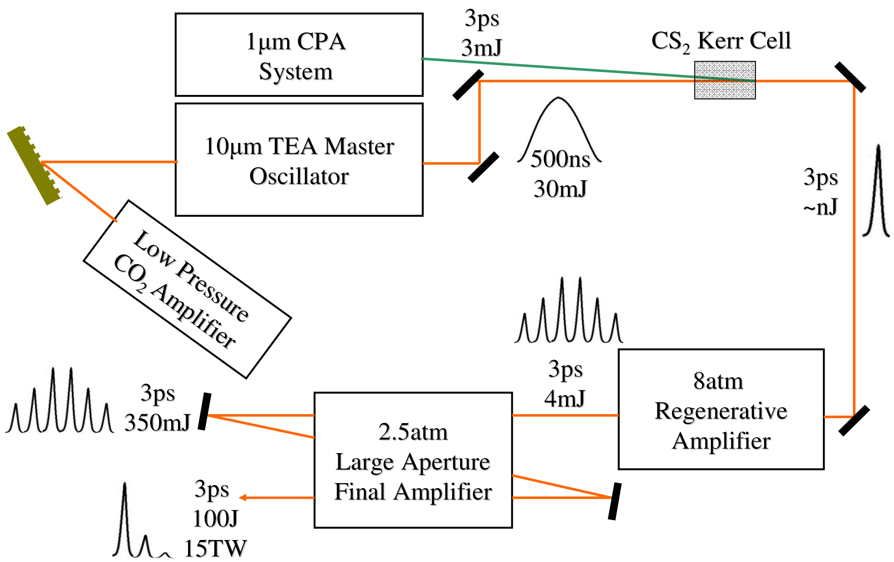


CO_2 is the current state of the art for LWIR production

Direct amplification in CO_2

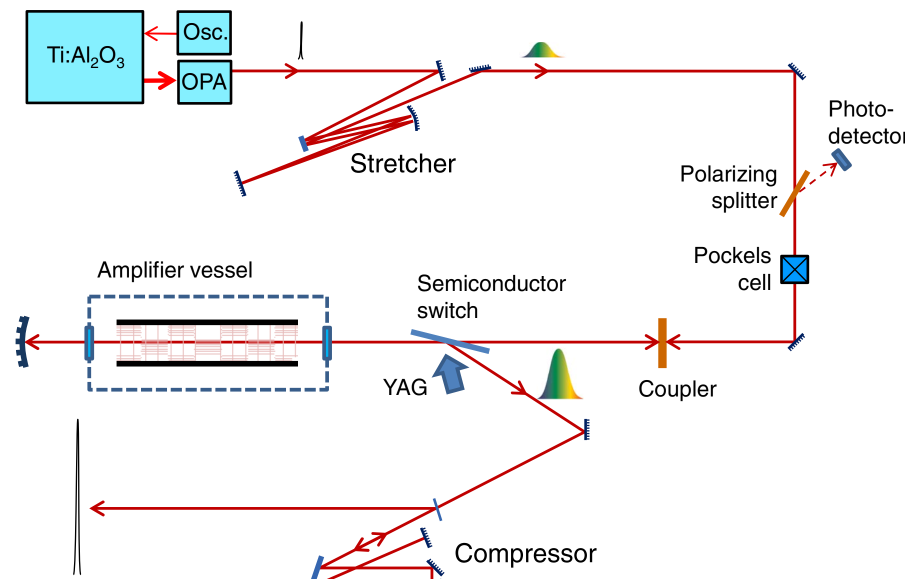


D. F. Gordon et al., Proc. SPIE (2016)



D. Haberberger et al., Opt. Express (2010)

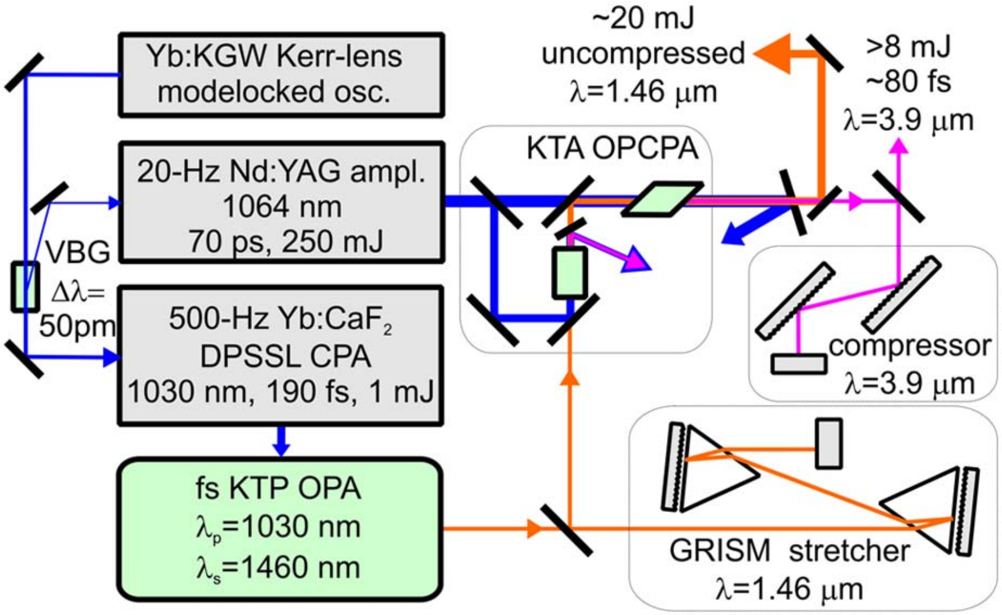
CPA in CO_2



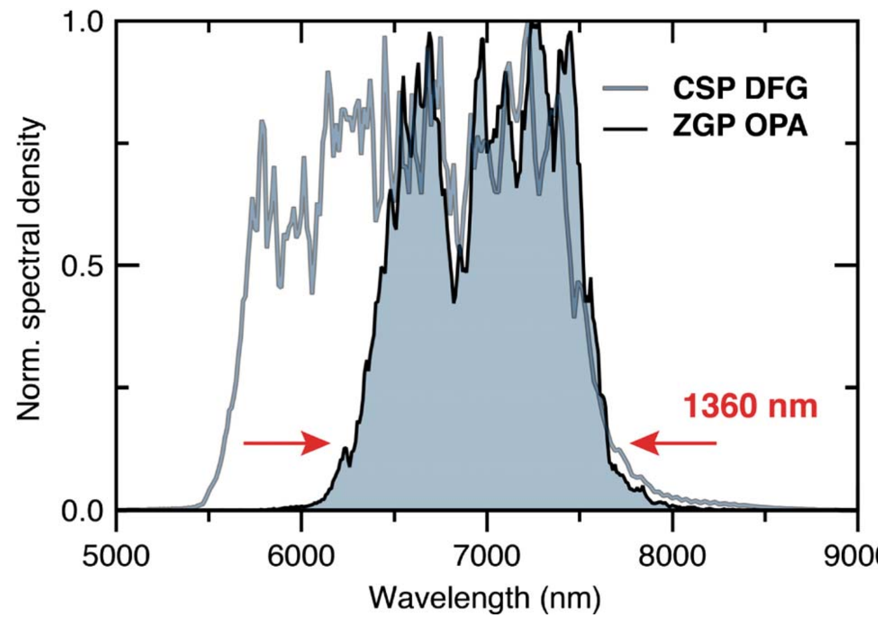
M. N. Polyanskiy et al., Optica (2015)

- high energy (1 J) needed to reach TW peak power with relatively long pulses (ps)
- limited tunability
- no CEP (yet)
- limited repetition rate (discharge in CO_2)

