Transforming the Idler to Seed Raman Amplification

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Summary

- An efficient Raman amplifier requires an energetic seed that matches the resonance condition

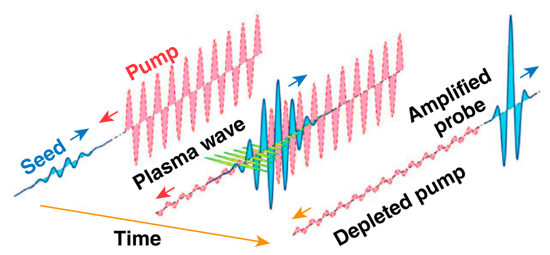
$$\omega_{pump} = \omega_{seed} + \omega_{plasma}$$

- A system is proposed for providing a Raman amplifier seed pulse using an optical parametric chirped-pulse–amplification (OPCPA) system—OPAL (optical parametric amplifier line)
- Two unique subsystems are needed to transform the idler for use in a Raman amplification experiment
  - grism stretcher
  - angular dispersion compensator

E26233

Motivation

Raman amplification transfers energy from a long-pulse pump laser to a short-pulse seed laser at the resonance condition



- A Raman amplifier has the potential to bypass current limits on peak laser intensity
- The highest transfer of energy occurs when the resonance condition is met:

$$\omega_{pump} = \omega_{seed} + \omega_{plasma}$$

  - pump: 1053 nm (Nd:glass)
  - plasma: $n_e = 10^{19}\ cm^{-3}$
  - Seed: 1110 to 1230 nm (OPCPA)

E25021b

Motivation

An efficient amplifier requires large electron plasma waves and a long seed pulse

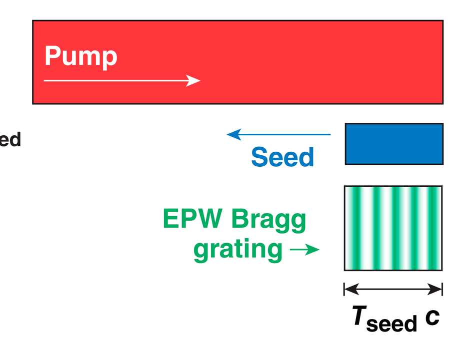
- The analytic solution to the coupled-wave equations for pump depletion is an attractor solution with the form

$$a_{seed} T_{seed} \sqrt{\omega_{pump}\omega_{plasma}} \simeq 5 \quad \text{Pump-depletion solution}$$

