SAND2010-3152C

Dual Wavelength Pumped 1.550μm High Power Optical Parametric Chirped-Pulsed Amplifier System

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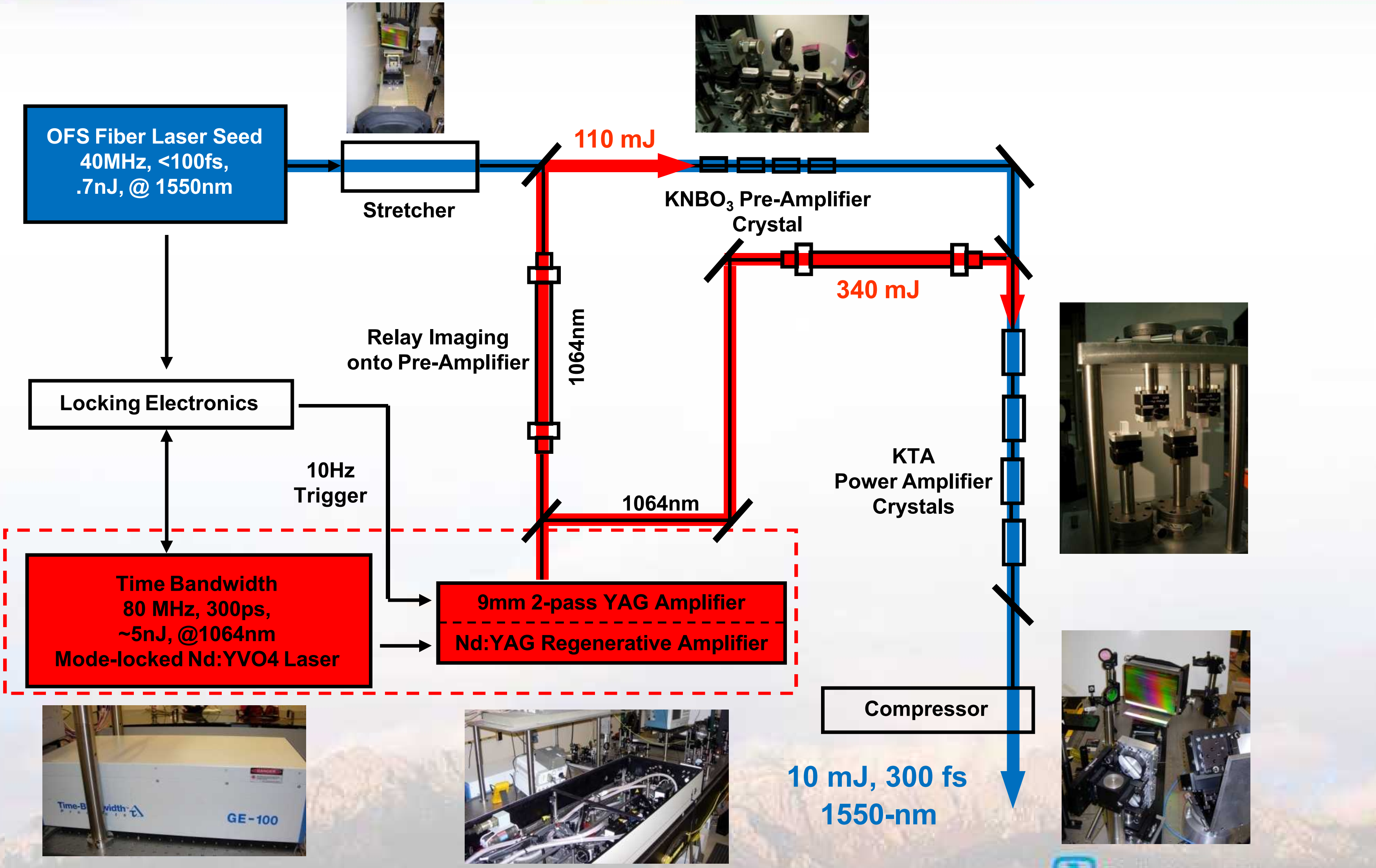
Motivation

- **Objective:**
  - Develop high power ultra-short pulse tunable laser (USPL) sources in the NIR/MWIR.
- **Key Challenges:**
  - Standard CPA methods do not work well in this regime due to lack of conventional laser gain media in these spectral regions.
  - COTS high power technology exists only at 800nm.
  - OPCPA Technology is less mature (TRL 2-3).

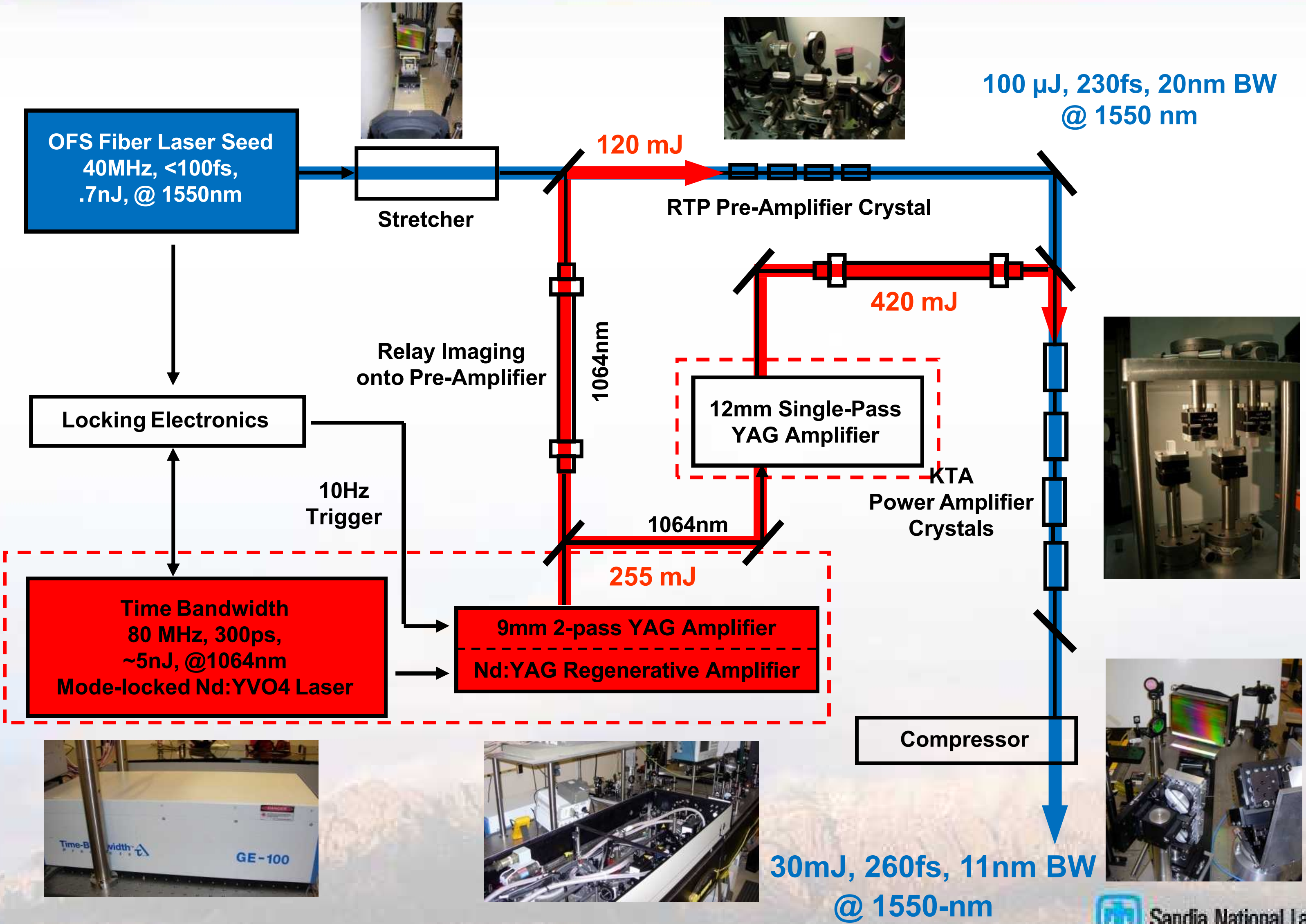
WHY OPCPA?