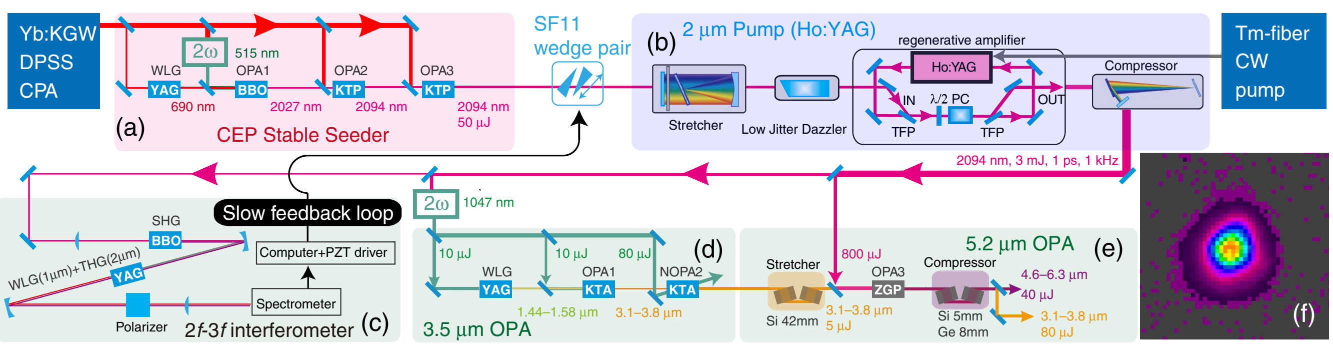
High-power solid-state sources in the MIR are pushing towards the LWIR range



G. Andriukaitis et al., Opt. Lett. (2011)

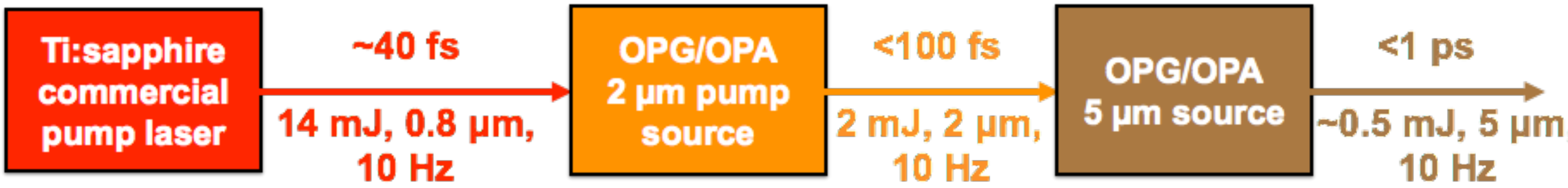


D. Sanchez et al., Optica (2016)

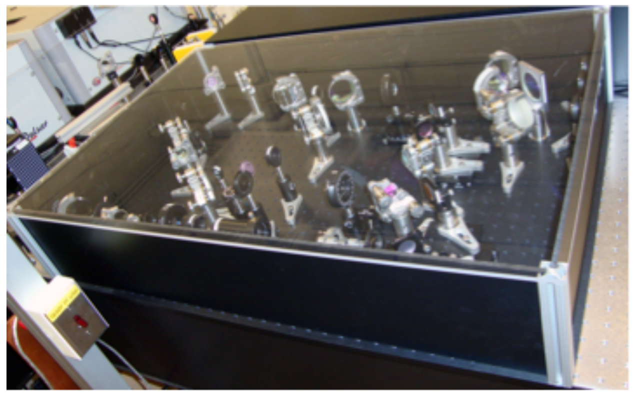


T. Kanai et al., Opt. Lett. (2017)

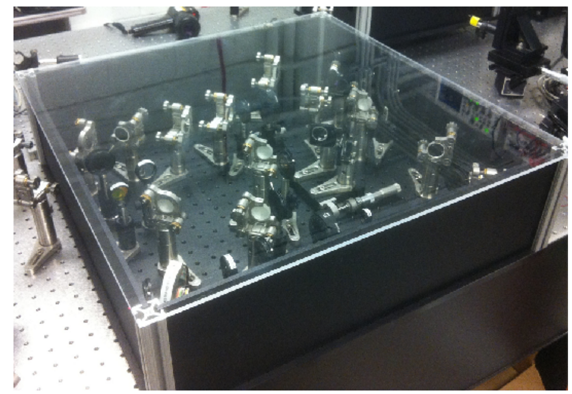
We have developed MIR OPAs at 2-5 μm



Previously: 10 Hz
Now: 0.5 kHz



2' x 3'

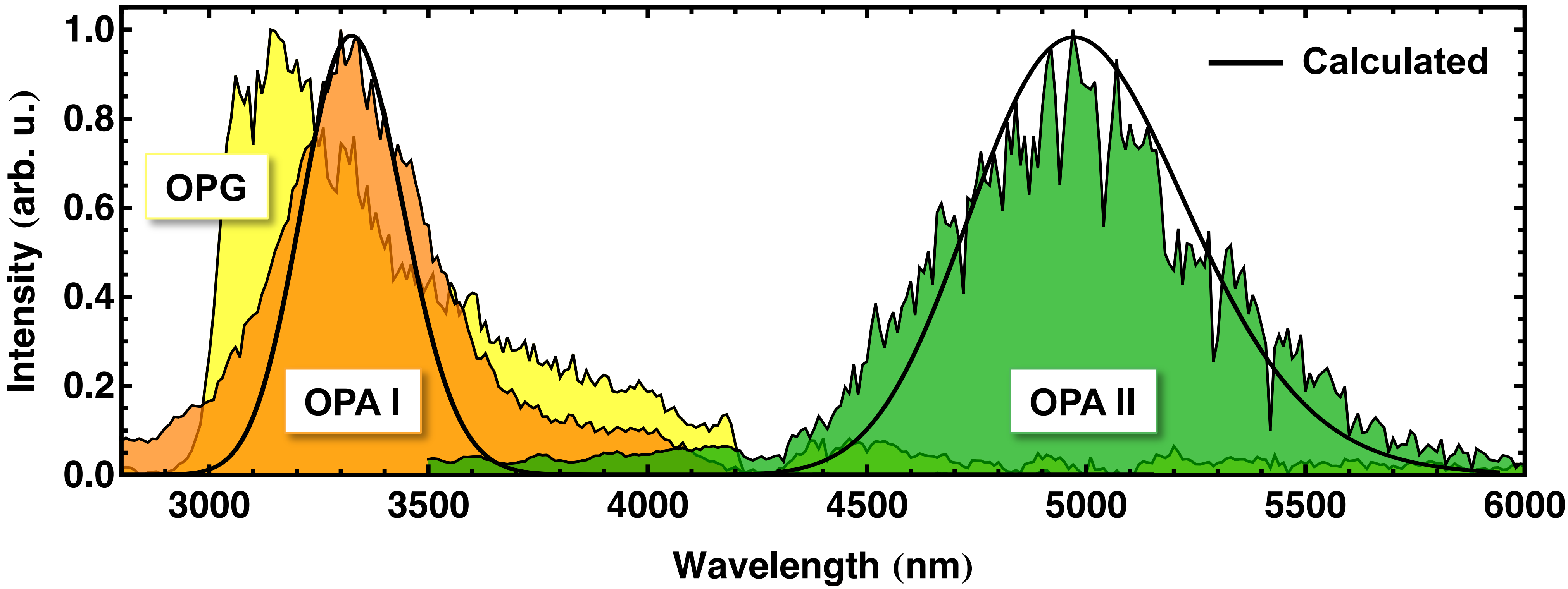


2' x 2'

G. Xu, S. Wandel, and I. Jovanovic, Rev. Sci. Instrum. (2014)
S. Wandel, G. Xu, Y. Yin, and I. Jovanovic, J. Physics B (2014)
S. Wandel, G. Xu, and I. Jovanovic, Opt. Express (2016)
S. Wandel, M.-W. Lin, Y. Yin, G. Xu, and I. Jovanovic, JOSA B (2016)

