High-power, high-energy ZGP OPA pumped by a 2.05-μm Ho:YLF MOPA system

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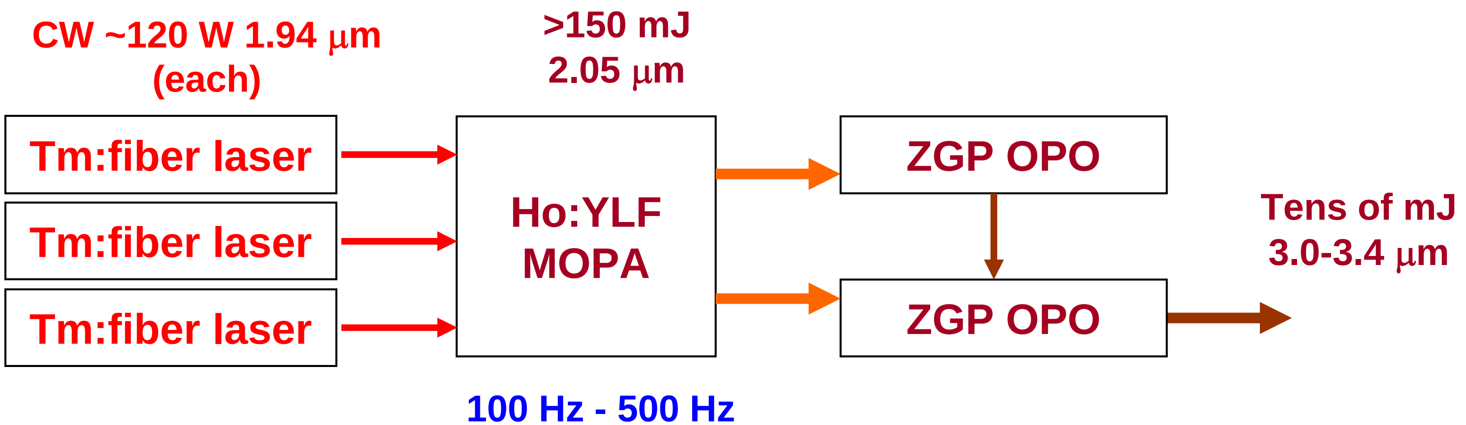
Outline

- Motivation
- Technical approach
- Ho:YLF MOPA
- ZGP RISTRA OPO - Modeling and Experiment
- ZGP OPA - Modeling and Experiment
- Conclusions

Motivation

- Development of an IR laser source for application in laser ultrasonics:
  - Wavelength range 3.0-3.4 μm
  - High-energy (up to 100 mJ)
  - High repetition rate (200-1000 Hz)
  - Short pulses (< 100 ns)
  - Good beam quality

Current work: objectives



- Our approach for 3-um pulsed source:
  - 3.0-3.4 μm — ZGP OPO/OPA – signal wave
  - OPO/OPA pump — 2-μm Ho:YLF MOPA
  - MOPA pump — CW Tm-fiber lasers

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OPO pump - why Ho-laser?

- ZGP crystals require pump sources with > 2 um wavelength (Absorption at 2.05 um < 0.05 cm^{-1})

- Most of the laser transitions in 2-um region have such a low gain cross-section that efficient, high-energy laser oscillation or amplification is impossible

- Only Ho-doped crystals, including Ho:YAG and Ho:YLF, have a large enough gain cross-section for effective high-energy operation.
  - Ho:YAG σ_{em}~$1x10^{-20}$ cm^2
  - Ho:YLF σ_{em}~$2x10^{-20}$ cm^2

- Ho:YLF
  - Long upper laser level lifetime ~ 15 ms
  - High emission cross-section
  - Naturally birefringent material
  - Low dn/dT –> weak thermal lensing
  - ~5% quantum defect

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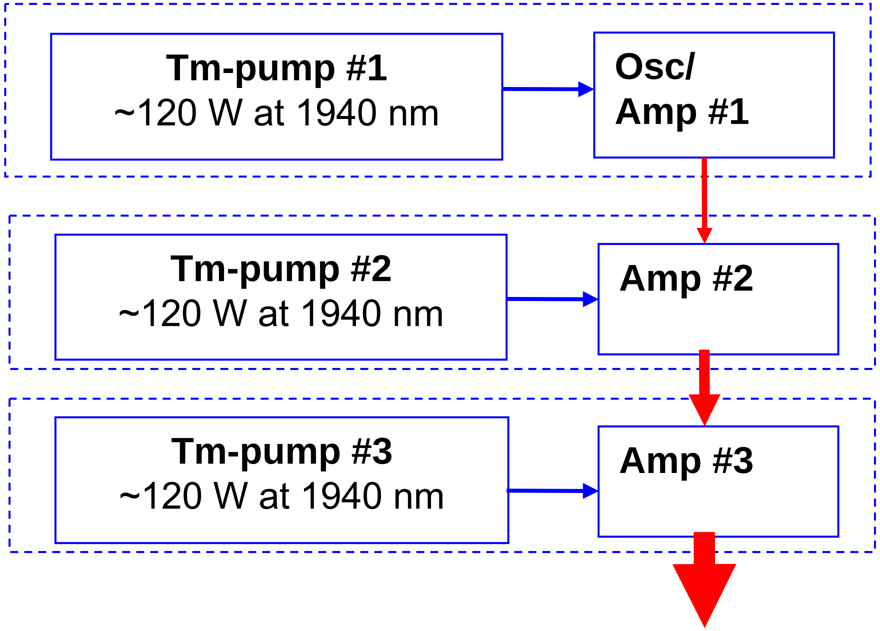
2.05-μm Ho:YLF MOPA



