Transforming the Idler for Use in Laser–Plasma Interaction Experiments

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University of Rochester, Laboratory for Laser Energetics

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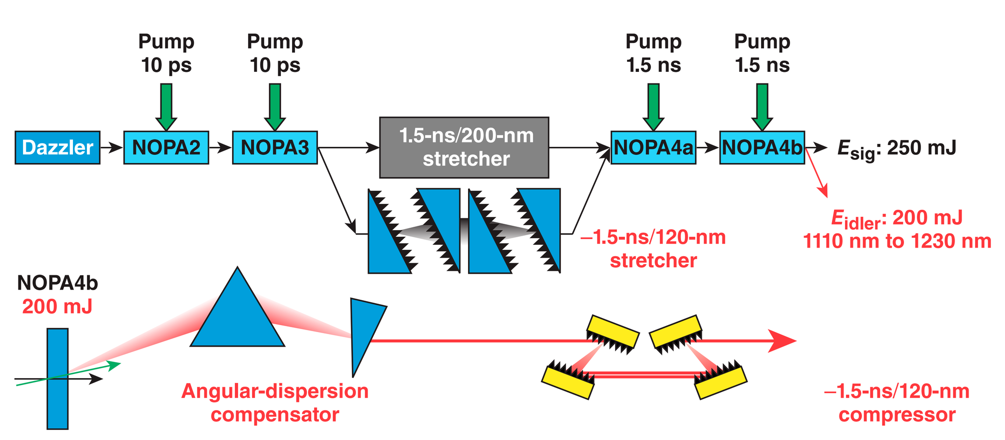
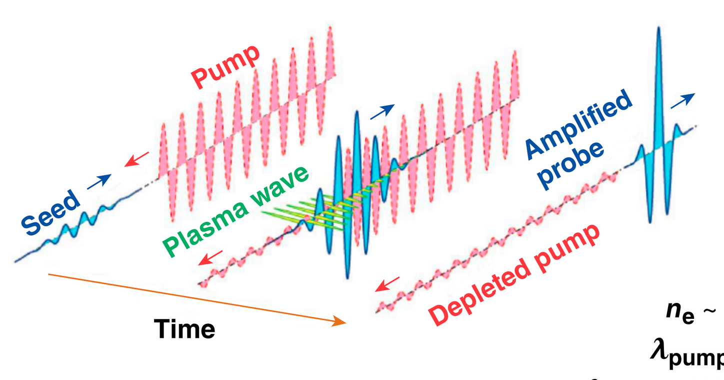


E25020

A high-intensity, near-infared, sub-100-fs laser pulse is required for Raman amplification

Resonance condition: $\omega_{pump} = \omega_{seed} + \omega_{plasma}$



$n_e \sim 10^{19}$ cm^{-3}

$\lambda_{pump} = 1053$ nm

$\lambda_{seed} = 1110$ nm to 1230 nm

E25021

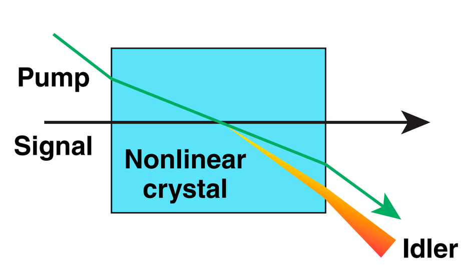
The idler from an optical parametric chirped-pulse–amplification (OPCPA) system provides a mJ pulse in the desired wavelength range

There are two issues related to the dispersion of the idler resulting from the optical parametric amplification (OPA):

- Temporal dispersion: compressing the idler is difficult because the phase is complex because of energy conservation resulting from the interior of the nonlinear crystal
- Angular dispersion: the idler is angularly dispersed because momentum is conserved inside the nonlinear crystal