- **Advantages to OPCPA:**
  - Can support large bandwidths
  - Tunable over large frequency range
  - Large single-pass gain is possible
  - Can result in undistorted signal phase
  - Reduced thermal effects in amplifier crystal
- **Disadvantages:**
  - Requires phase matching
  - Requires temporal alignment
  - Gain dependent on intensity

Sandia Gen 1 OPCPA System



Sandia Gen 2 OPCPA System



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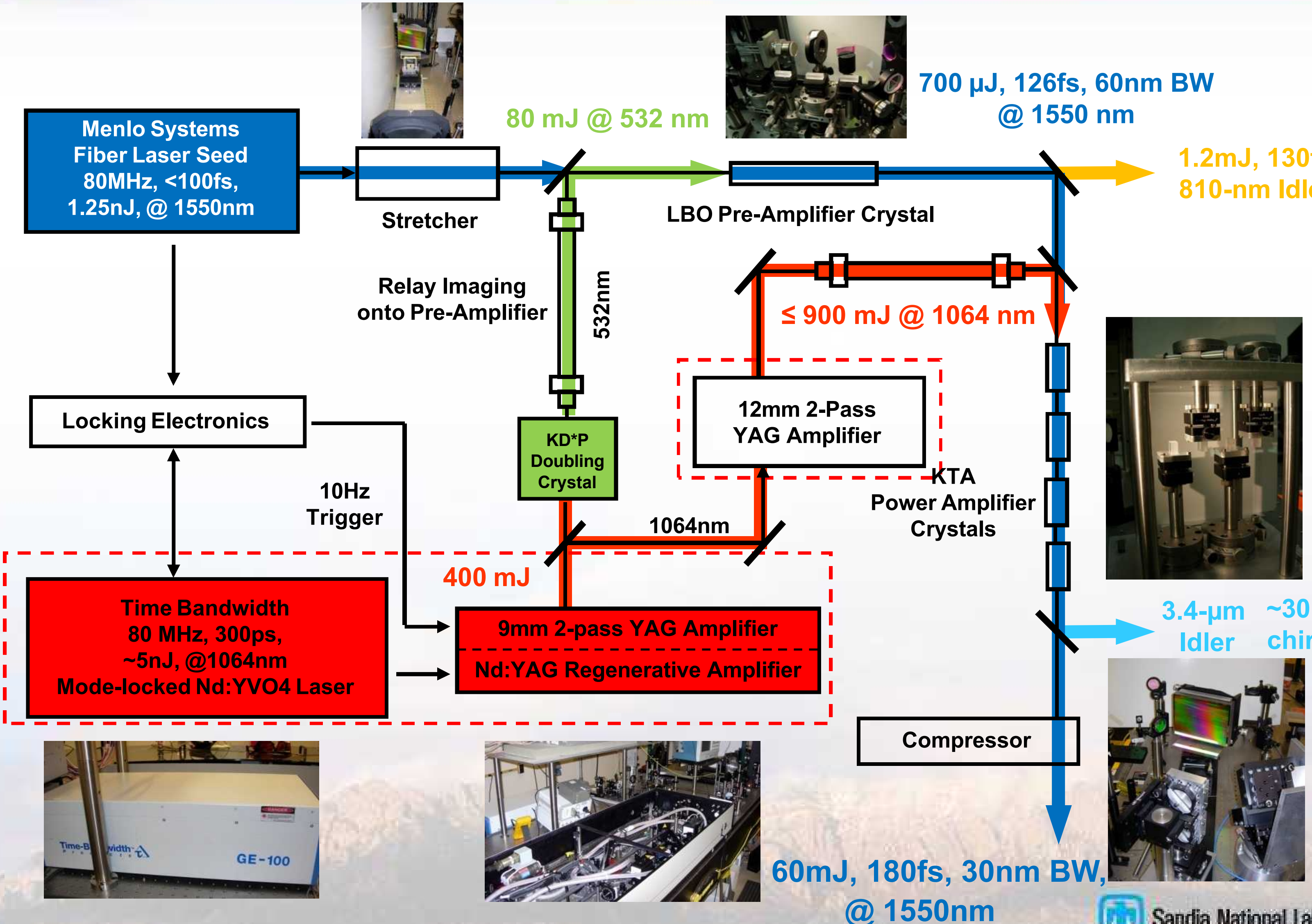
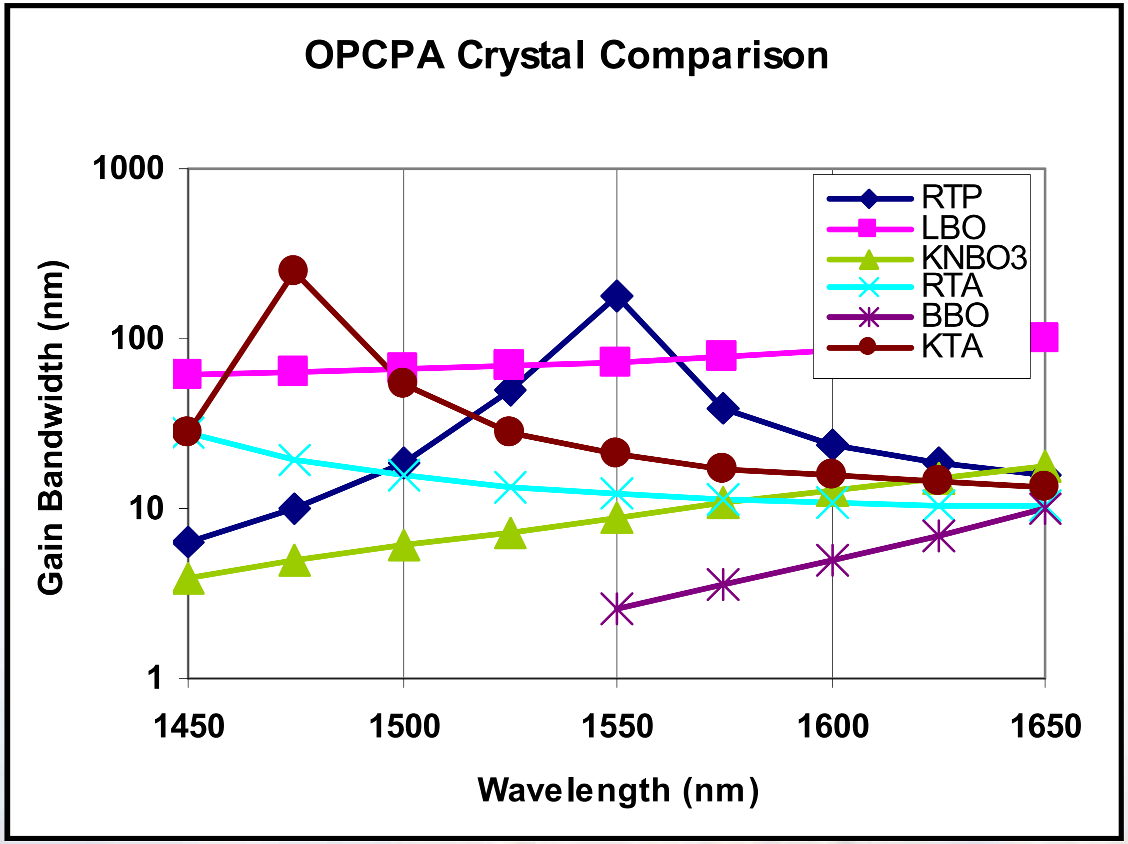
Sandia Gen 3 OPCPA System