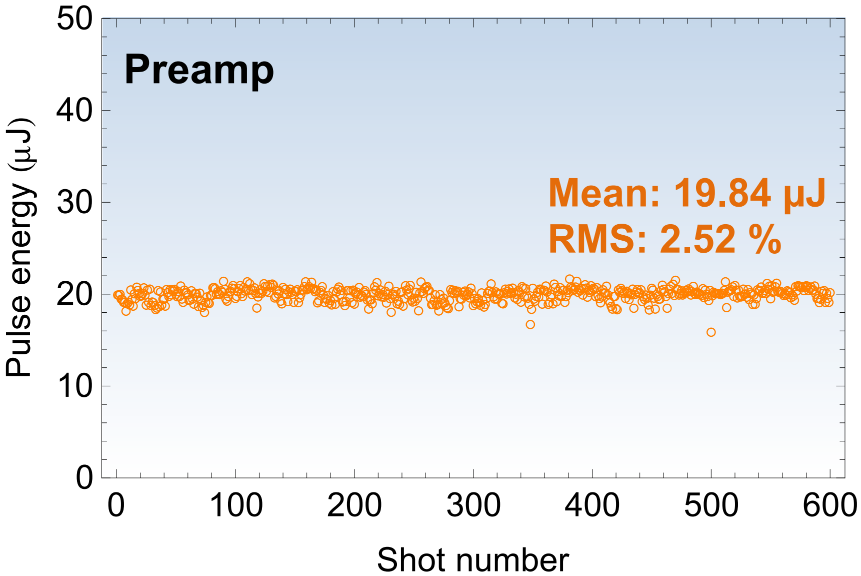
- **2 μm source now operates at 0.5 kHz**
- **5 μm source reactivation in progress**

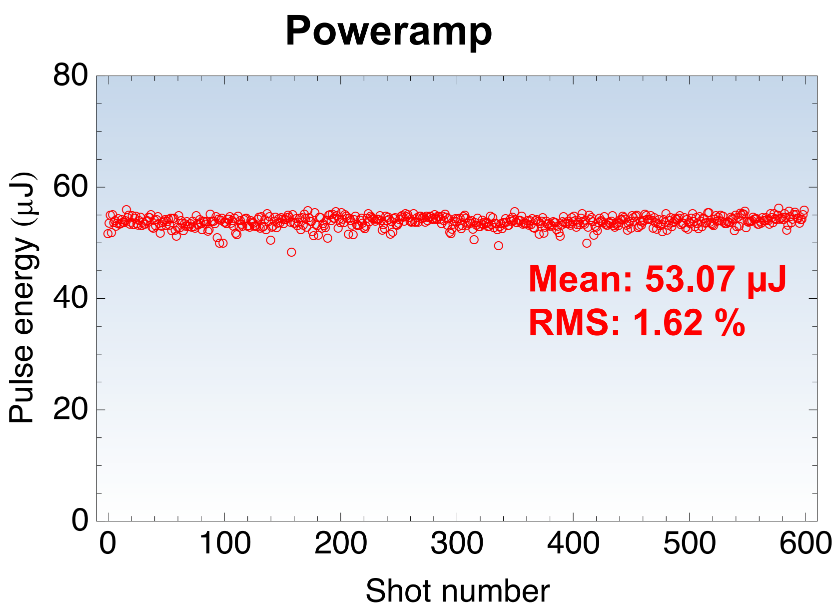
Amplified pulse spectrum supports transform-limited pulse duration of 50 fs (~3 optical cycles)



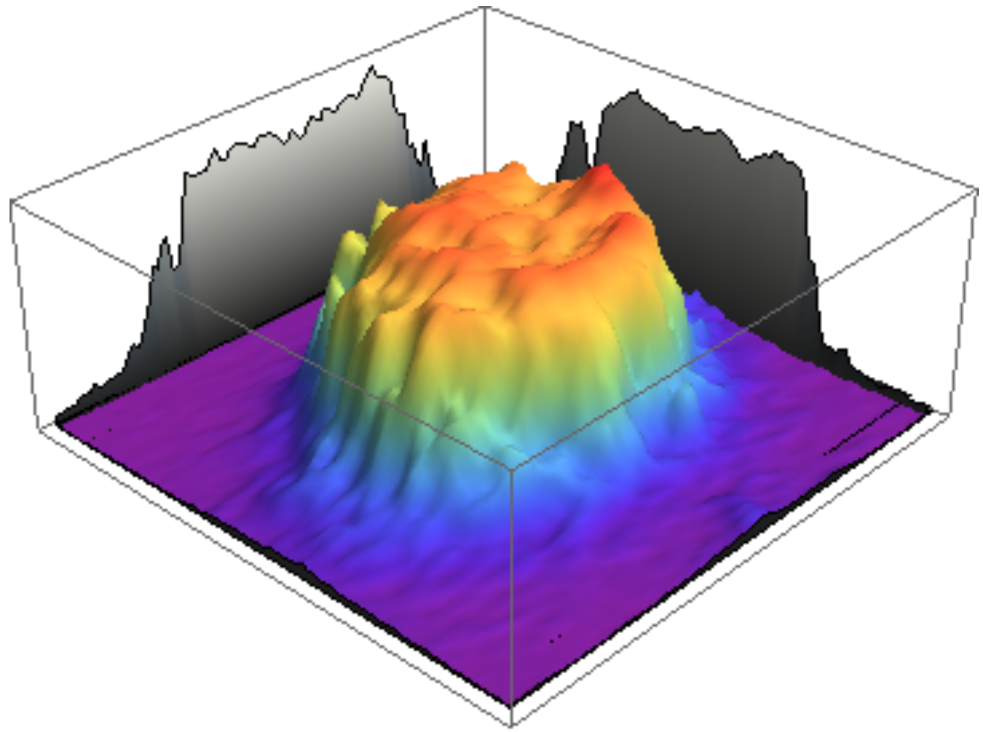
A simple 1D coupled-wave OPA model is in relatively good agreement with the measured spectrum.

Amplified 5-µm pulses exhibit excellent shot-to-shot energy stability and a uniform beam profile