- This can be understood by modeling the plasma wave as a volume Bragg grating

efficiency $\propto \Delta n_e L_{seed} \propto \sqrt{I_{seed}}\, T_{seed}$

  - the electron plasma wave amplitude is proportional to the seed electric field

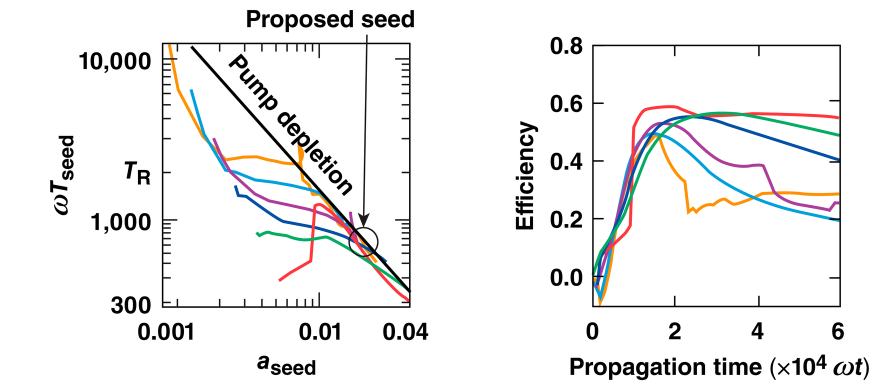


E26234

EPW: electron plasma wave

Motivation

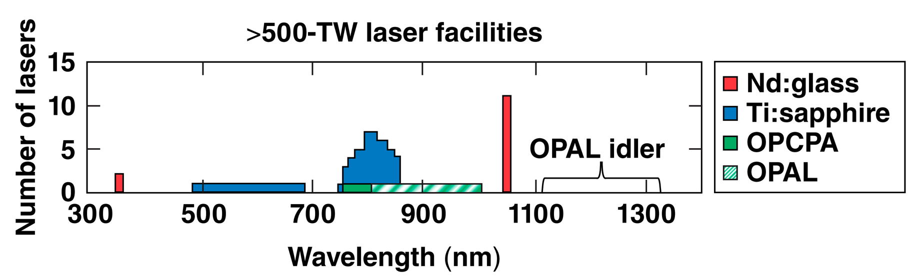
Efficiency is capped for seed pulses longer than the Raman growth rate



Immediate entrance into the pump depletion regime requires an energetic seed.

E26235

The creation of an energetic and resonant seed is challenged by the availablity of high-power lasers at the resonance condition

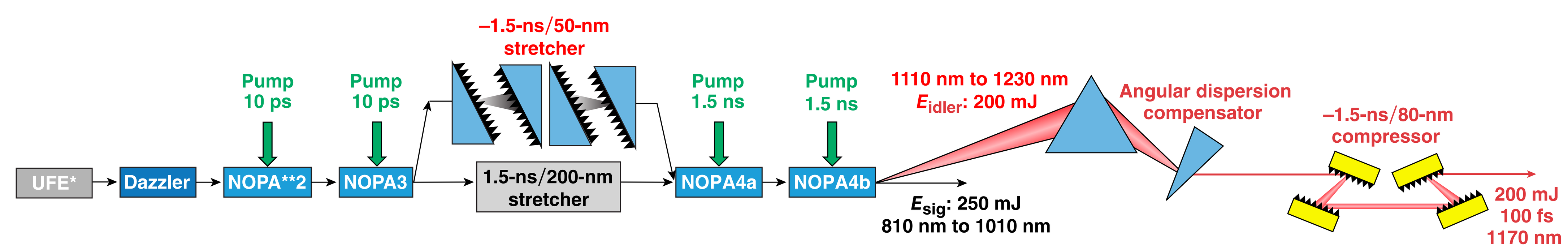


- The idler from an OPCPA system at LLE (OPAL) spans the region set by the resonance condition and a 1053-nm pump laser

OPCPA: optical parametric chirped-pulse amplification
OPAL: optical parametric amplifier
*C. Danson *et al.*, High Power Laser Science and Engineering 3, e3 (2015).

E26236

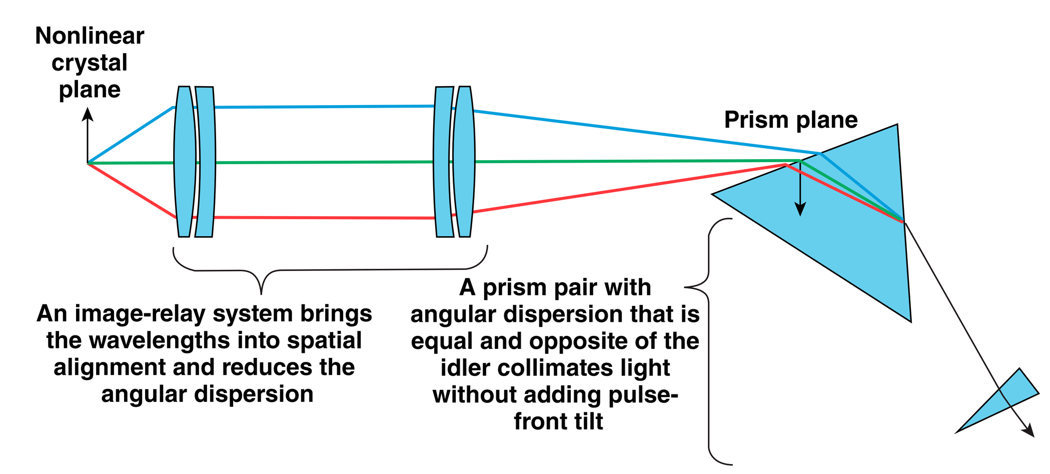
An energetic seed at the resonance condition can be obtained from the idler of an OPCPA system