Ho-stage/ Regime	CW	100 Hz	500 Hz
Osc/Amp #1	39 W	55 mJ	50 mJ
Amp#2	76 W	110 mJ	95 mJ
Amp#3	115 W	170 mJ	140 mJ

Tm-fiber laser TLR-100-1940
IPG Photonics
www.ipgphotonics.com

Operation regime	CW
Beam Profile	TEMoo
Output power	≥ 120 W
Wavelength	1940 nm
Polarization	Random
Linewidth	≤ 2 nm

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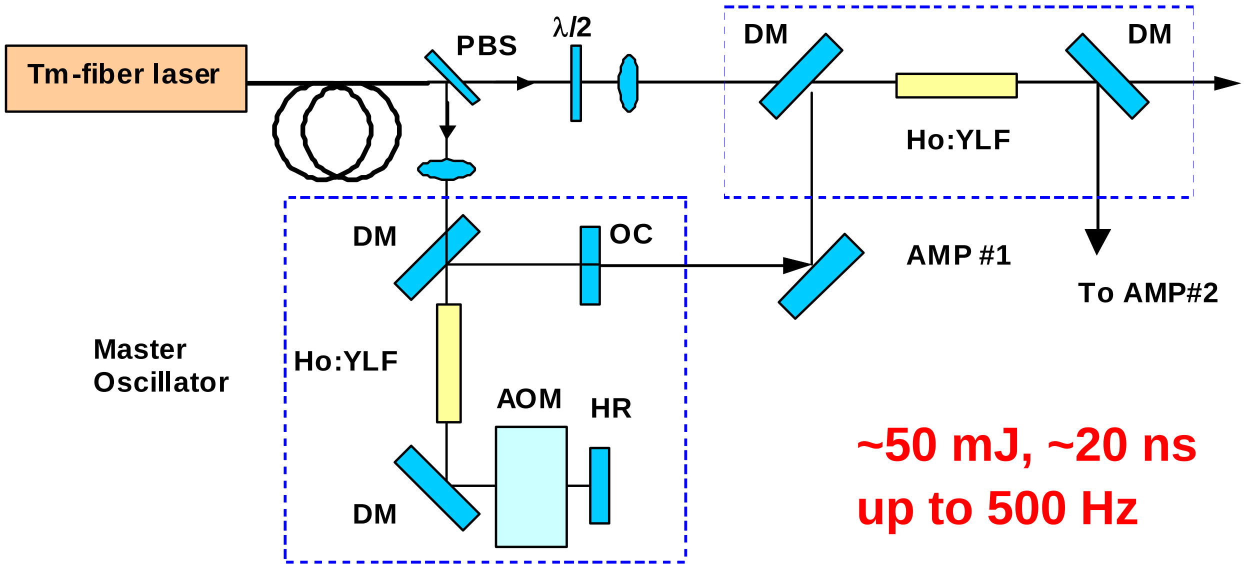
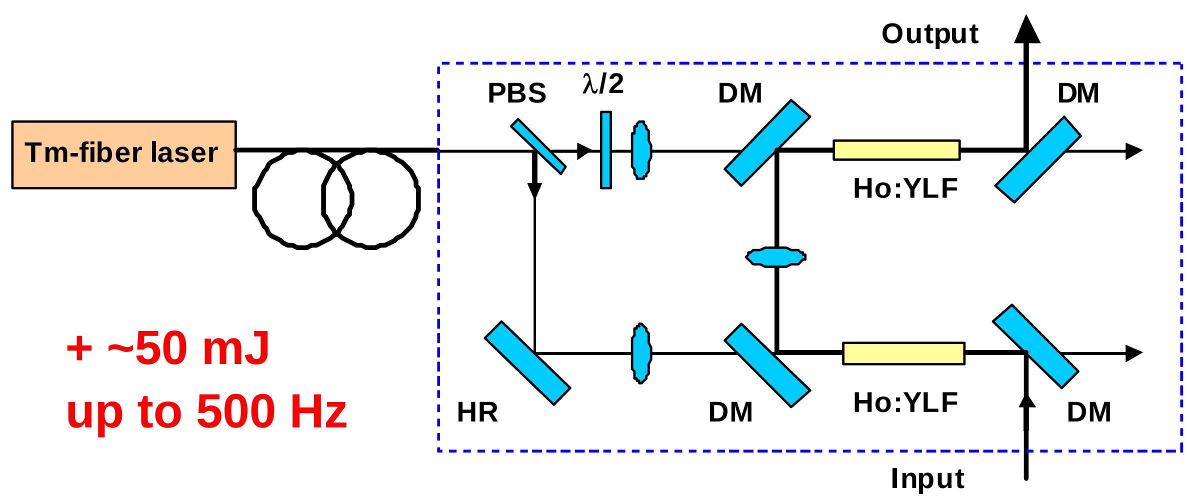
Ho:YLF MOPA – dual-crystal modules