Non-linear crystal comparison



<u>Damage threshold</u>

LBO – 25 J/cm^2

KTA – 15 J/cm^2

RTP – 15 J/cm^2

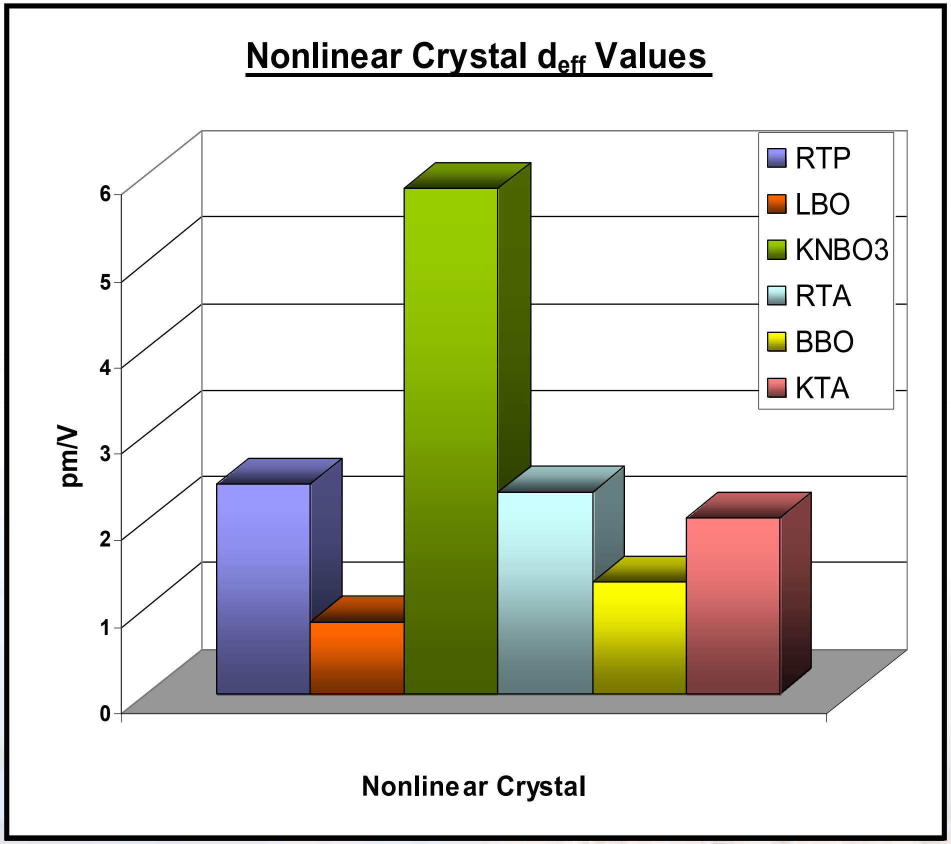
RTA – 15 J/cm^2

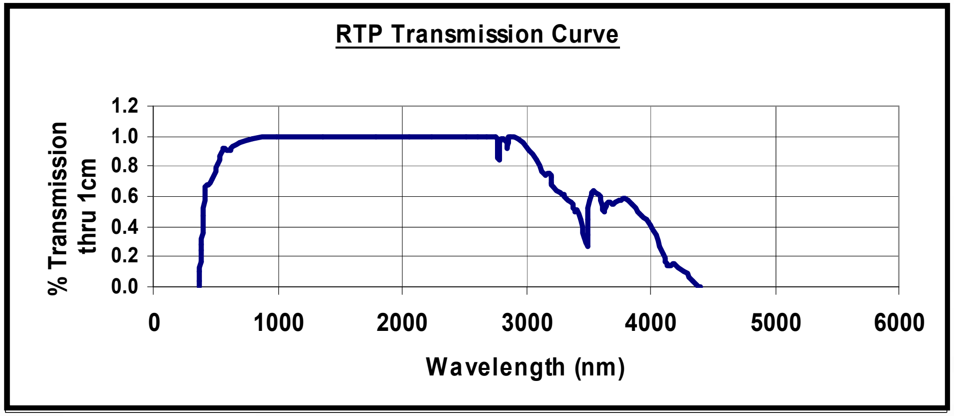
BBO – 13 J/cm^2

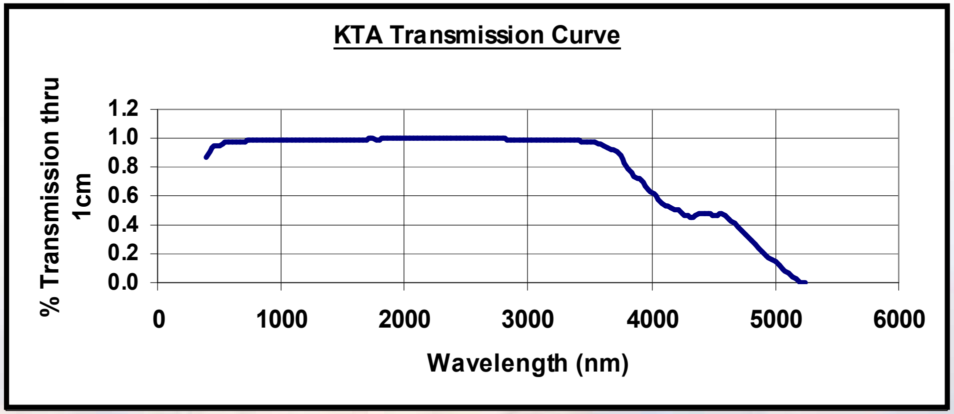
$KNBO_3$ - 1.7 J/cm^2

* Results from SNLO nonlinear optics code available from A.V. Smith, AS-Photonics

Non-linear crystal comparison







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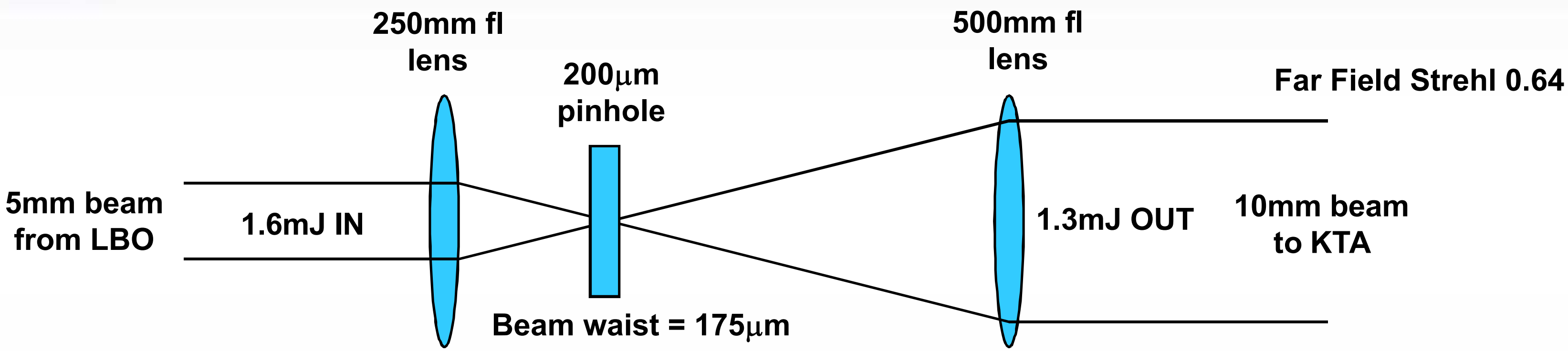
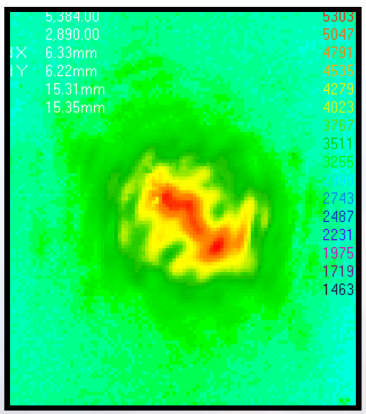
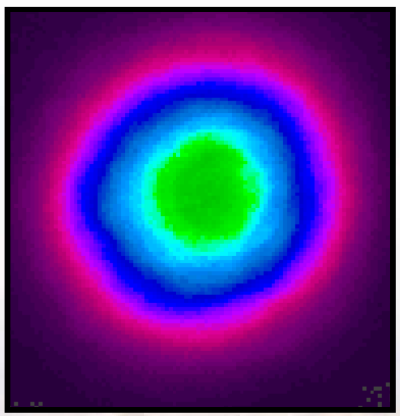
Interstage Spatial/OPG Filter



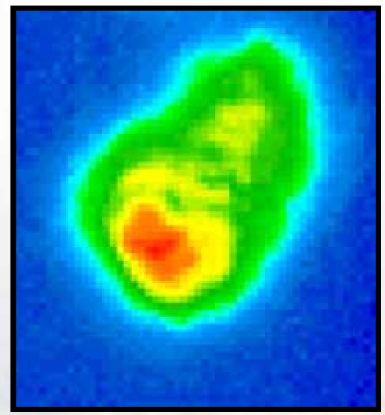
LBO Pre Amplifier Output	KTA Amplifier Output
Pre SF = 1.6mJ uncomp. / Post SF = 1.3mJ uncomp.	Pre SF = 35mJ comp. / Post SF = 45mJ comp.