*UFE: ultra-broadband front end
**NOPA: noncollinear optical parametric amplifier

E25020b

Angular dispersion is removed by imaging the idler onto a dispersive element



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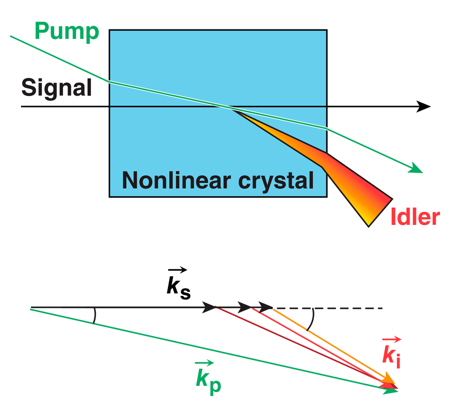
The idler is an existing byproduct of all OPCPA systems, but has two problems preventing its use as a high-fidelity laser

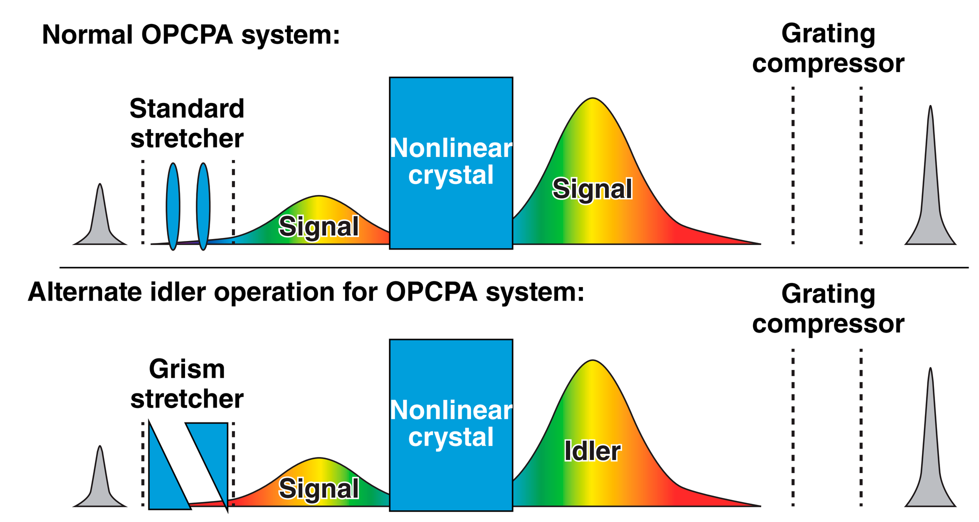


- Optical parametric amplification is a three-wave mixing process inside a nonlinear crystal
  - pump: narrowband, transfers energy to the signal and idler
  - signal: broadband, gains energy from the pump
  - idler: has equal energy and normalized bandwidth as the signal
- Conservation of energy and momentum produces an idler with
  - complicated phase relationship to the signal
  - angular dispersion

Complex spectral phase and angular dispersion make the idler a challenge to use as a high-fidelity laser.

E25023c

The complex phase reversal of the idler requires a stretcher with negative second-and third-order phase to use with a grating compressor

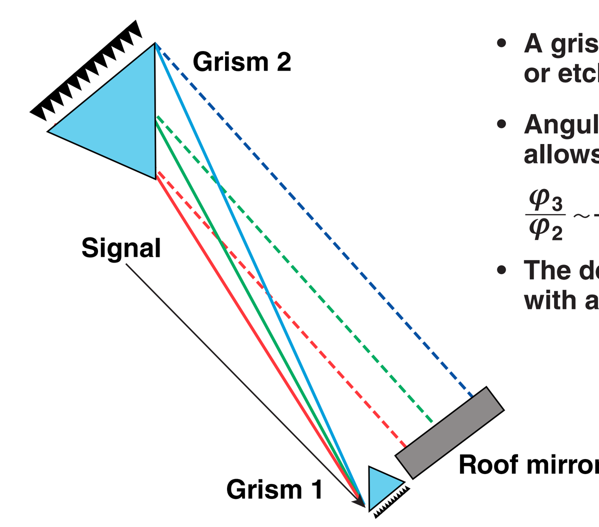


- The optical parametric amplifier (OPA) changes the chirp (second-order spectral phase) but not third-order spectral phase of the idler