Osc/Amp module

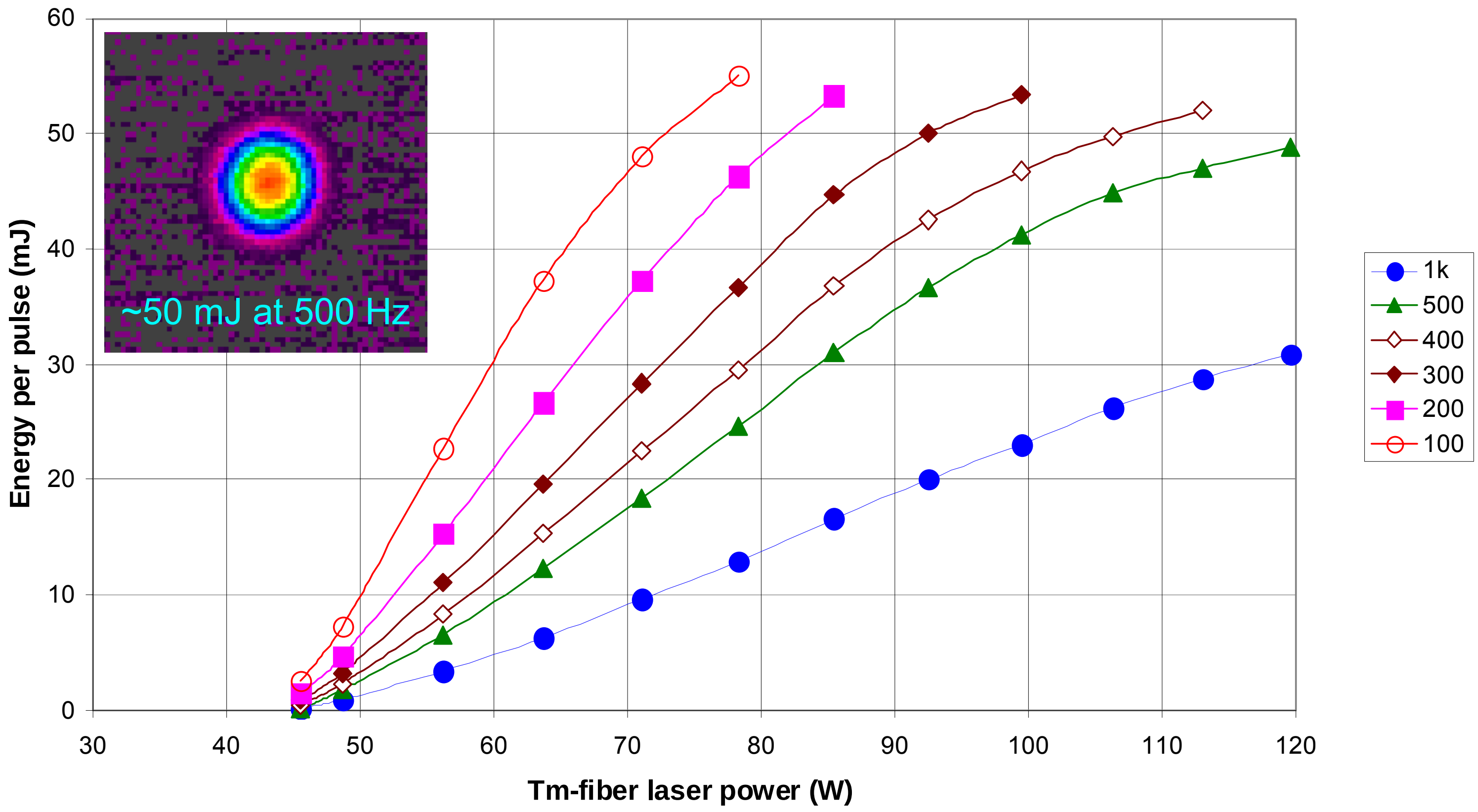
~50 mJ, ~20 ns
up to 500 Hz

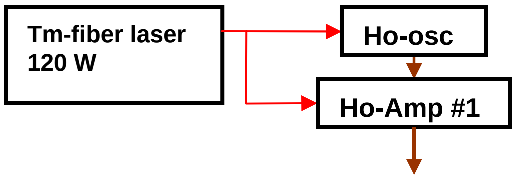


Dual-crystal amplifier module

+ ~50 mJ
up to 500 Hz

Ho:YLF MOPA – Osc/Amp#1





	CW	100 Hz	500 Hz
MO	19 W	25 mJ	25 mJ
Amp 1	42 W	55 mJ	50 mJ

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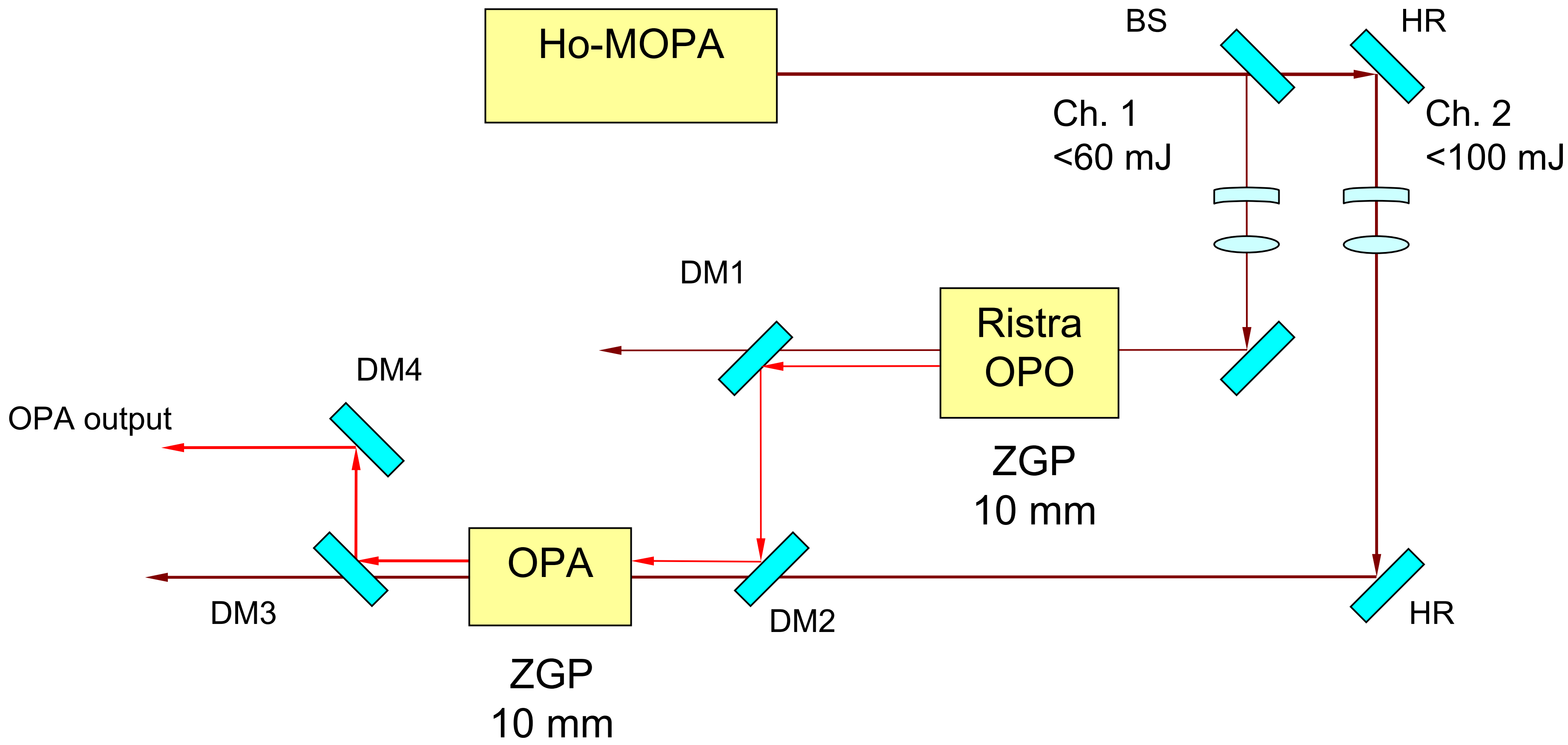
OPO/OPA layout