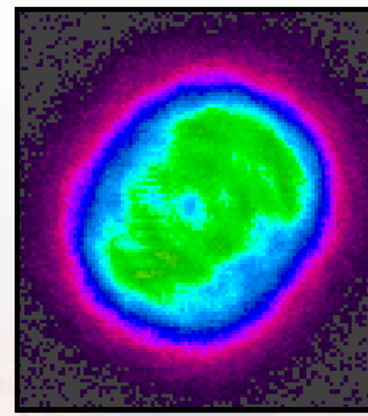
1st stage amplified beam before SF installed



1st stage amplified beam after SF installed

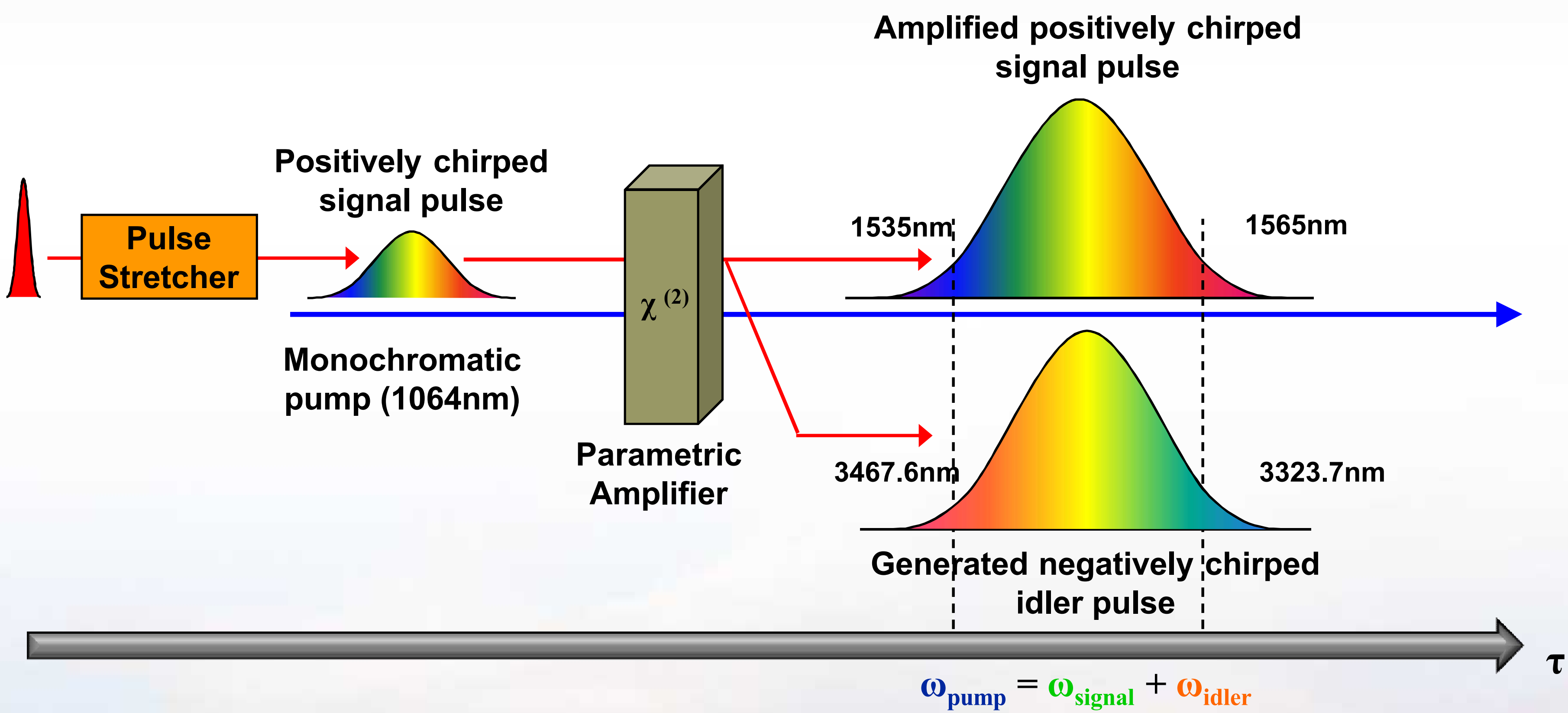


2nd stage amplified beam before SF installed



2nd stage amplified beam after SF installed

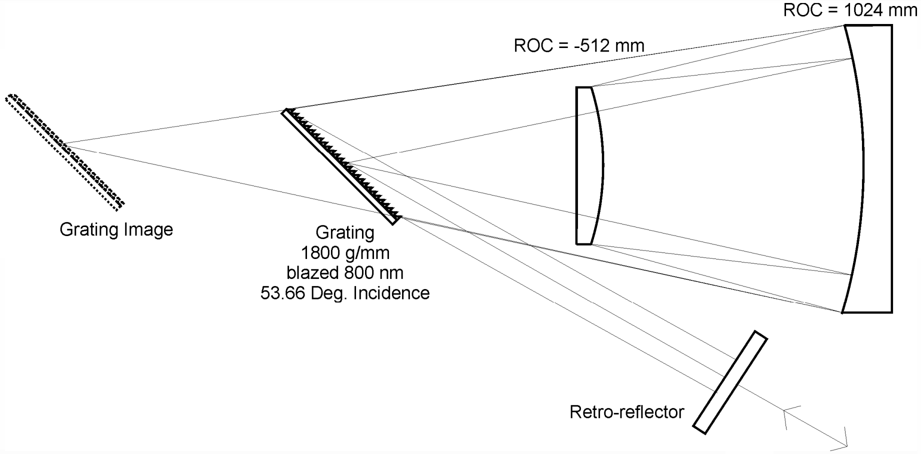
Signal/Idler Compression



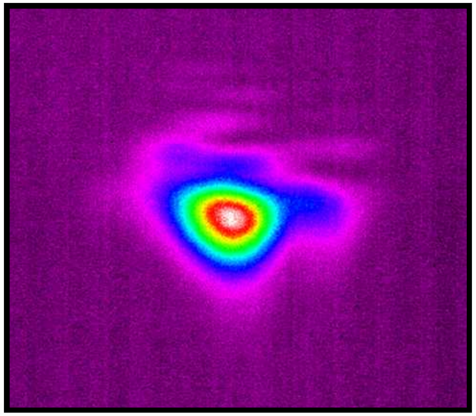
<u>Ex.</u> $\omega(1064nm) = 2.8176+^{14}$; $\omega(1535nm) = 1.953+^{14}$; $2.8176+^{14} - 1.953+^{14} = 8.646+^{13}$; $C/\ 8.646+^{13} = 3467.4nm$

$\omega(1064nm) = 2.8176+^{14}$; $\omega(1565nm) = 1.9156+^{14}$; $2.8176+^{14} - 1.9156+^{14} = 9.02+^{13}$; $C/\ 9.02+^{13} = 3323.7nm$