		Stretcher	Amplified idler/ signal	Compressor	Compressed pulse
Normal operation	$\varphi^{(2)}(\omega)$	+	+	–	0
	$\varphi^{(3)}(\omega)$	–	–	+	0
Idler operation	$\varphi^{(2)}(\omega)$	–	+	–	0
	$\varphi^{(3)}(\omega)$	–	–	+	0
Explanation		Stretcher accounts for most of the signal phase	OPA changes second order but not third order phase of the idler $\varphi_s^{(2)} \approx -\varphi_i^{(2)}$ $\varphi_s^{(3)} \approx -\varphi_i^{(3)}$	Property of grating compressor	Requirement for a transform-limited pulse

E25024a

A grism stretcher uses grating–prism elements to provide negative second- and third-order phase



- A grism is a grating mounted next to or etched onto a prism
- Angular dispersion from bulk material allows for negative third order phase

$$\frac{\varphi_3}{\varphi_2} \sim -\left[1 + n\sin(\theta_{diff})\sin(\theta_{in})\right]$$

- The design achieves a 200-fs FWHM* with a standard grating compressor

*FWHM: full width at half maximum

E26237

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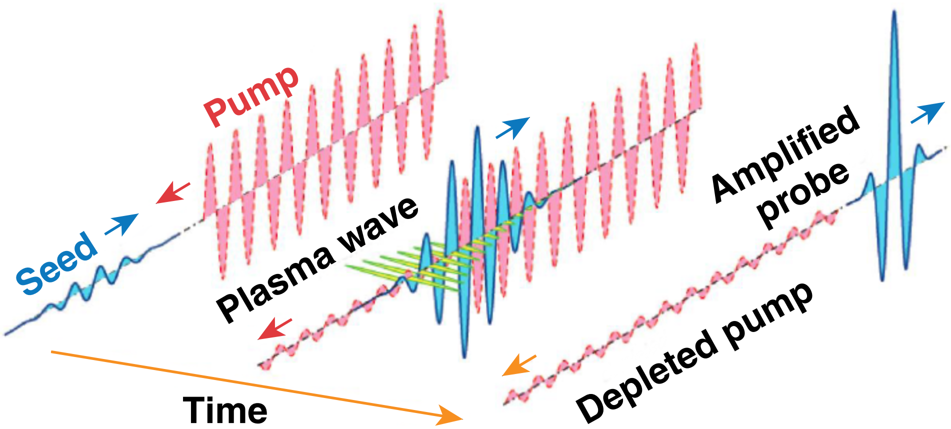

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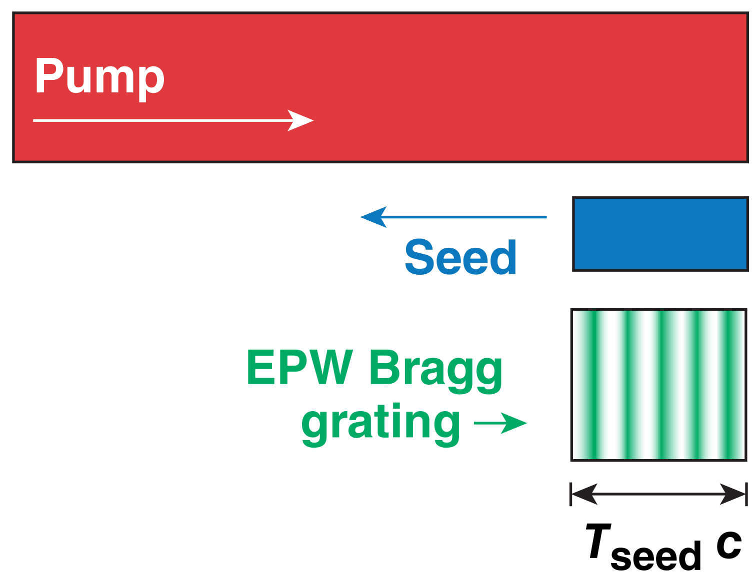