- ZGP obtained from Inrad

RISTRA quasi-monolithic cavity assembly

Rotated Image Singly-resonant Twisted RectAngle

- Non-planar geometry requires no cavity mirror adjustments
- Quasi-monolithic, highly-stable cylindrical design
- Excellent beam quality for cavity Fresnel numbers > 100
- 8 mm flat-top beams for high output at fluences of 1–2 J/cm2
- RISTRA OPO was demonstrated using KTP, KTA and BBO crystals with 0.5-um and 1-um pumps
- US Patents: 6,647,034; 6,647,033; 6,775,054

- Details: JOSA **B** 19, 1801–1814 (2002)

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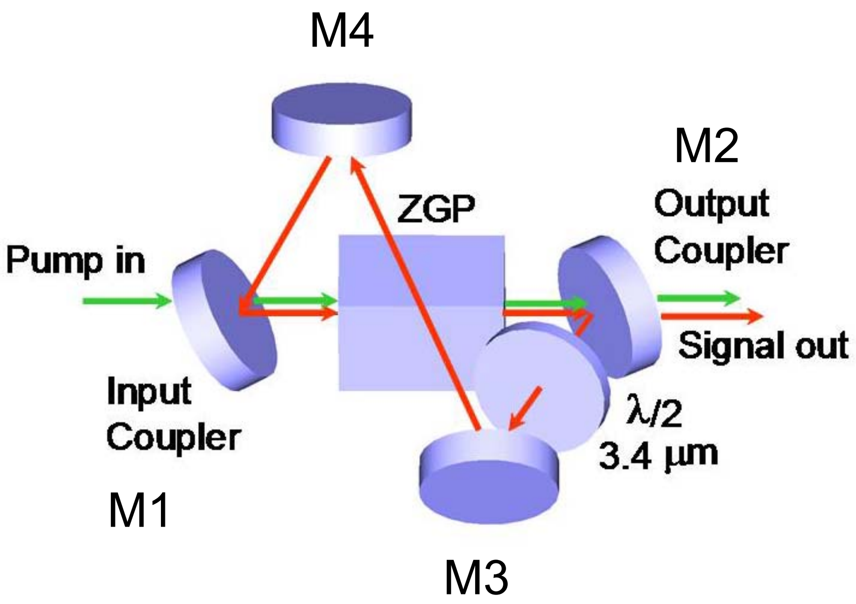
ZGP RISTRA OPO



- All mirrors are flat
- All mirrors – HT at idler
- M1, M3, M4 – HR at signal/HT at pump
- M2 – OC for signal

One-crystal RISTRA OPO:

- Advantages:
  - Simple design
  - λ/2 plate sees no idler light – can be fabricated from sapphire
- Modeling conditions:
  - TEMoo pump beam
  - 5 mm and 10 mm crystal lengths
  - Various output couplers

- Details: Opt. Express 15, 14404–14413 (2007)