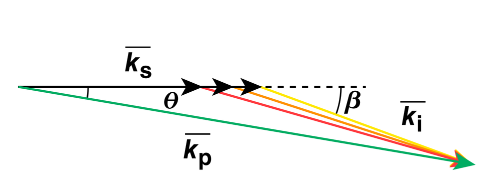
E25022

OPA creates a broadband idler beam with angular dispersion



OPA is a three-wave mixing process inside a nonlinear crystal

Conservation of energy $\omega_p = \omega_s + \omega_i$

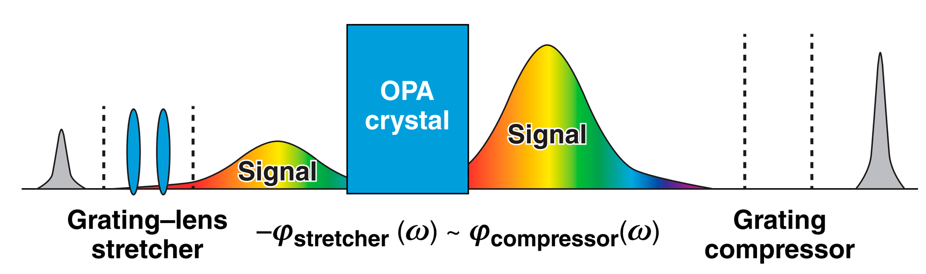


The idler has angular dispersion because of the broadband signal and conservation of momentum

Conservation of momentum $\overline{k}_p = \overline{k}_s + \overline{k}_i$

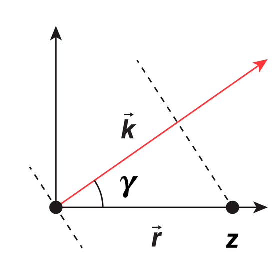
E25023

A typical stretcher and compressor for OPCPA systems stretches and compresses a pulse with approximately the same phase



E25024

Stretchers and compressors introduce second-order and higher-order spectral phases



Spectral phase is proportional to the optical distance traveled by a wavefront of a plane wave between two points

$$\varphi(\omega) = \frac{2\pi \ell_{optical}}{\lambda} = \bar{k} \cdot \bar{r} = \frac{\omega \cdot z}{c} \cos(\gamma)$$

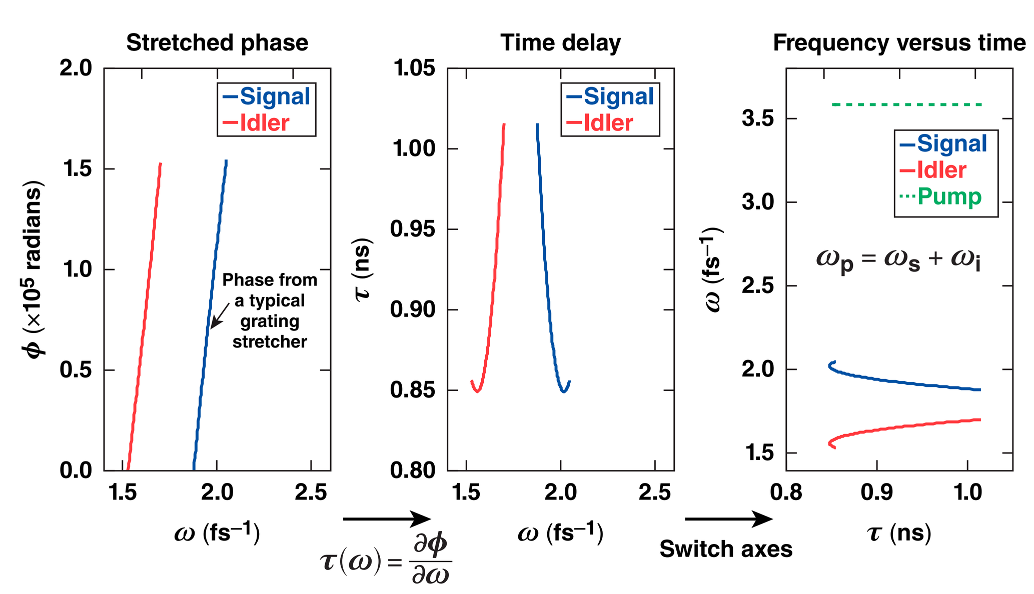
Taylor expansion of spectral phase, $\phi(\omega)$:

$$\phi(\omega) = \phi^{(0)}(\omega_0) + \phi^{(1)}(\omega_0)(\omega - \omega_0) + \frac{1}{2}\phi^{(2)}(\omega_0)(\omega - \omega_0)^2 + \cdots$$

- Phase of the central wavelength
- Group delay: the time it takes for a wave packet to travel through an optical system
- Group delay dispersion: measures the rate at which a pulse will increase in time through an optical system

E25025

The relation between signal and idler spectral phase for OPA



E25026

Energy conservation of through OPA switches the even idler phase orders but not the odd idler phase orders