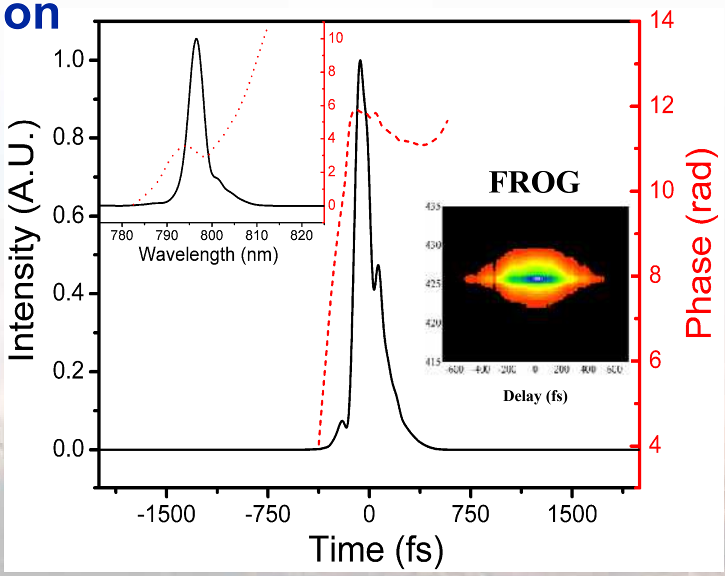
800-nm Idler Pulse from Pre-Amplifier



Beam Profile

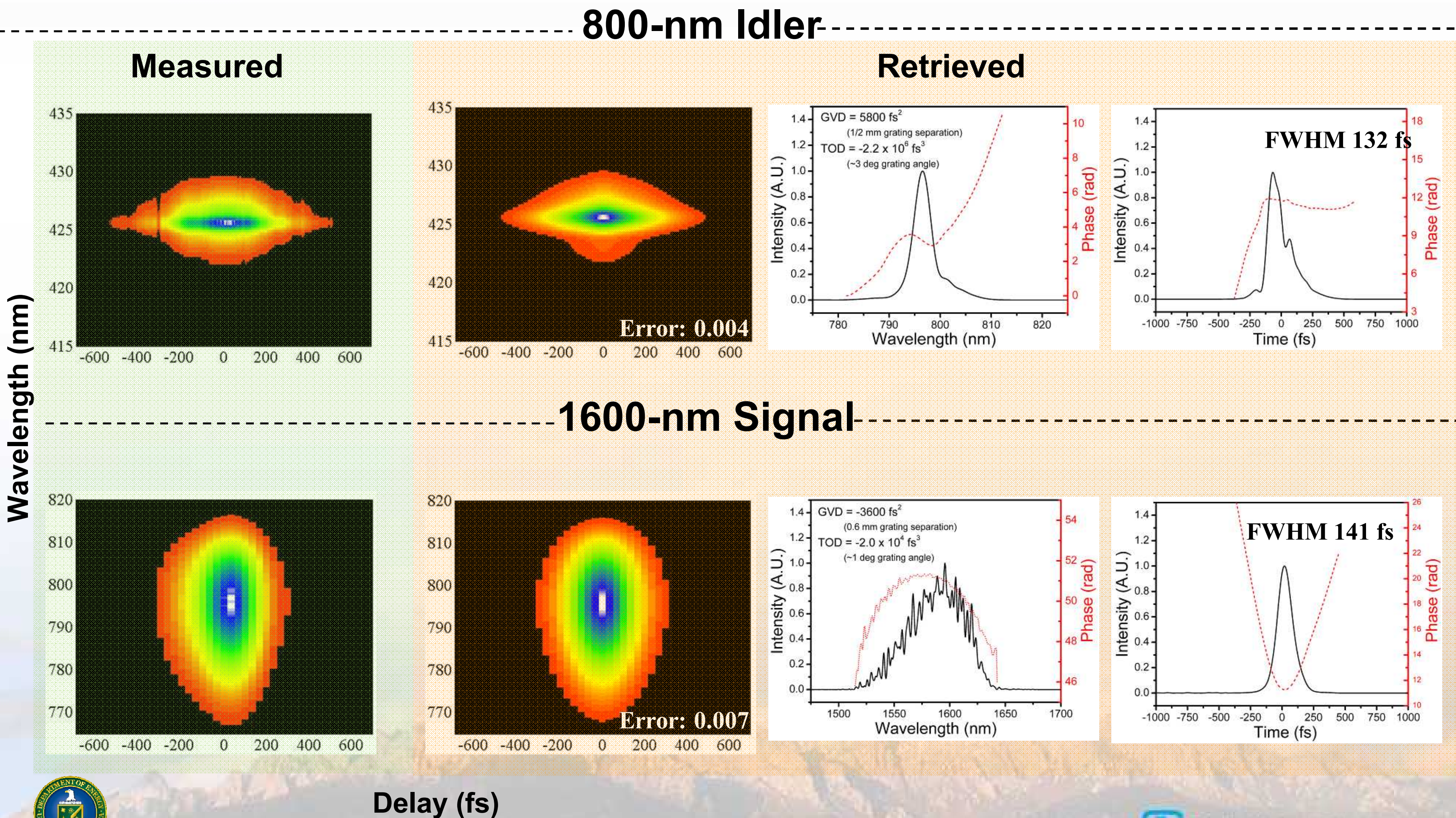


- **1.2-mJ energy, ~130-fs duration**
- **75% beyond transform limit**
- **~7.5 GW peak power**

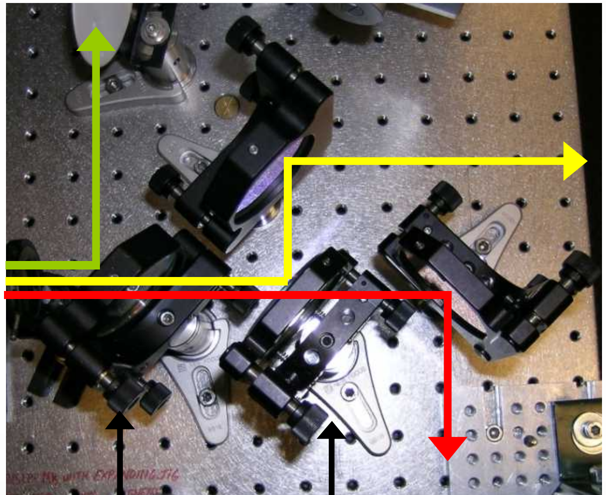


Continuum in Glass

Simultaneous Signal/Idler Compression from Pre-amplifier



3.4-µm Idler Pulse from Power Amplifier



Optic #1 Optic #2

IR Separator Installation

Optic #1
R > 99% @ 1064nm (S)

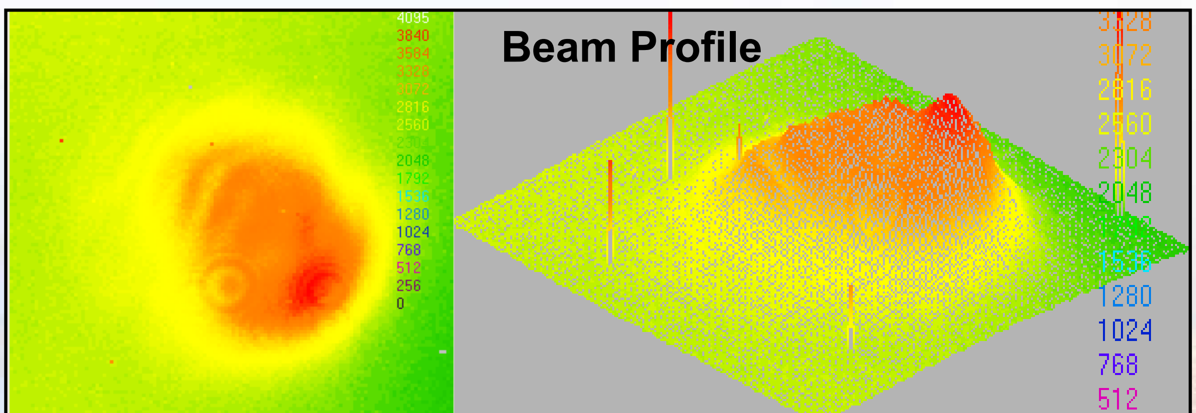
T > 99% @ 1520-1580nm (P)
& 3300-3500nm (S)

Optic #2
R > 99% @ 1520-1580nm (P)

T > 99% @ 3300-3500nm (S)

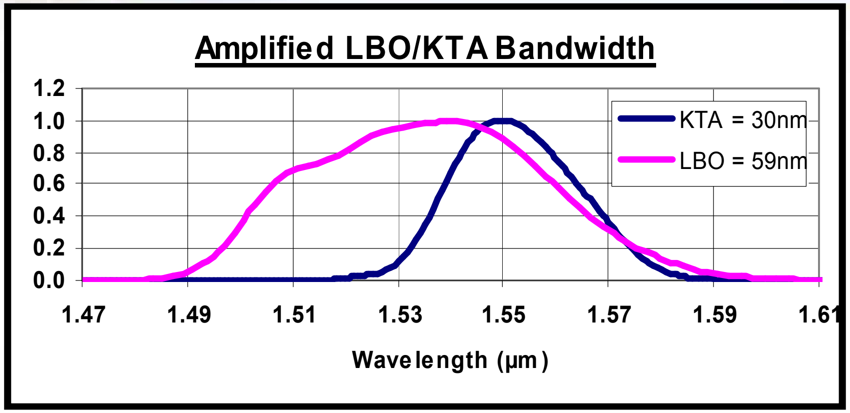
- 25mJ before compression (measured)
- Expect ~50% compressor efficiency