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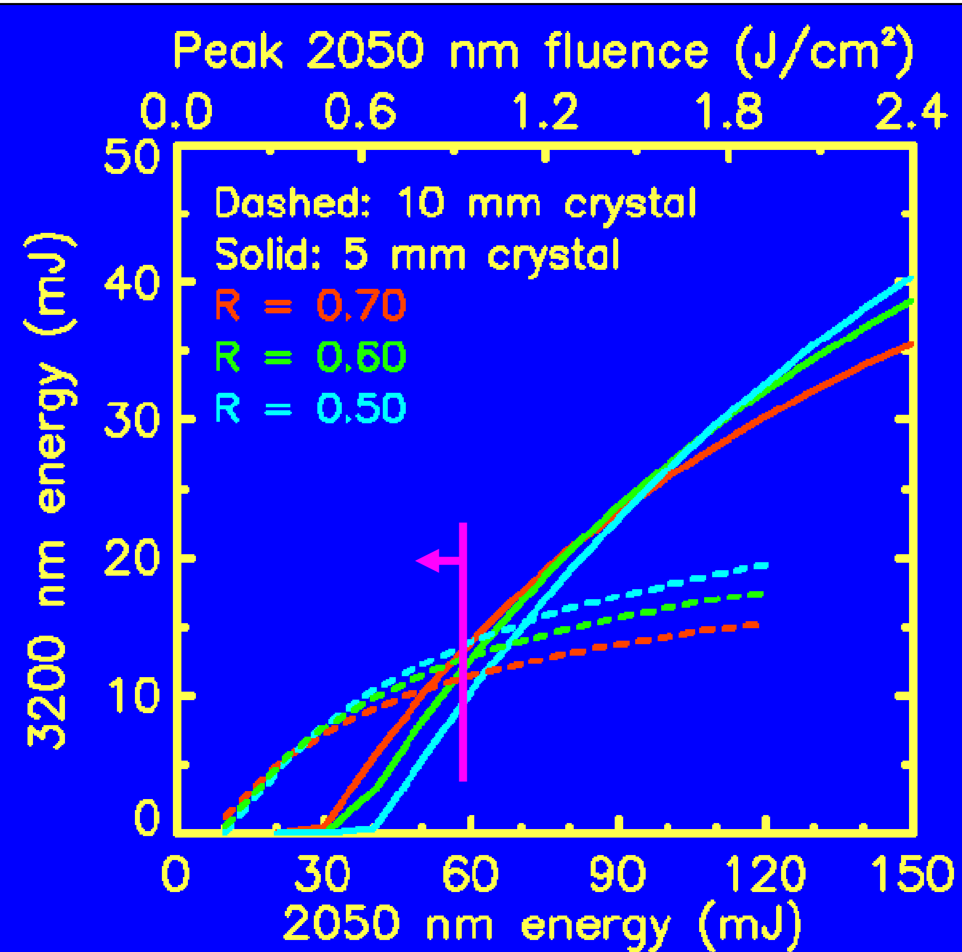
ZGP RISTRA - numerical model

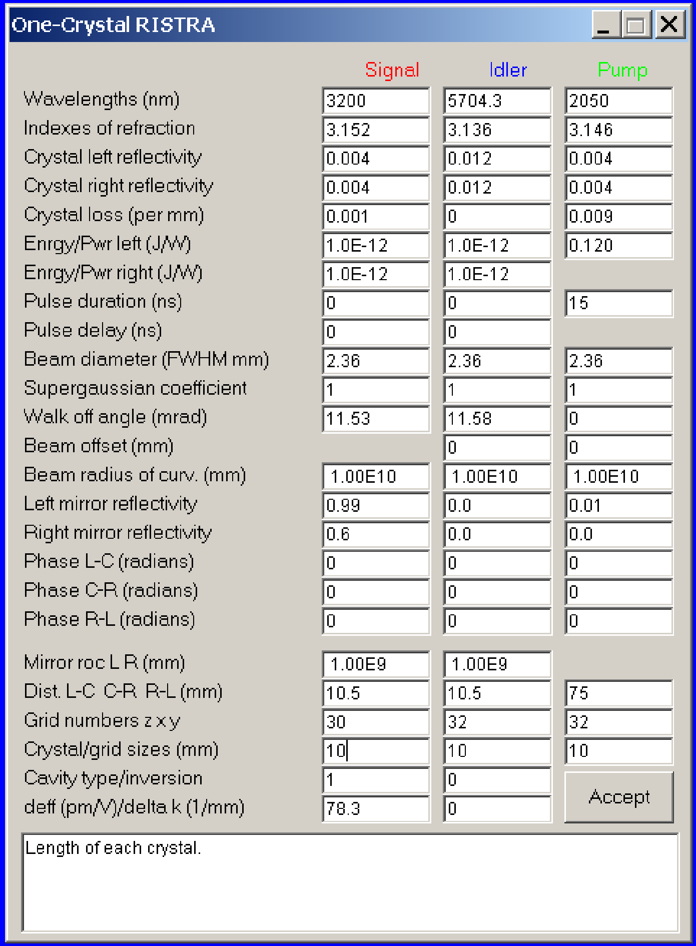
- The RISTRA OPO codes are derived from 2D-OPO-LP in SNLO

- The RISTRA code includes:
  - 2D spatial profiles
  - Birefringent walkoff and diffraction
  - Image rotation in RISTRA geometry
  - Arbitrary pump fields: user inputs spatial fluence profile and phase. Pump temporal profile is Gaussian
  - Single frequency pump, signal, and idler fields

- The RISTRA codes do not include:
  - Broadband pump or broadband oscillation. A 3D calculation for the RISTRA cavity requires powerful computing capabilities
  - Start up from noise. (Oscillation *does not* start from quantum fluctuations in the signal and idler fields. To mimic the strength of the fields at start up, we injection seed the cavity with approximately one photon.)
  - Absorptive heating in nonlinear crystals or other intra-cavity optics.. (It's essentially impossible to include heat flow in the model in a general way).

One-crystal & Gaussian pump profile




One-Crystal RISTRA

	Signal	Idler	Pump
Wavelengths (nm)	3200	5704.3	2050
Indexes of refraction	3.152	3.136	3.146
Crystal left reflectivity	0.004	0.012	0.004
Crystal right reflectivity	0.004	0.012	0.004
Crystal loss (per mm)	0.001	0	0.009
Enrgy/Pwr left (J/W)	1.0E-12	1.0E-12	0.120
Enrgy/Pwr right (J/W)	1.0E-12	1.0E-12	
Pulse duration (ns)	0	0	15
Pulse delay (ns)	0	0	
Beam diameter (FWHM mm)	2.36	2.36	2.36
Supergaussian coefficient	1	1	1
Walk off angle (mrad)	11.53	11.58	0
Beam offset (mm)		0	0
Beam radius of curv. (mm)	1.00E10	1.00E10	1.00E10
Left mirror reflectivity	0.99	0.0	0.01
Right mirror reflectivity	0.6	0.0	0.0
Phase L-C (radians)	0	0	0
Phase C-R (radians)	0	0	0
Phase R-L (radians)	0	0	0
Mirror roc L R (mm)	1.00E9	1.00E9	
Dist. L-C C-R R-L (mm)	10.5	10.5	75
Grid numbers z x y	30	32	32
Crystal/grid sizes (mm)	10	10	10
Cavity type/inversion	1	0	Accept
deff (pm/V)/delta k (1/mm)	78.3	0	

Length of each crystal.