Second-order phase: $\frac{\partial^2 \varphi}{\partial \omega^2} = \frac{\partial \tau}{\partial \omega}$

- Signal: –
- Idler: +

Third-order phase: $\frac{\partial^3 \varphi}{\partial \omega^3} = \frac{\partial^2 \tau}{\partial \omega^2}$

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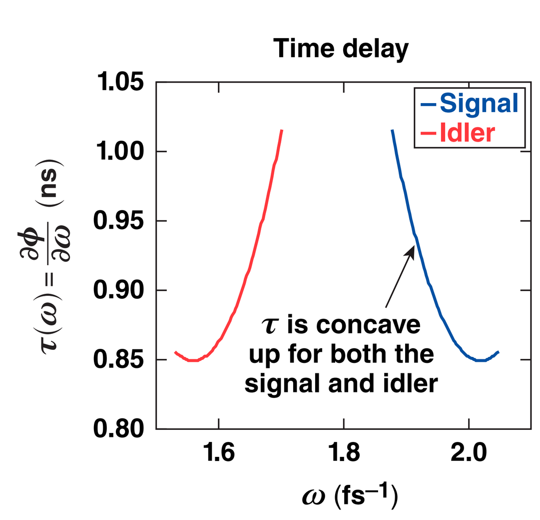
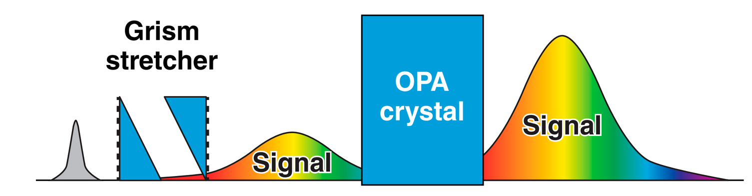


E25027

The complicated temporal dispersion of the idler can be compensated for using a grism stretcher



Even orders of phase:

$\varphi_{idler}(\omega) \sim -\varphi_{signal}(\omega)$

$\varphi_{stretcher}(\omega) \sim \varphi_{compressor}(\omega)$

Odd orders of phase:

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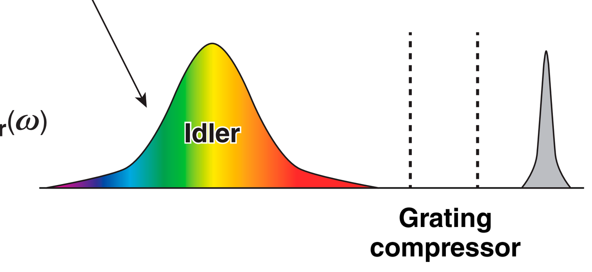


E25028

Imaging the idler onto a dispersive element can reduce angular dispersion

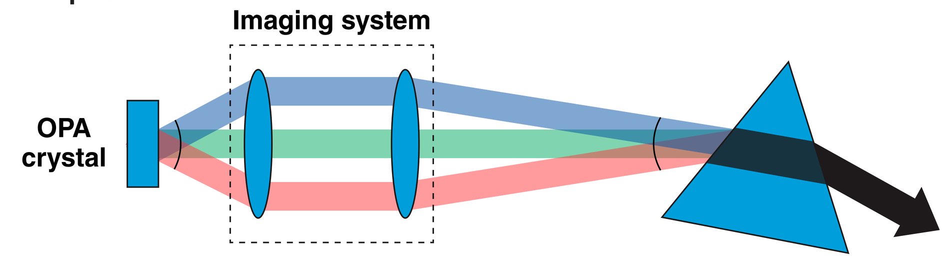
Wavelengths separate in space

The image brings the wavelengths into spatial alignment

Wavelengths are angularly dispersed

A dispersive element with angular dispersion that is equal and opposite of the incident beam would output light at a single angle