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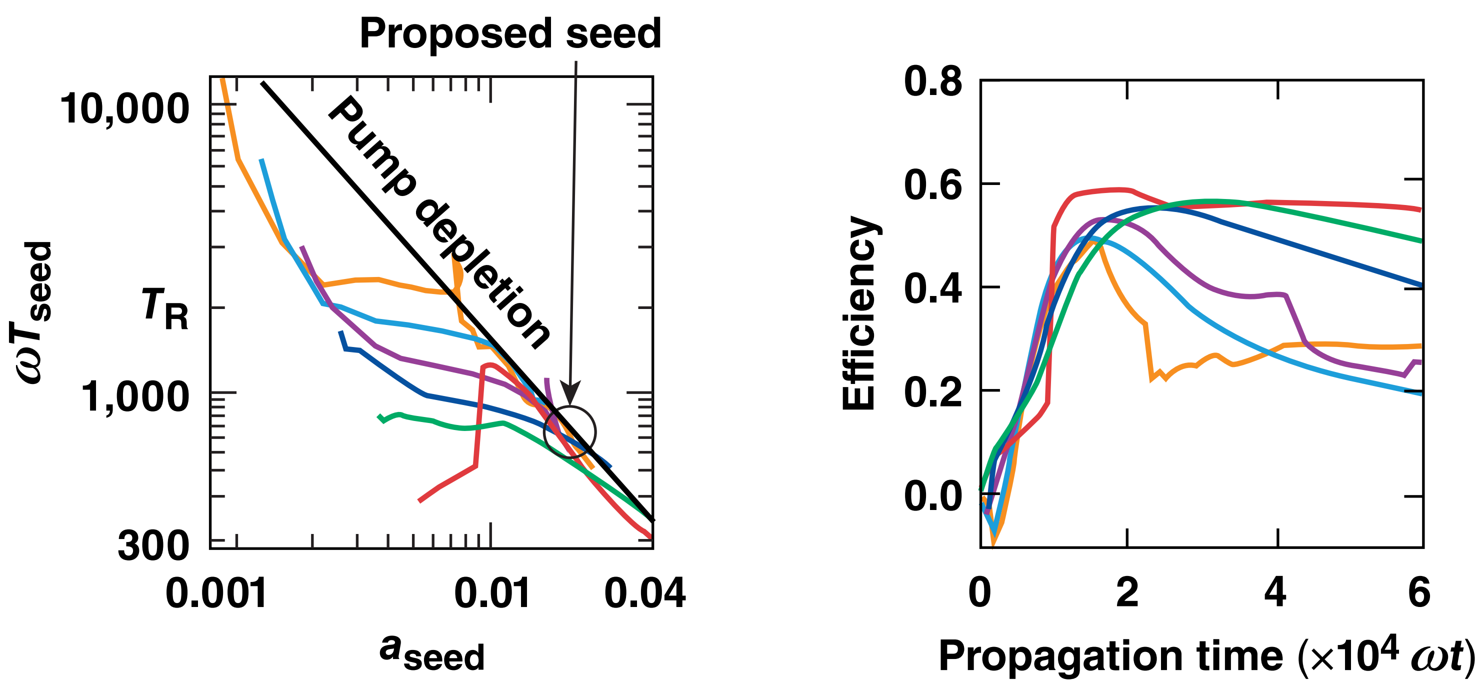