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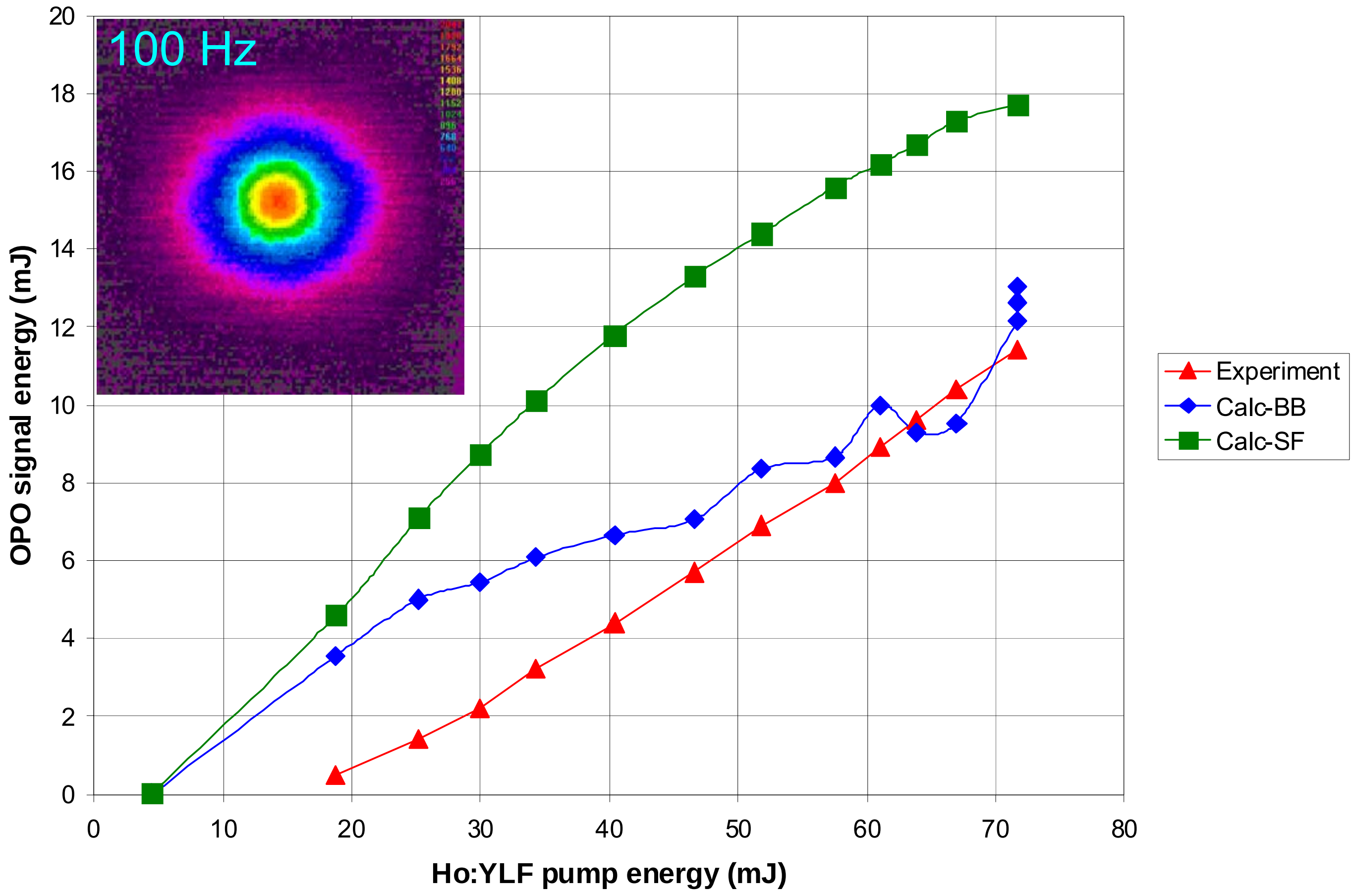
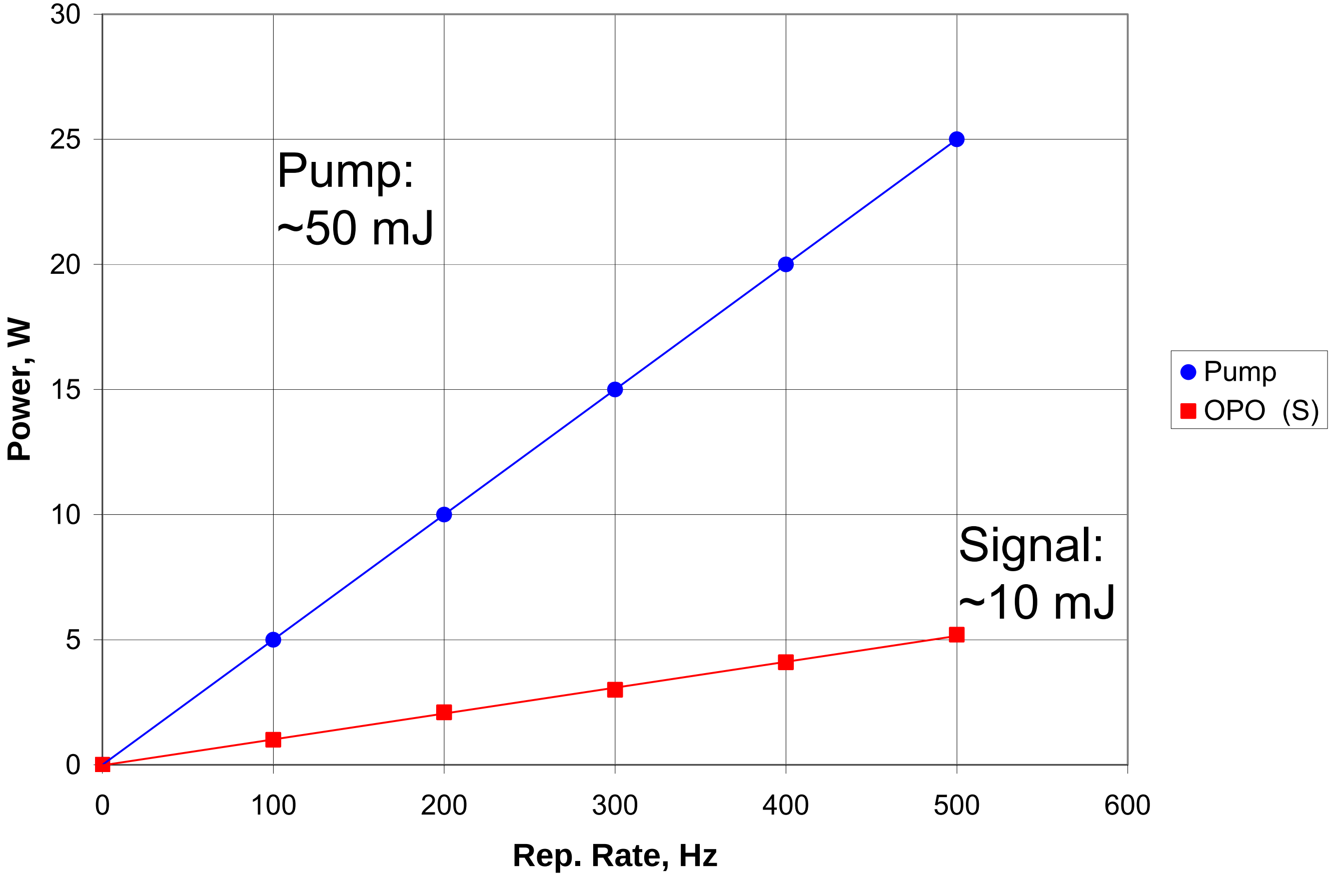
ZGP RISTRA – signal wave