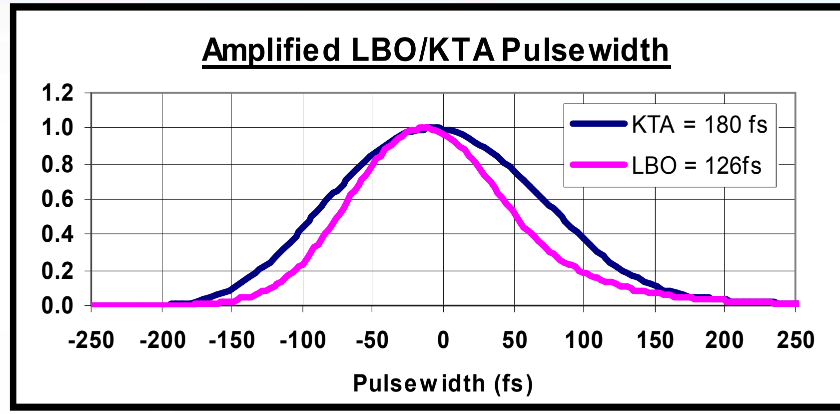
  12 mJ @ 3.4µm (210fs)
- $P_{estimated}$ ~ 57 GW (up from 30GW)

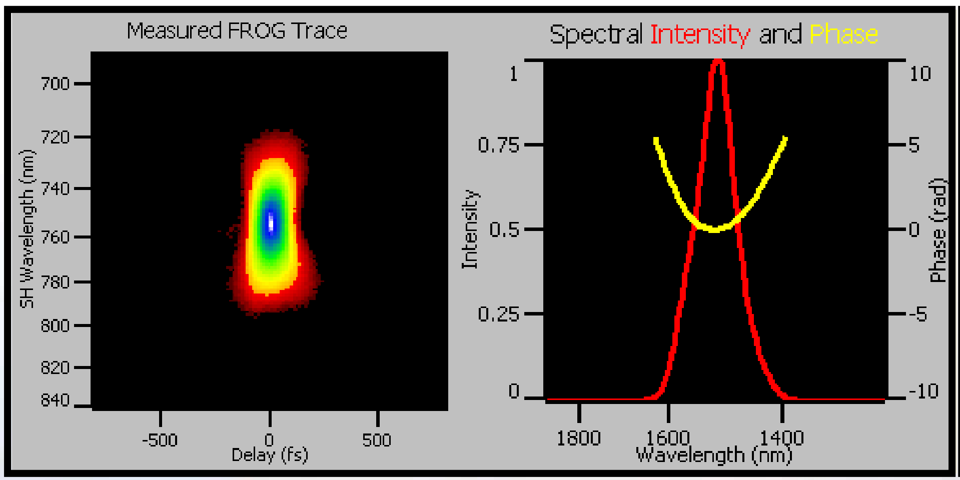


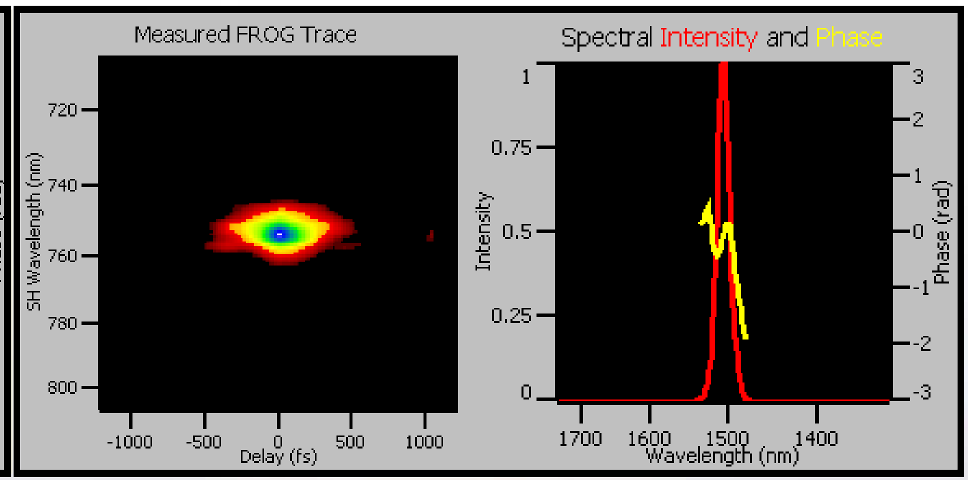
Idler Spectrum

1550-nm Signal from Both Amplifier Stages









- Ist Stage Peak Power: 7.5 GW
- Energy: 0.7 mJ
- Pulse Width: 126 fs (previous 145fs)
- Amplified Bandwidth: 59 nm

- System Peak Power: 333 GW (previous 160GW)
- Energy: 60 mJ (previous 35mJ)
- Pulse Width: 180 fs (previous 220fs)
- Amplified Bandwidth: 30nm

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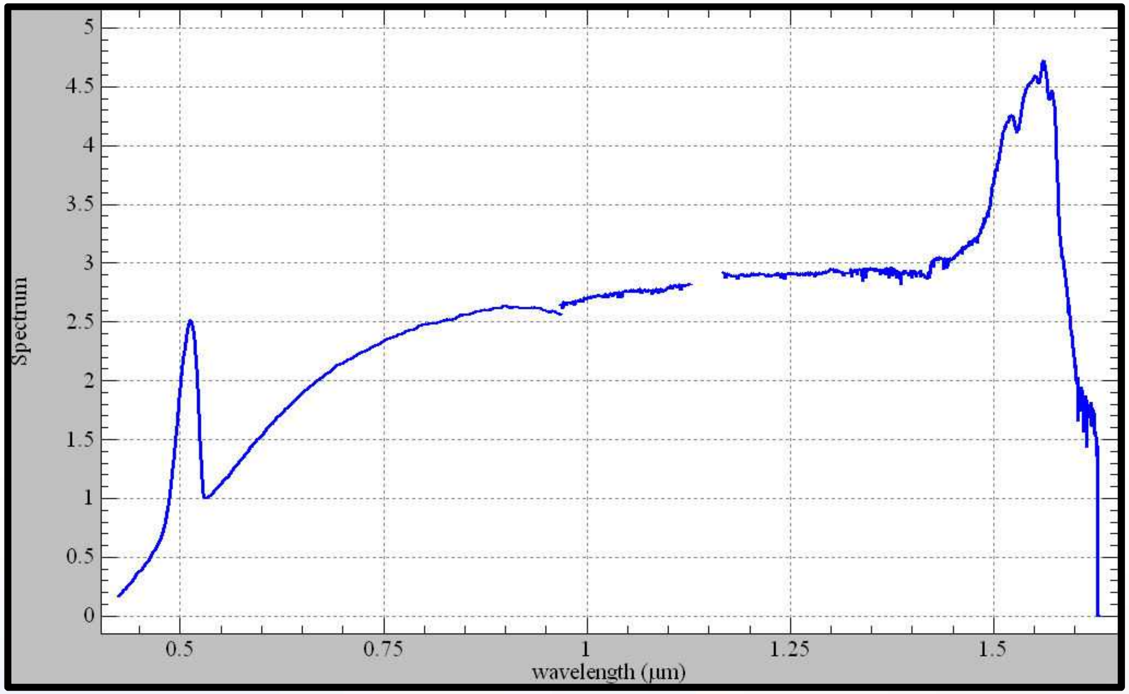
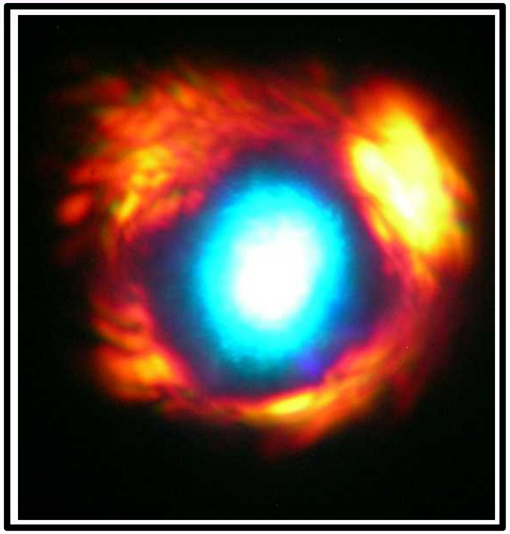
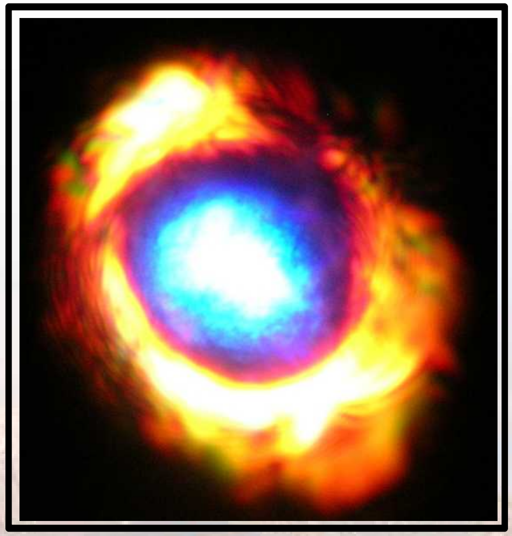
Continuum and Harmonic Generation in Air