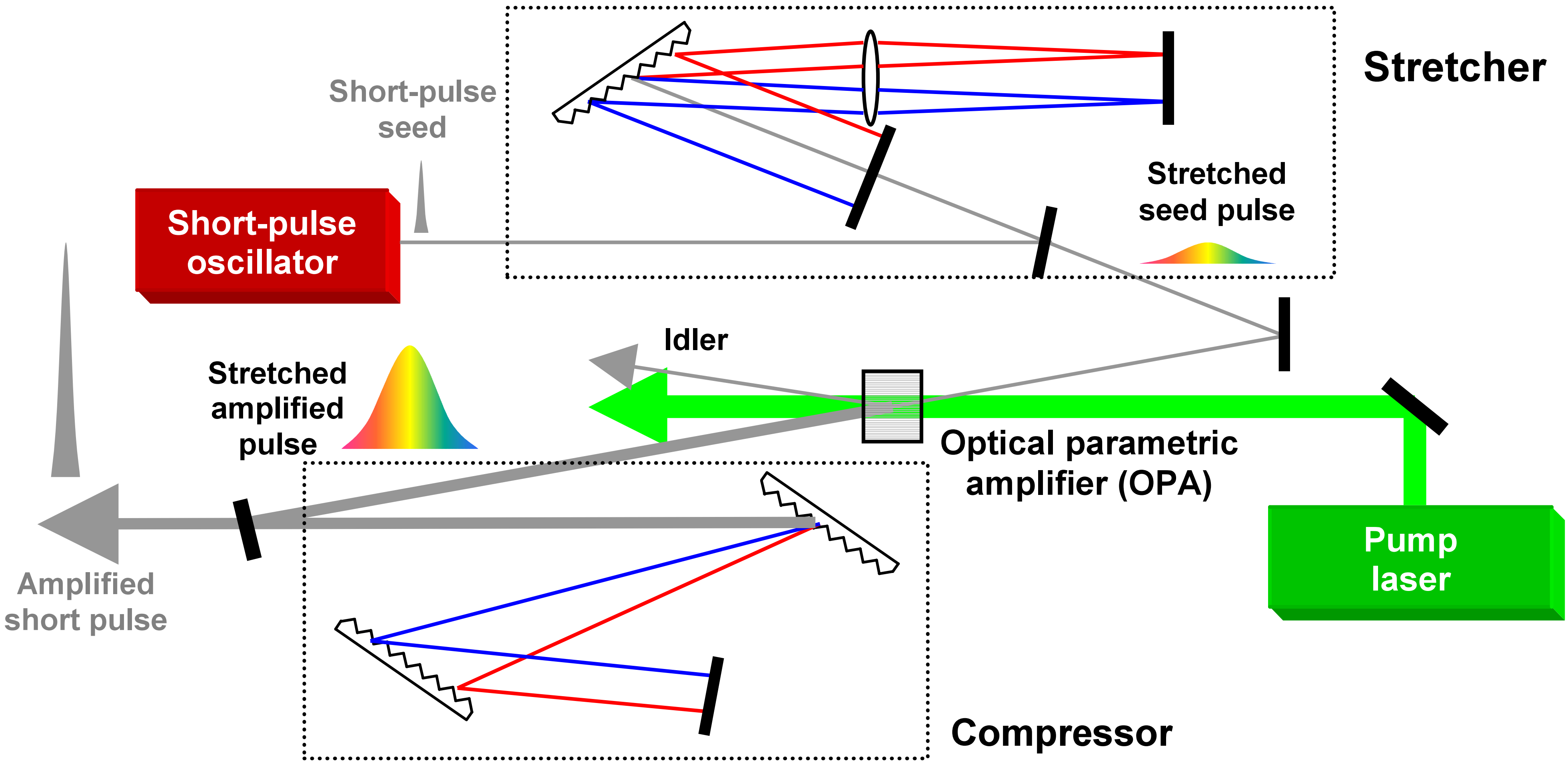


High pump depletion in the OPA II significantly improves the energy stability.

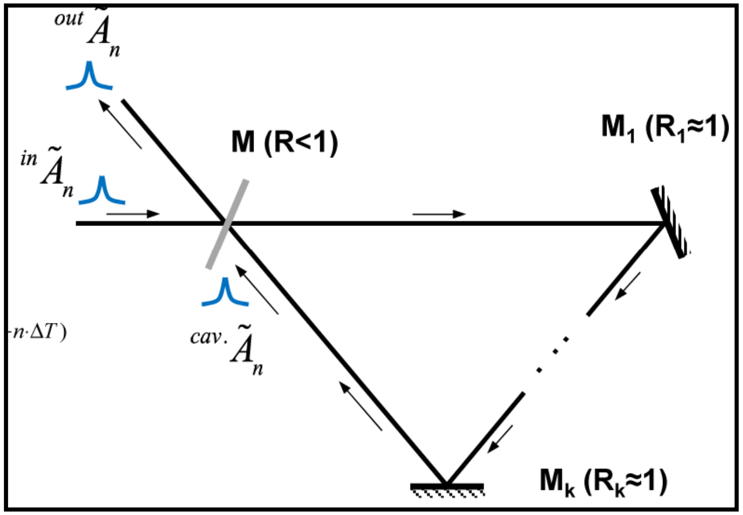


Near-field beam profile measured with InSb array camera

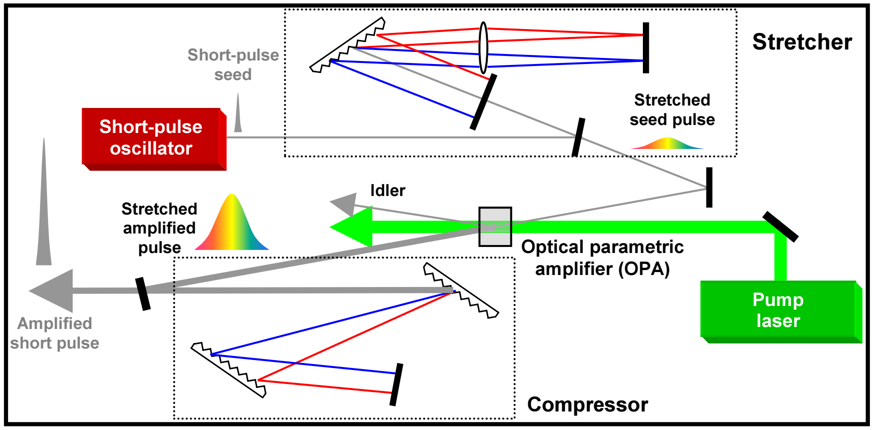
We need to transition to OPCPA to support higher pulse energies



Our technical approach is based on 8-12 µm OPCPA in GaAs pumped by coherently pulse stacked 2.75 µm Er:ZBLAN



up to kHz



Er:ZBLAN

0.5-1 J, 1 ns, 2.75 µm
Coherent pulse stacking
(A. Galvanauskas talk)

GaAs OPCPA

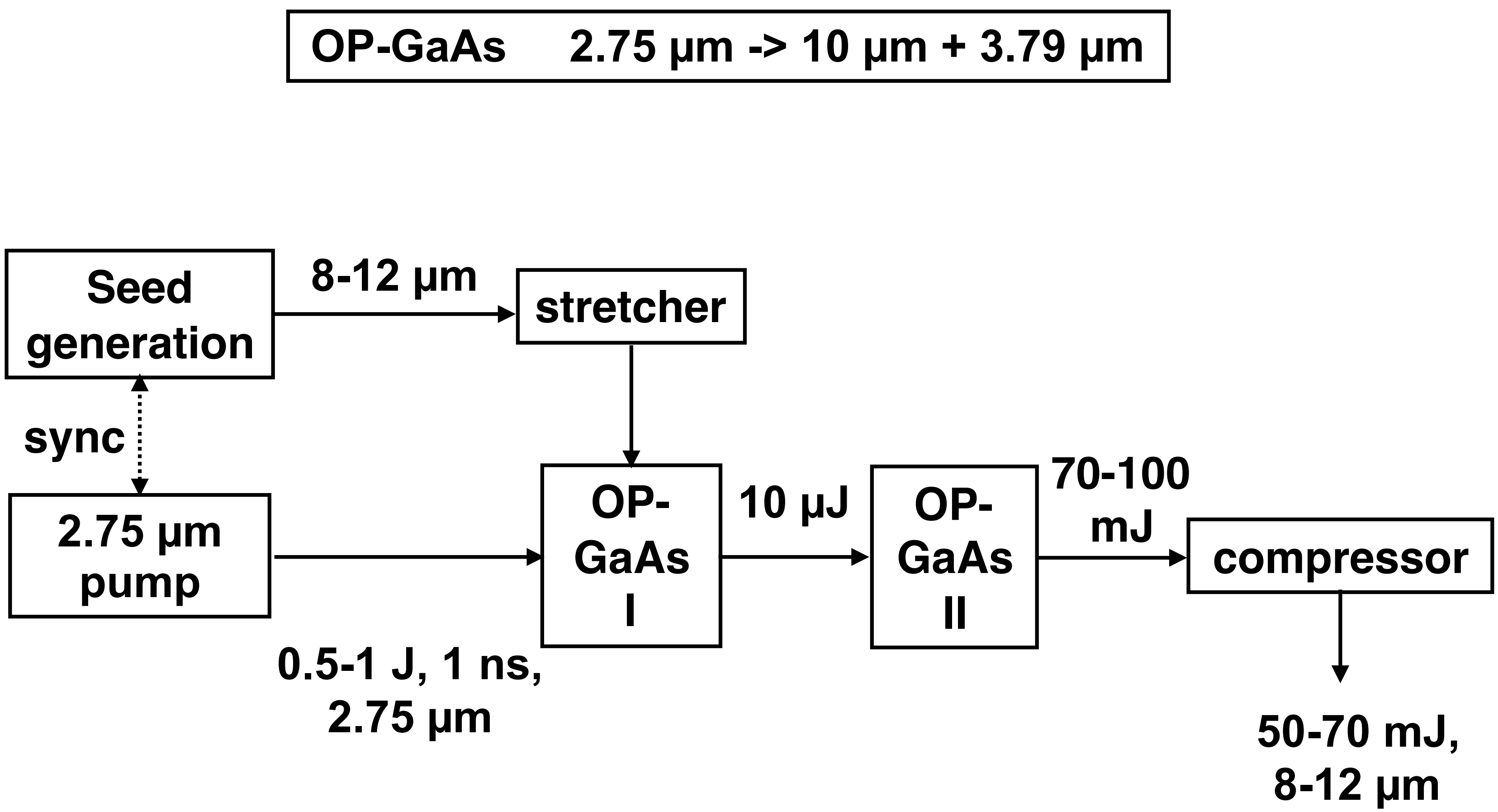
50-70 mJ, <100 fs 8-12 µm
Long-stretch (ns)