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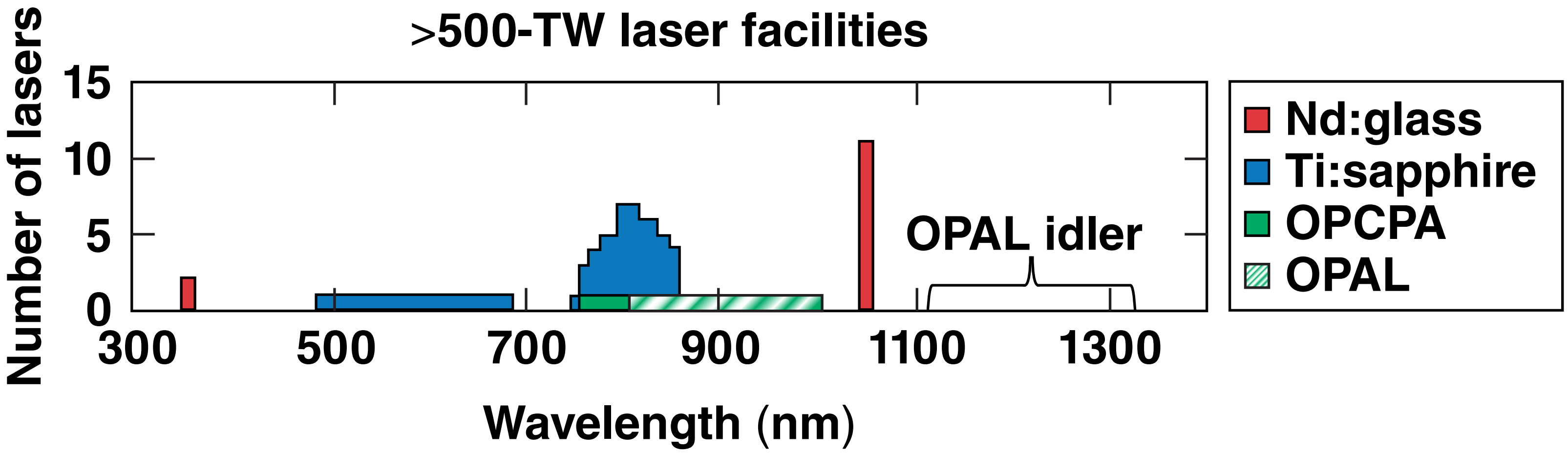

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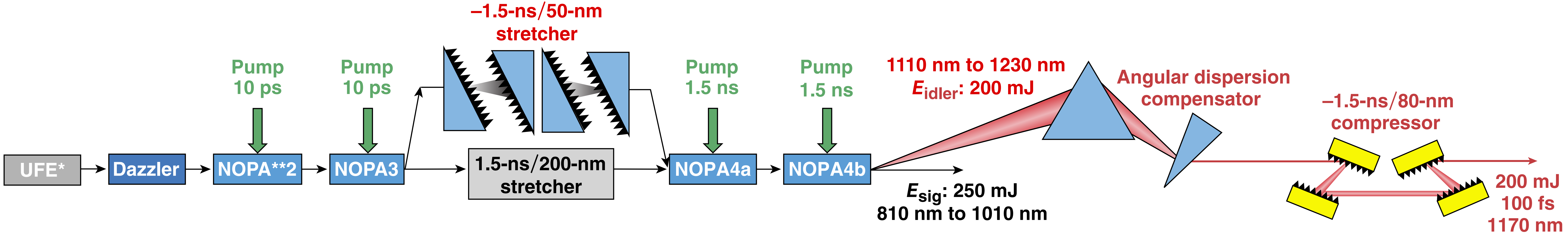