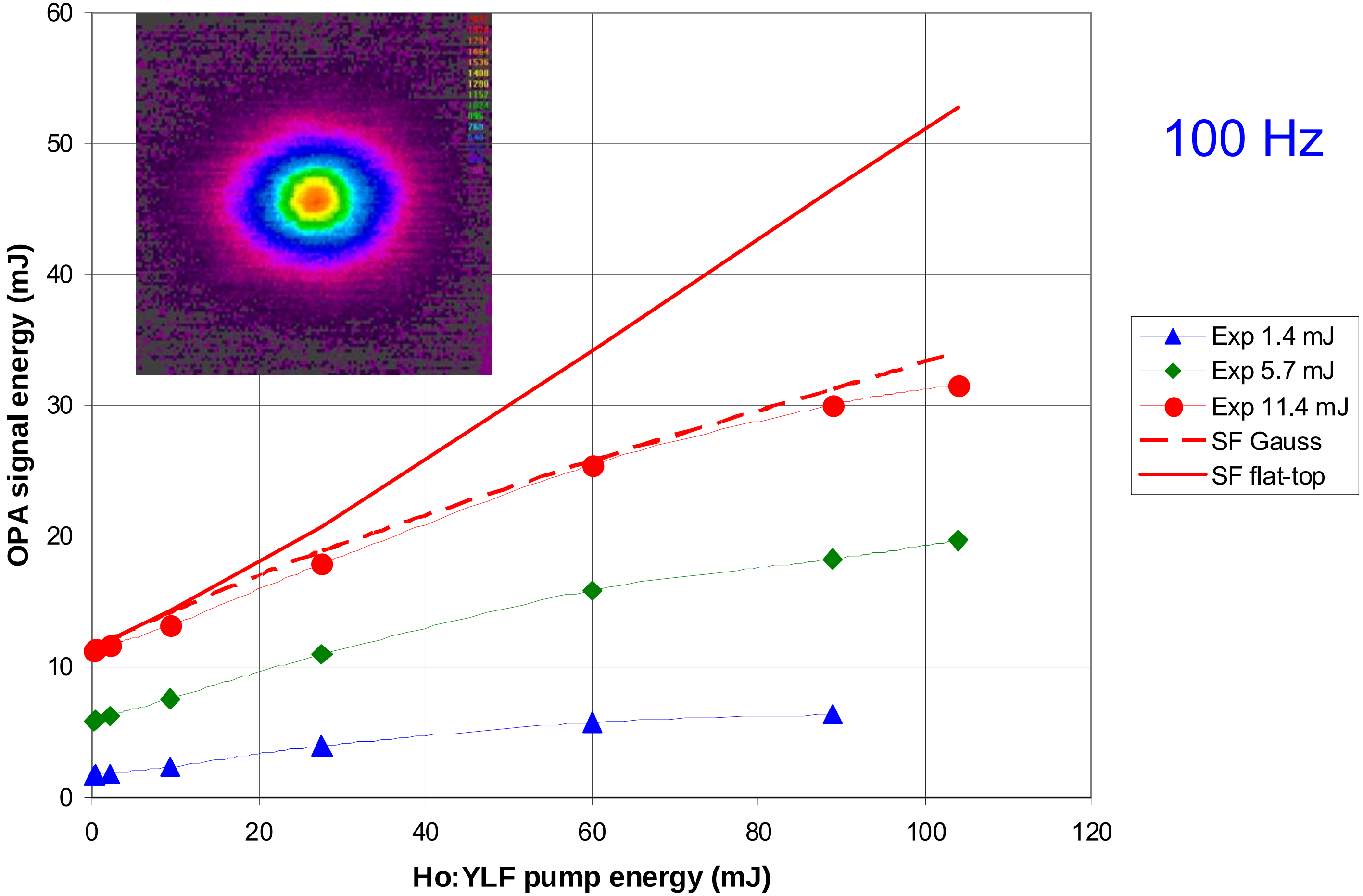


λ	***3.4 um***
Δλ	***< 40 nm***
τ	***~12 ns***
Pump beam ($1/e^2$)	***~ 4 .0 mm***
Energy Density (Peak)	***1 J/cm2***

ZGP RISTRA – various repetition rates



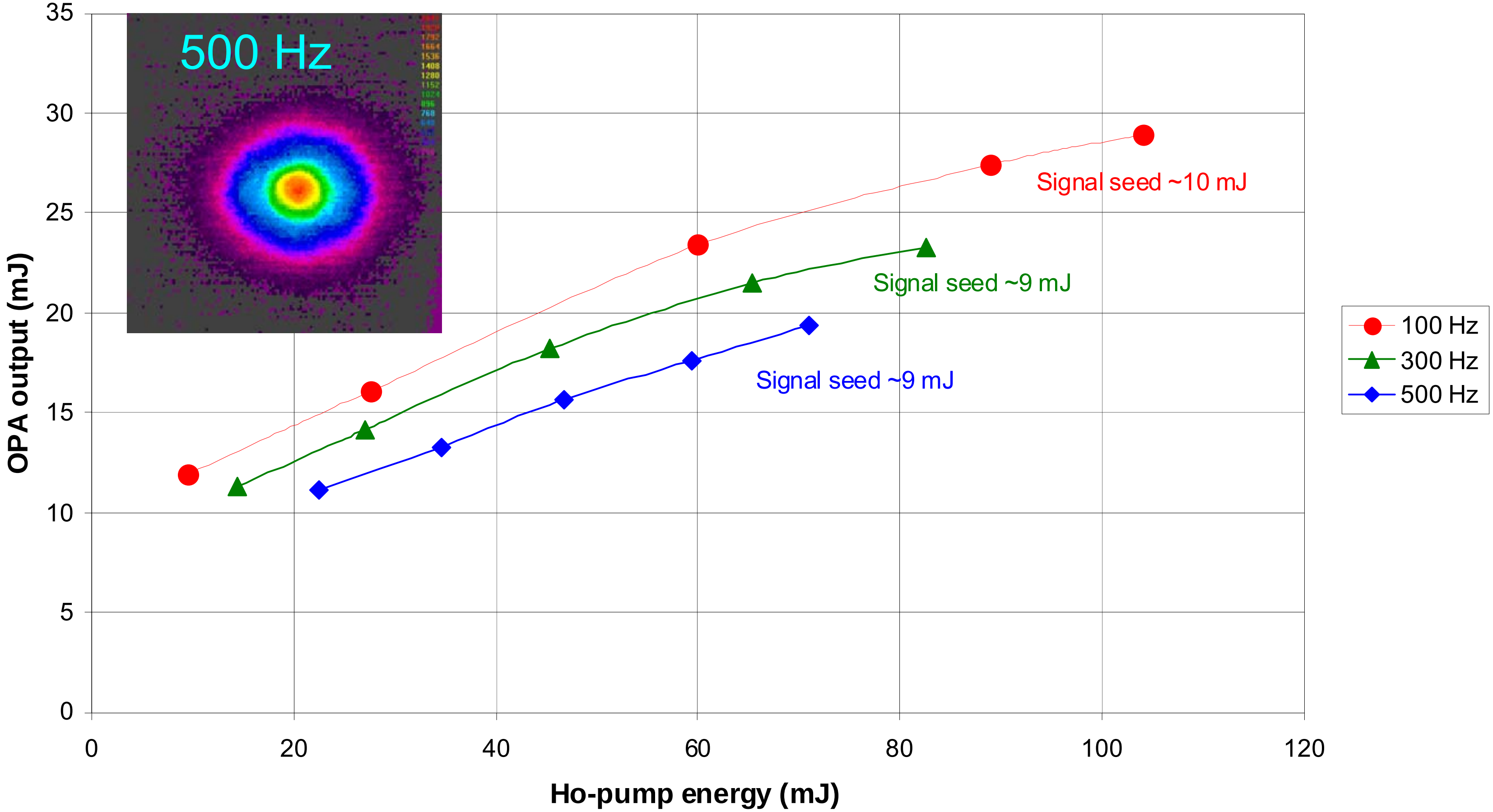
ZGP OPA vs seed energy



100 Hz

Pump beam (1/e²)	*4.5-5.0 mm*
Energy Density (Peak)	*~1 J/cm2*

ZGP OPA - various repetition rates



OPA pump beam size remains optimized for max pulse energy of ~100 mJ (100 Hz)

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Conclusions

Using a 2-um Ho:YLF MOPA pumped with cw-Tm-fiber-lasers:

- Repetition rates in wide range (Hz to kHz), particularly at 100-500 Hz
- High beam quality (TEM_{00} beam)
- Energy per pulse > 150 mJ

We demonstrated ZGP OPO/OPA :

- > 10 mJ output energy (signal only) from ZGP RISTRA OPO
- > 30 mJ output from ZGP OPA
- 100-500 Hz repetition rate
- Beam quality close to diffraction limited

We would like to thank:

- All our vendors who provided crystals, optics and coatings

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