2.75 µm —> 10 µm + 3.8 µm

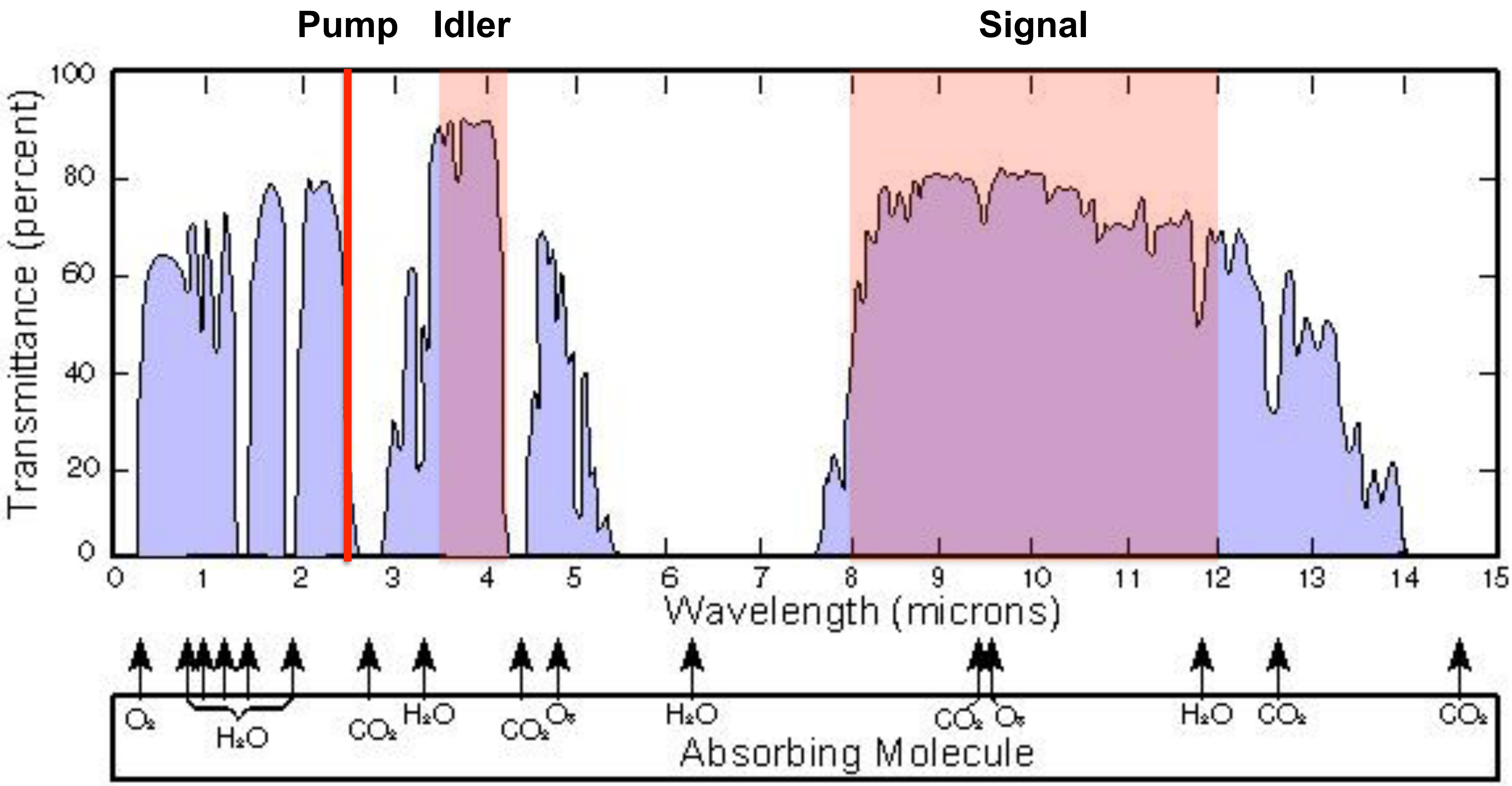
Theoretical maximum conversion efficiency: 2.75/10 = 27.5%

Expected experimental conversion efficiency: ~10 %

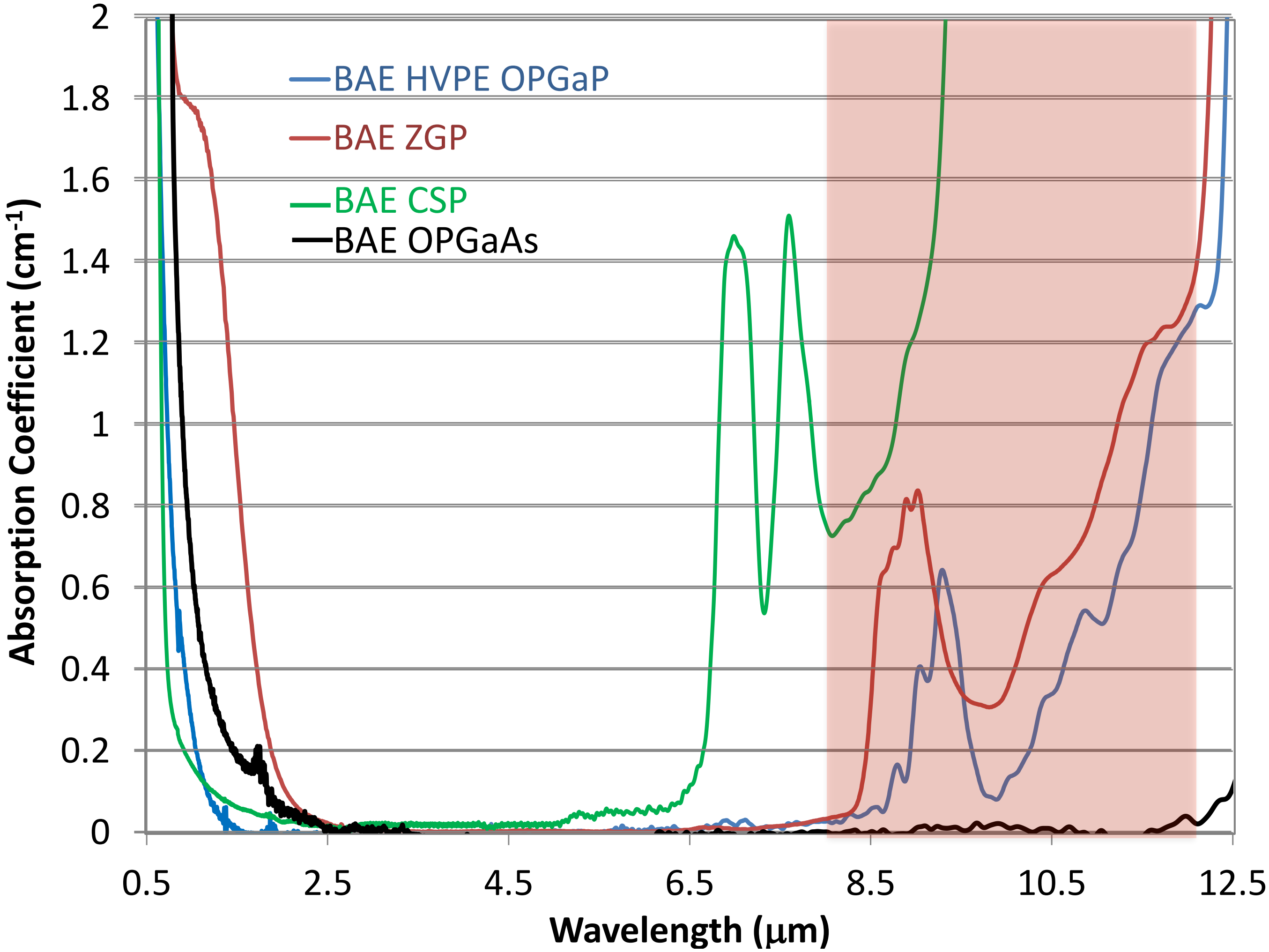
Path to TW solid-state LWIR source scalable to high average power