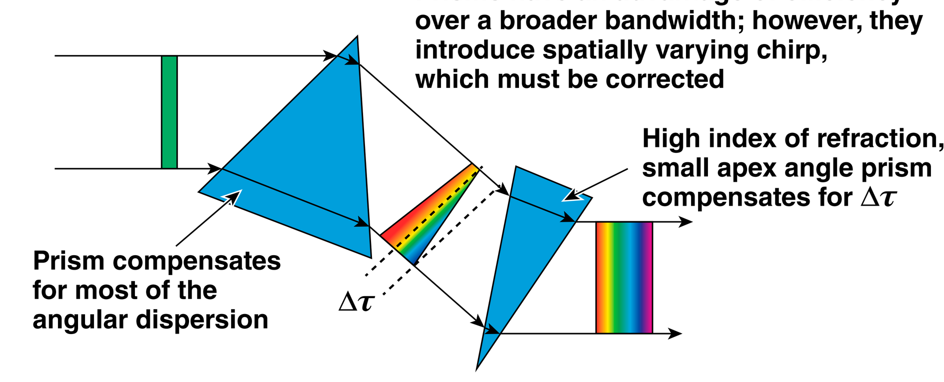
- Two obvious choices for dispersive elements:
  - gratings
  - prisms



E25029

A two-prism design can compensate for spatially varying chirp that is caused by the geometry of any single prism

Prisms have an advantage of efficiency over a broader bandwidth; however, they introduce spatially varying chirp, which must be corrected



An N-KZFS2 prism (apex angle = 74°) and an SF57 prism (apex angle = 24°) reduces angular dispersion from 15 mrad to 10 μrad and has a spatially varying chirp ($\Delta\tau$) of <10 fs.

E25030

Summary

The idler from an OPCPA system provides a mJ pulse in the desired 1100-nm to 1230-nm wavelength range

- Temporal dispersion:
  - problem: compressing the idler is difficult because of its complex phase
  - solution: by using a grism stretcher, even and odd orders of phase are separately tunable, making it possible to design a stretcher such that can be compressed by a standard grating compressor
- Angular dispersion:
  - problem: the idler is angularly dispersed out of the OPA crystal
  - solution: imaging onto a set of prisms such that the angular dispersion of the idler matches that of the prism pair reduces the angular dispersion without adding spatially varying chirp

E25031

UNIVERSITY of ROCHESTER

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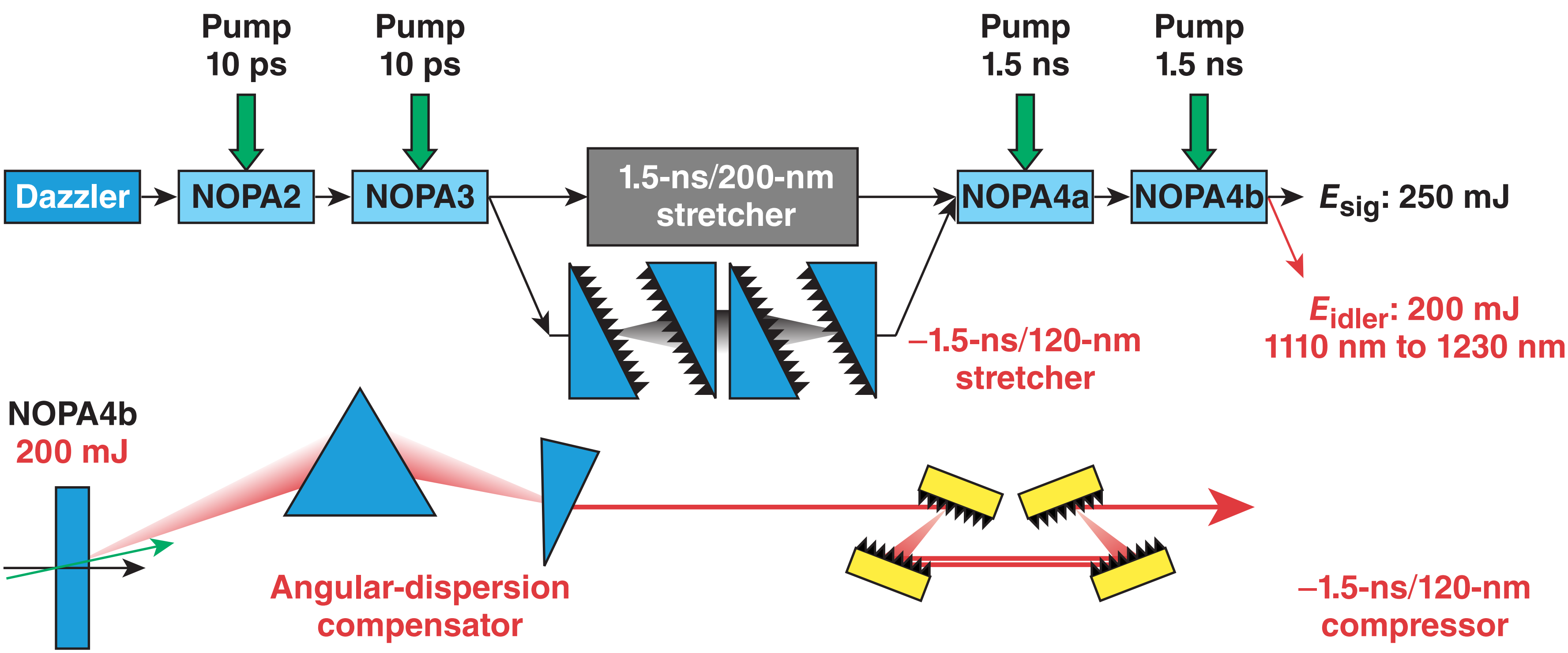