45mJ, 180fs
Focused with 30cm lens
Conversion efficiencies to THG (517nm) >1%
Possible nonlinear Raleigh Beacon
Launches NIR (atmospheric propagation more favorable)
Generates green light at target.

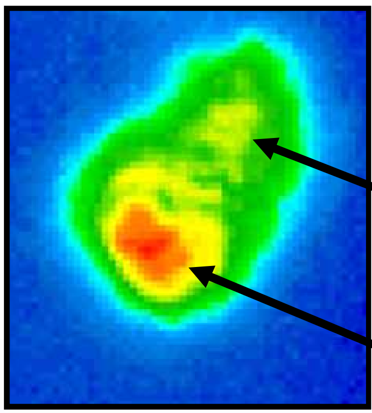
Summary

- OPCPA system constructed to generate unprecedented power (>330 GW) at the key wavelength of 1550nm.
- Significant improvement in gain bandwidth, pulsewidth, and output energy (thus peak power) from previous Sandia OPCPA designs.
- High power radiation is also generated at the very useful wavelengths of 810nm and 3393nm in the OPCPA process.
- Improved beam quality (focusability) by a factor of ~3.
- First demonstrated simultaneous compression of signal and idler beams from an OPCPA.
- First demonstrated laser filamentation at 1.6μm.

*Acknowledgements : Funding provided under CRADA with Lockheed Martin Missile and Fire Control (Orlando, FL).

Beam Quality Issues

Previous beam quality

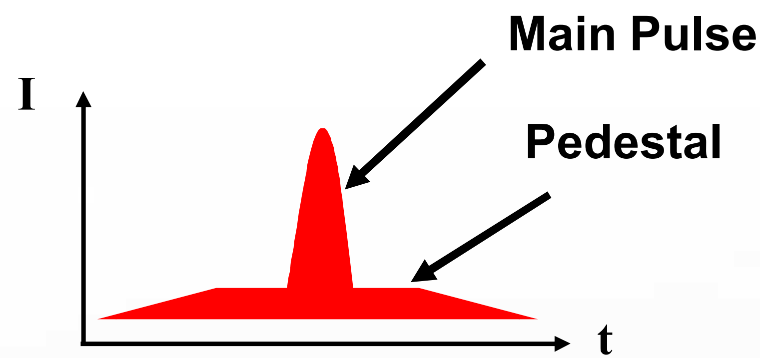


Focus is several X diffraction limited

Beam or OPG?

Main Beam

Pulse Contrast



- Difficult to characterize beam
- What is the actual "intensity"?
- Hot spots in beam damage components
- Limit overall output energy

OPCPA Evolution

Gen 1 – $KNBO_3$ pre-amp + KTA power amp (>30GW)

- Final Output = >30mJ uncompressed/10mJ compressed, 300fs, 10nm BW

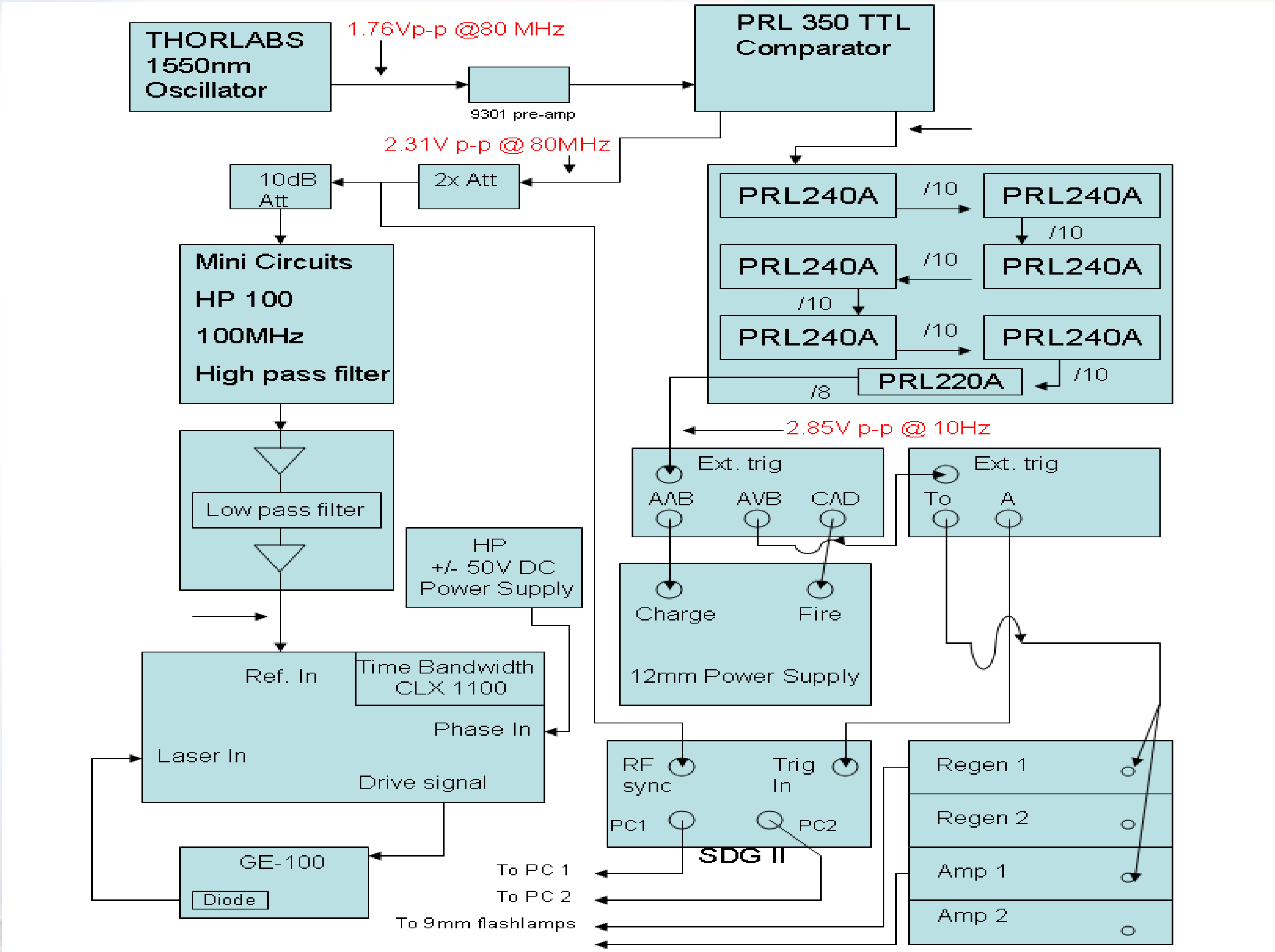
Gen 2 – RTP pre-amp + KTA power amp (100GW)