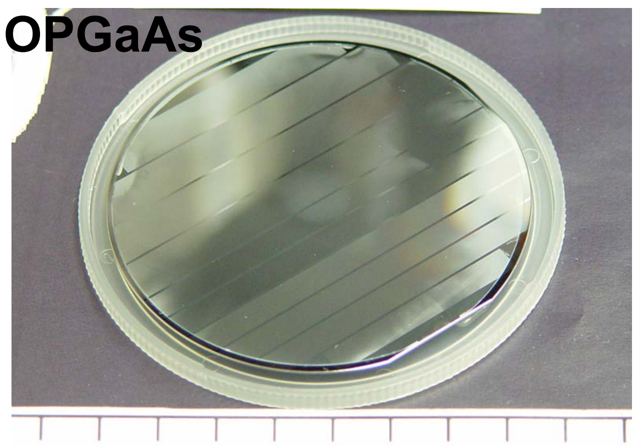


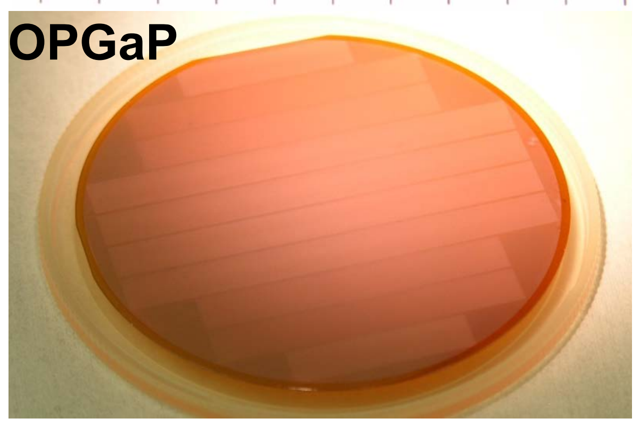
Atmospheric transmittance is a consideration in source design