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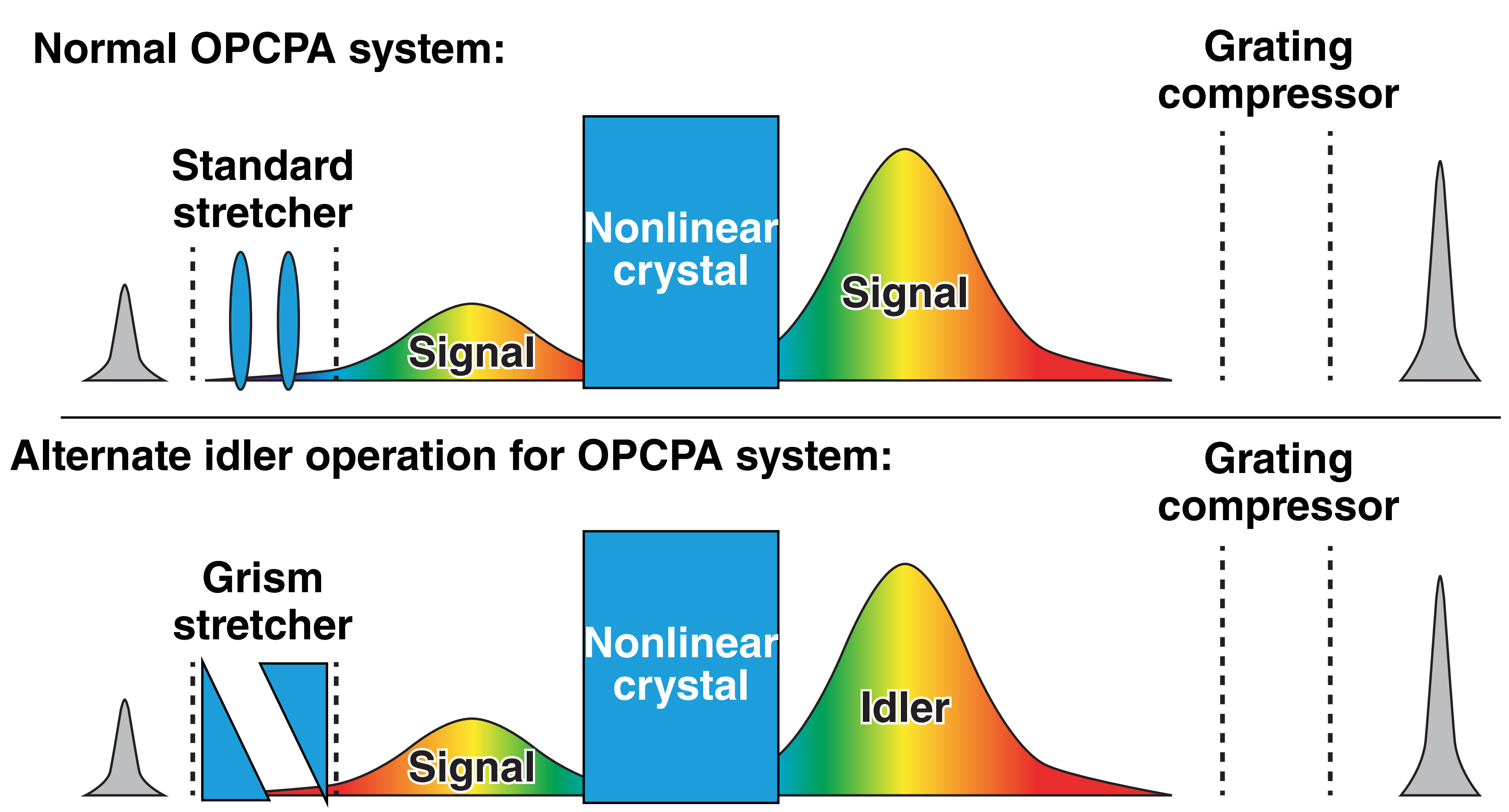