- 1st stage output = 100μJ, 230fs FWHM, 20nm
- 2nd stage output = 66mJ uncompressed/30mJ compressed, 260fs FWHM, 11nm

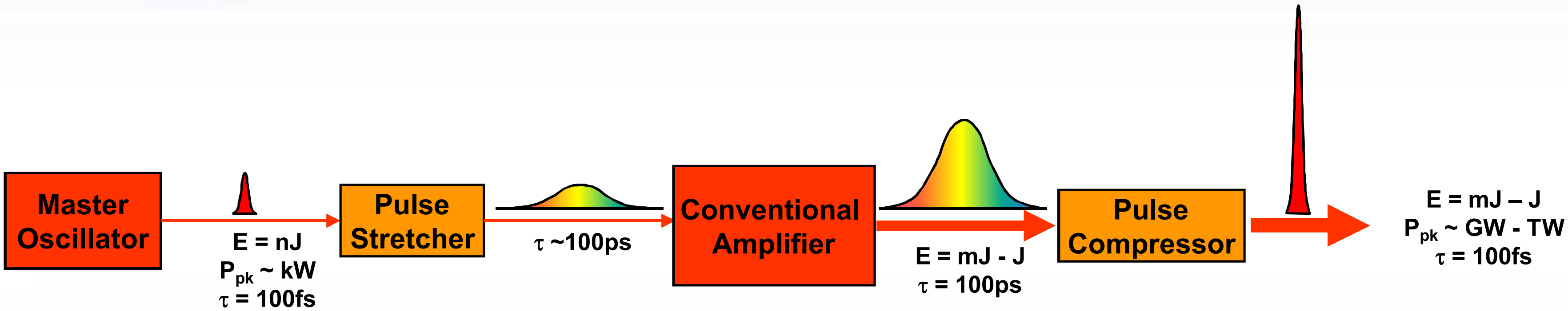
Gen 3 – LBO pre-amp + KTA power amp (>310GW)

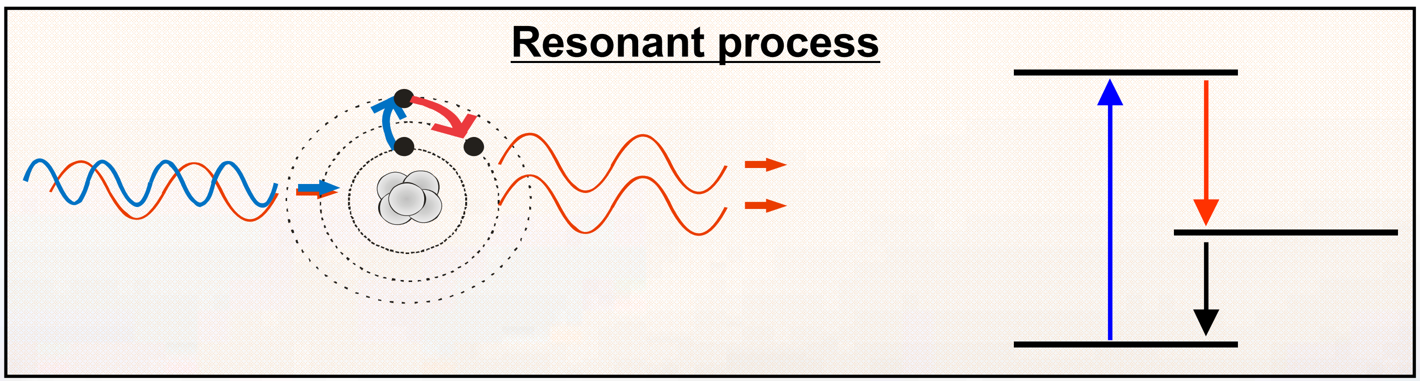
- 1st stage output = 700μJ, 126fs FWHM, 60nm BW
- 2nd stage output = 60mJ compressed, 180fs FWHM, 30nm

Menlo/Timing diagram slide?



Conventional Chirped Pulse Amplification (CPA)





Advantages

- Relatively simple setup
- Well-known physics

Disadvantages

- Finite lifetime and spectral bandwidth
- Wavelengths restricted to available laser gain media
- Gain limited by amplified spontaneous emission (ASE)
- Prone to parasitic losses such as thermal recombination

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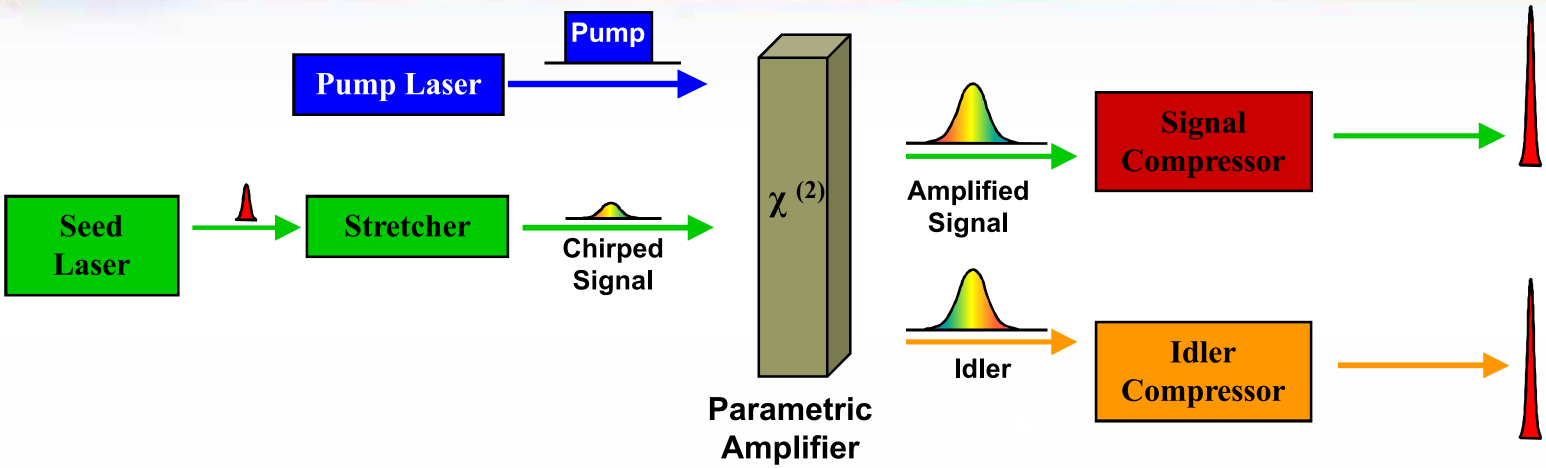
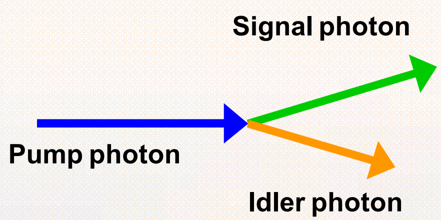
Optical Parametric Chirped Pulse Amplification (OPCPA)

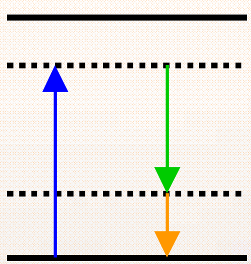


Virtual process



$$\omega_{pump} = \omega_{signal} + \omega_{idler}$$

$$\vec{k}_{pump} = \vec{k}_{signal} + \vec{k}_{idler}$$



Advantages

- Can support large bandwidths
- Tunable over large frequency range
- Large single-pass gain possible
- Reduced nonlinear effects (B-integral)
- Can result in undistorted signal phase

Disadvantages

- Gain dependent on intensity (need pulses)
- Requires temporal alignment
- Requires phase matching

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Transform limited bandwidth for Gaussian pulses

Pulsewidth	Center λ	Bandwidth if pulse is transform limited (nm)
2.5000E-14	1.5500E-06	141.0442
5.9000E-14	1.5500E-06	59.7645
1.1753E-13	1.5500E-06	30.0018
1.8000E-13	1.5500E-06	19.5895
3.5250E-14	1.5500E-06	100.0314