Transparency is an important characteristic of crystals



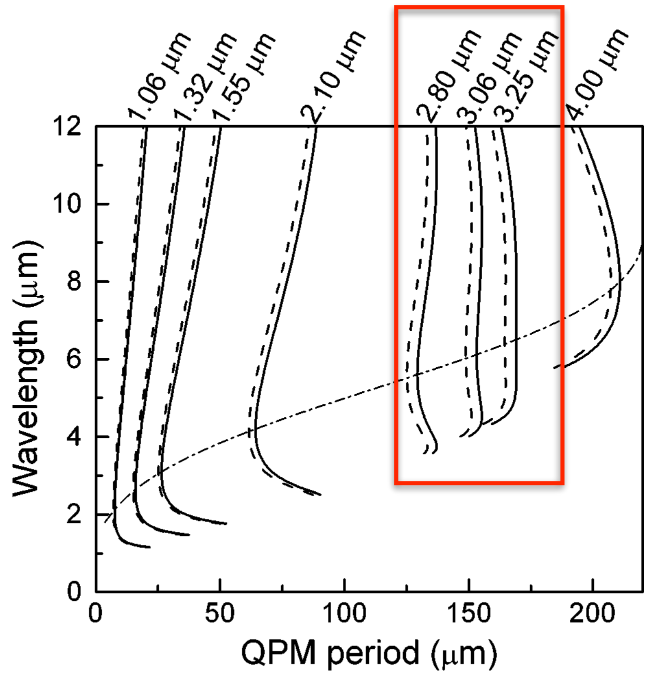


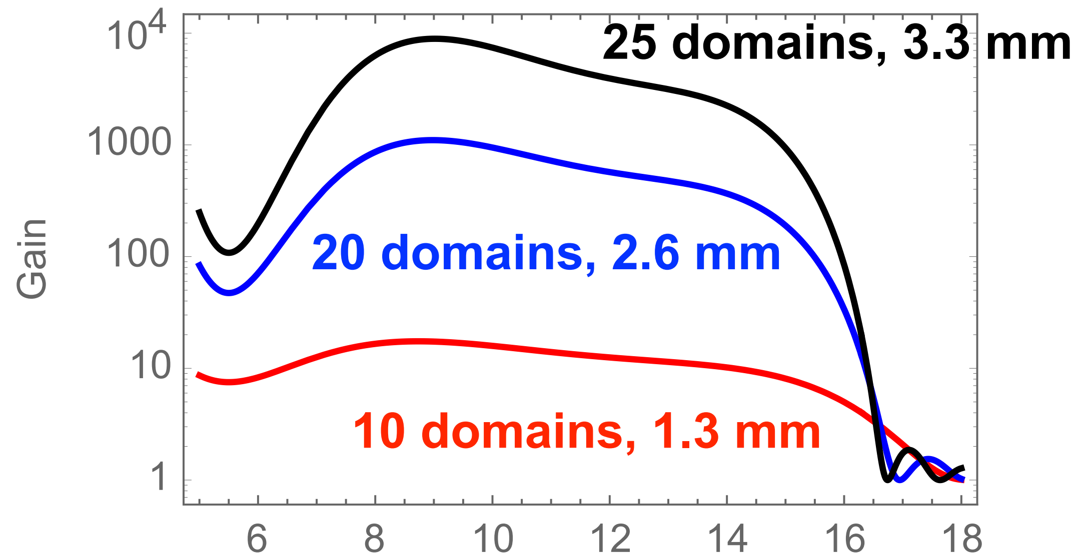


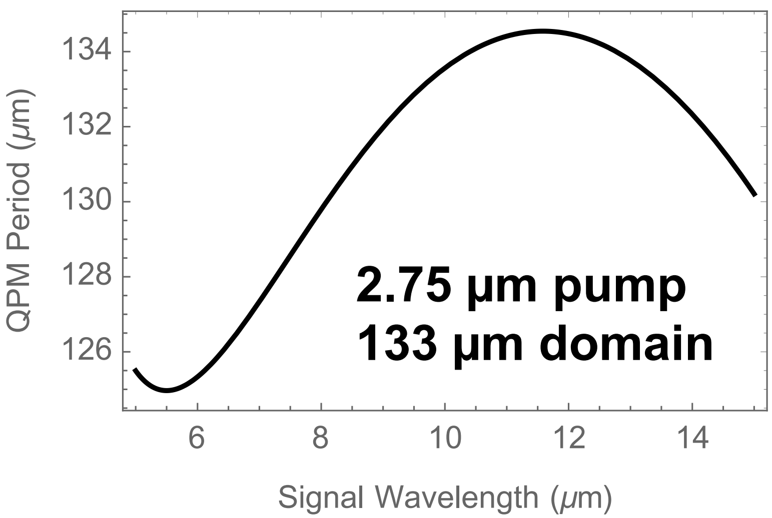
Courtesy P. Schunemann, BAE Systems

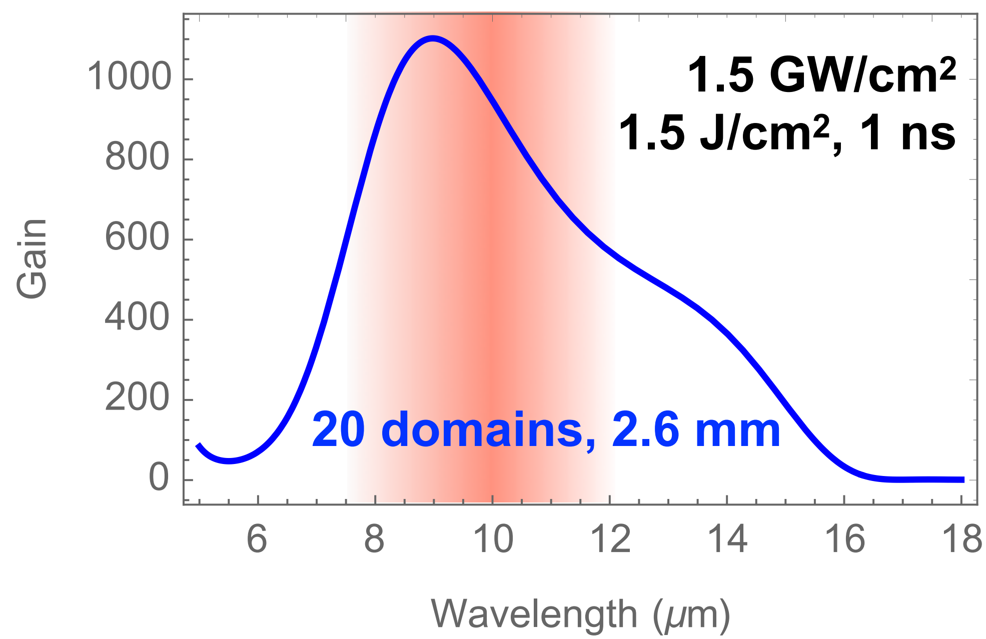
The other major consideration is the gain and bandwidth

T. Skauli et al., J. Appl. Phys. (2003)









OP-GaAs is limited in aperture, but multi-mJ pulses are possible with nanosecond OPCPA

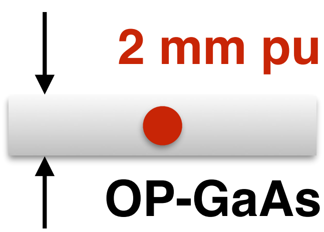
Damage threshold for both GaAs and ZGP: 2.5 J/cm², ns @ 2 μm
Operate at 1.5 J/cm² -> the required beam size for 1 J pulse is ~1 cm

Maximum OP-GaAs crystal thickness produced by BAE Systems (P. Schunemann): 3 mm

BAE SYSTEMS
INSPIRED WORK

Assume 2 mm beam size on crystal, 1.5 J/cm²: we can pump OP-GaAs with a maximum of ~50 mJ

2 mm pump, 1.5 J/cm², ~50 mJ



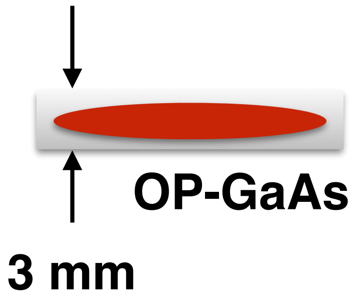
OP-GaAs

3 mm

Assuming real-world efficiency of 10%:

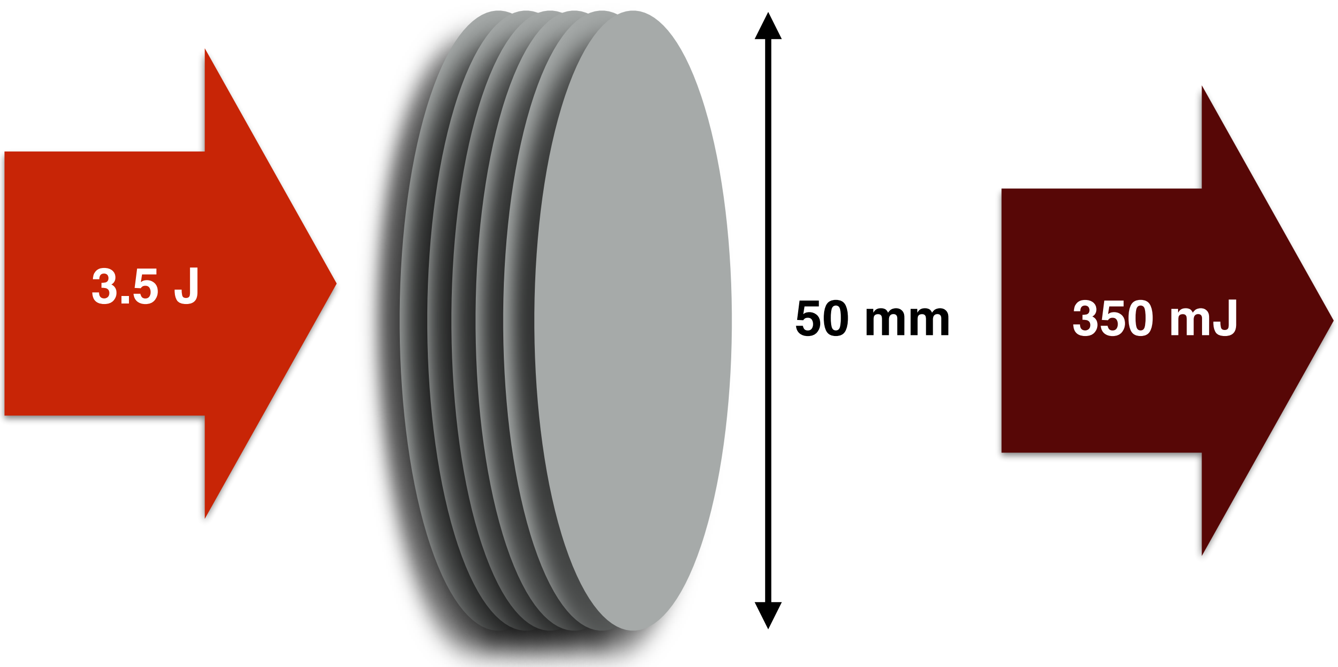
maximum energy of ~5 mJ from OPGaAs

To take this OPCPA approach to TW (~100 mJ) and beyond, we can consider two possibilities



With large-aspect-ratio elliptical beams (20:1), we could obtain 100 mJ!

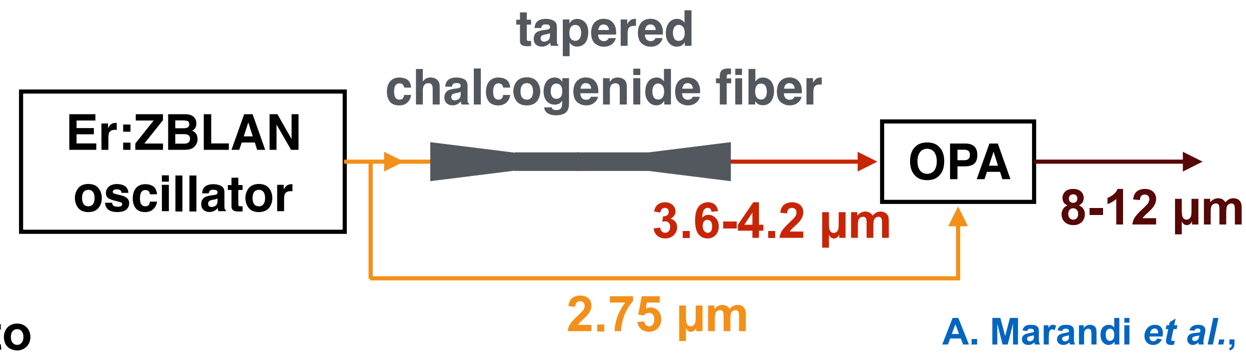
Stacked 133-μm thick GaAs wafers



Generation of seed ultrashort pulses for LWIR OPCPA

Direct generation from Er:ZBLAN

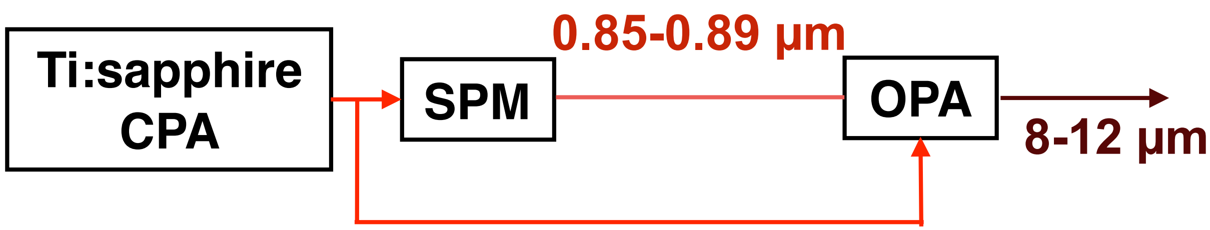
- Single source
- Automatic locking to pump laser