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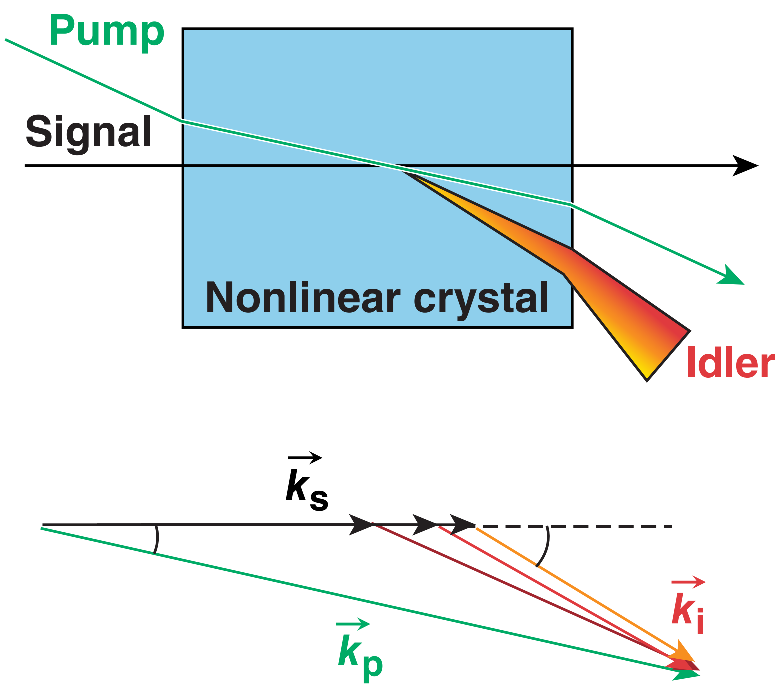

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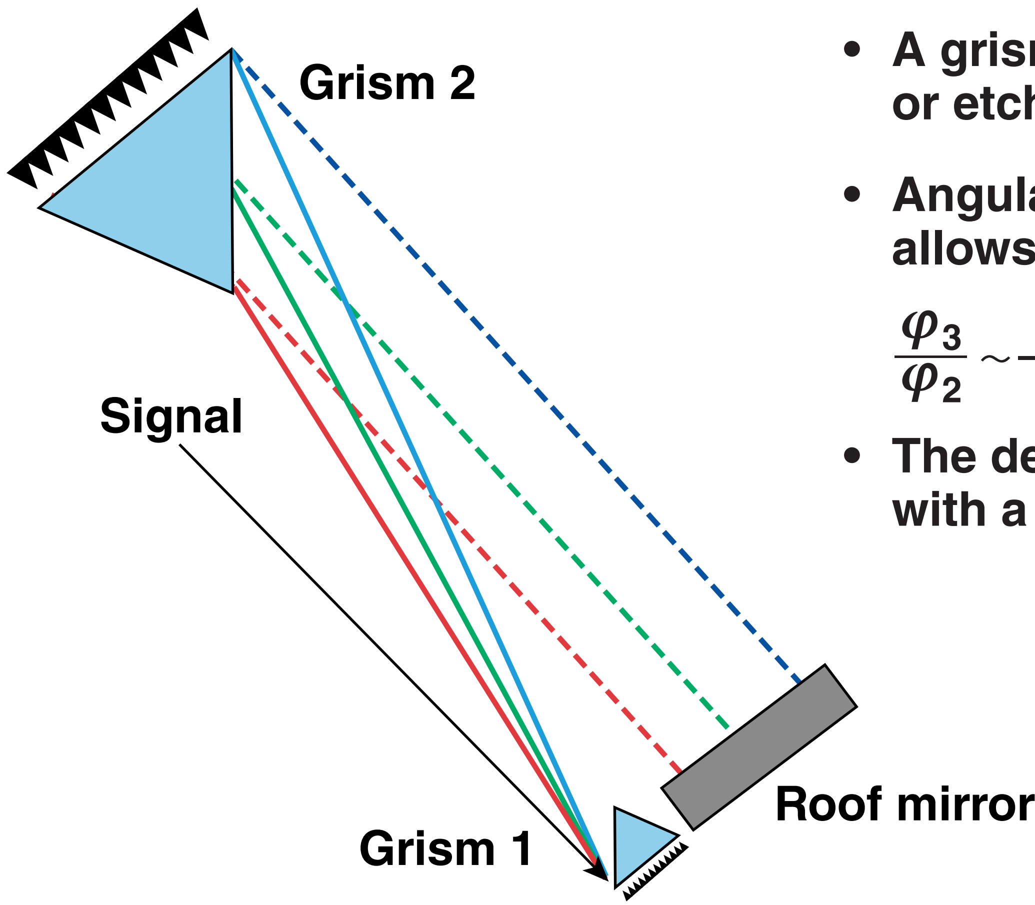

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