A. Marandi *et al.*, CLEO 2012

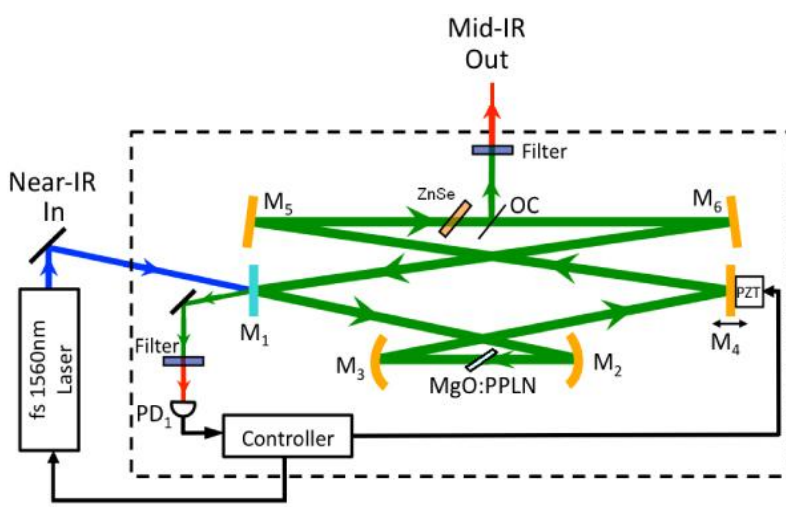
DFG to LWIR using NIR ultrafast laser

- Separate source
- Short term testing



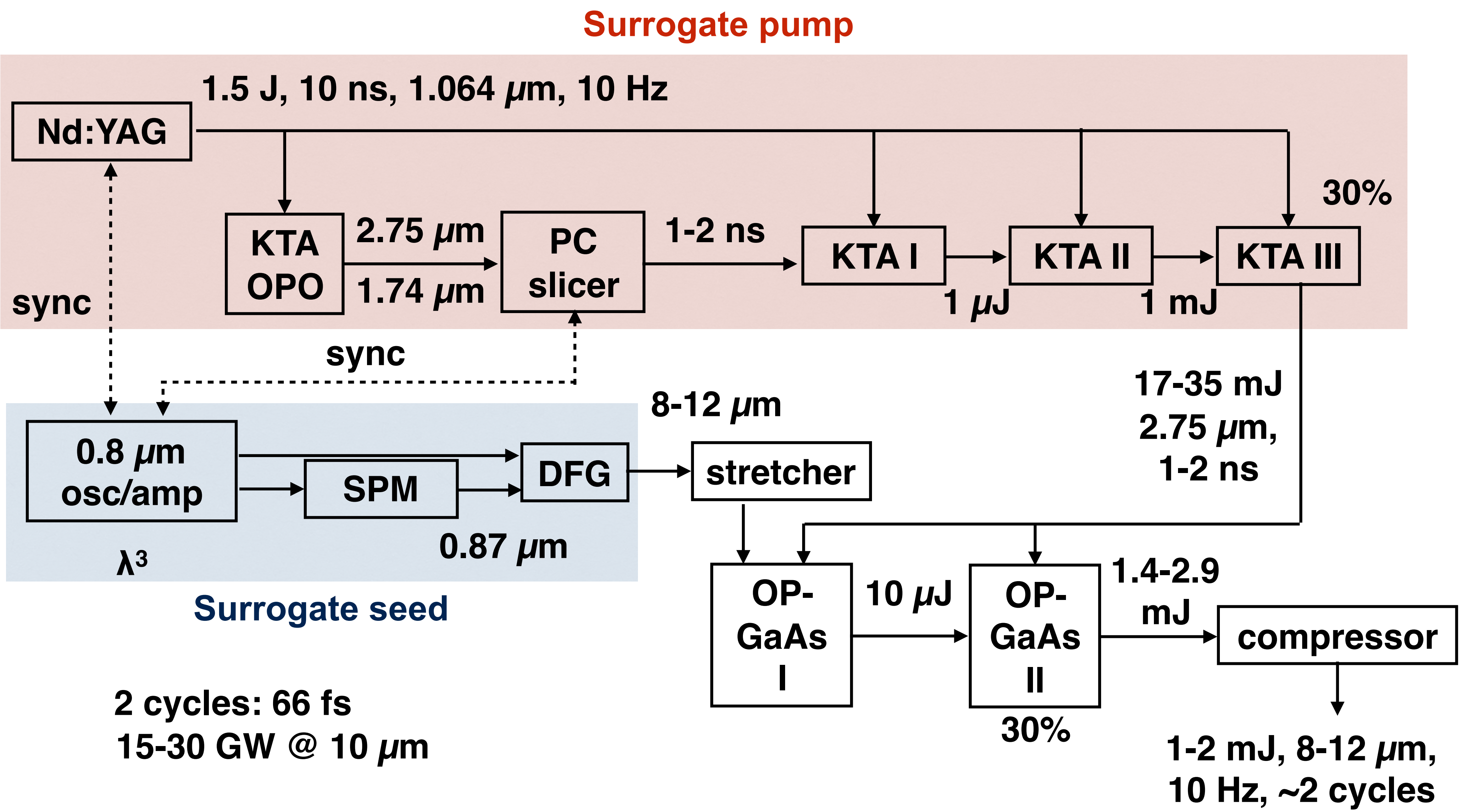
Nonlinear frequency divider to LWIR

- Pumping by Er:ZBLAN?
- Locking to Er:ZBLAN



N. Leindecker *et al.*, Opt. Express 2011

We will first demonstrate the LWIR OPCPA architecture using surrogate seed and pump sources



2 cycles: 66 fs
15-30 GW @ 10 μm

MURI R&D roadmap at the University of Michigan

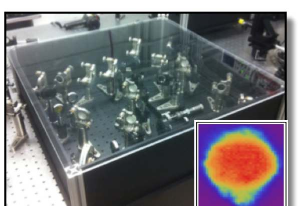
2017 2018 2019 2020 2021 2022

Source Development

- OPCPA design
- Surrogate pump construction
- Seed generation
- OPCPA construction
- Er:ZBLAN source design
- Er:ZBLAN source construction
- Er:ZBLAN/OPCPA integration

Measurements

- 5 μm source optimization
- 5 μm measurements
- 8-12 μm measurements



Existing 5 μm source at CUOS

S. Wandel, G. Xu, and I. Jovanovic, Opt. Express 24, 5287 (2016)

Conclusions

- LWIR solid-state sources are in their infancy
- Under this MURI we will demonstrate a novel 8-12 OPCPA architecture based on GaAs and pumped by a 2.75 μm Er:ZBLAN fiber
- The new architecture is scalable to high peak and average power
- We will compress and use our existing 5 μm OPA source to conduct measurements at 5 μm