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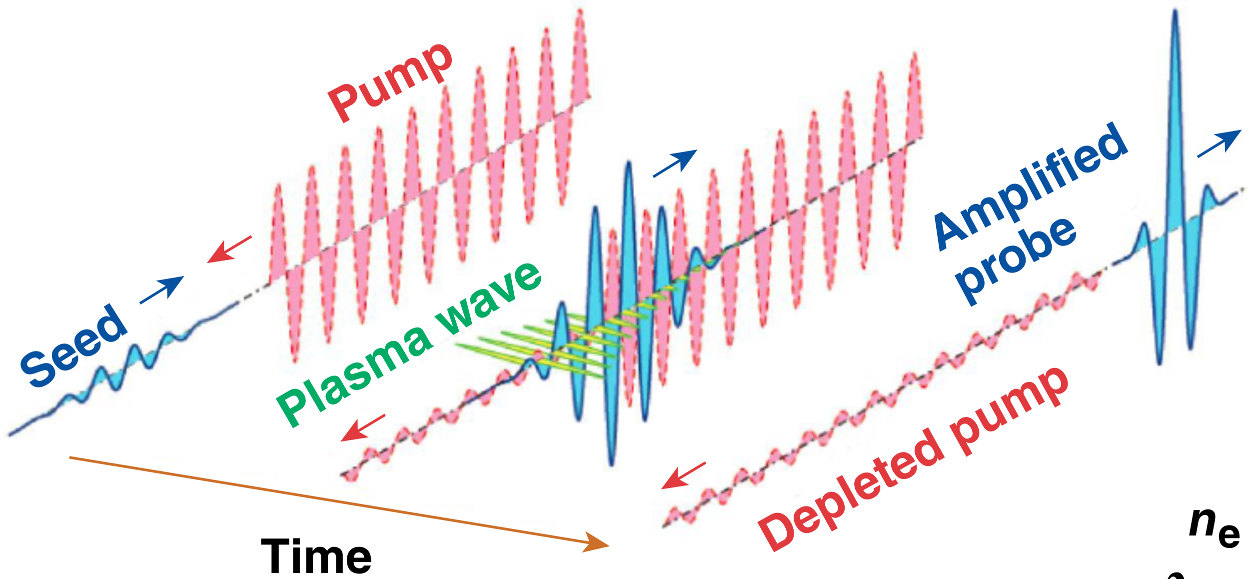

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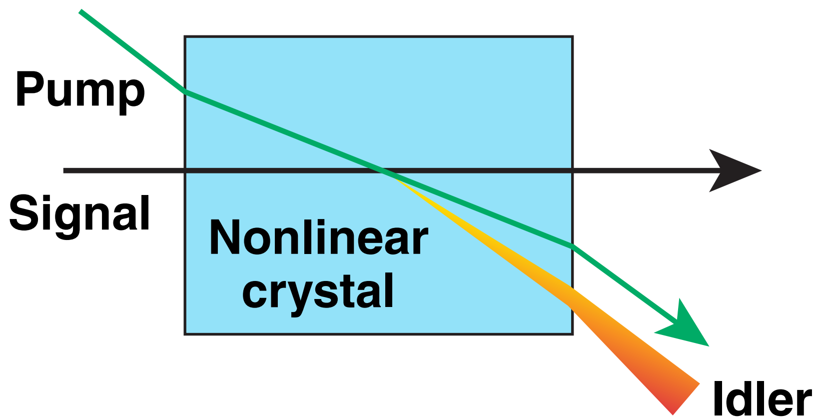

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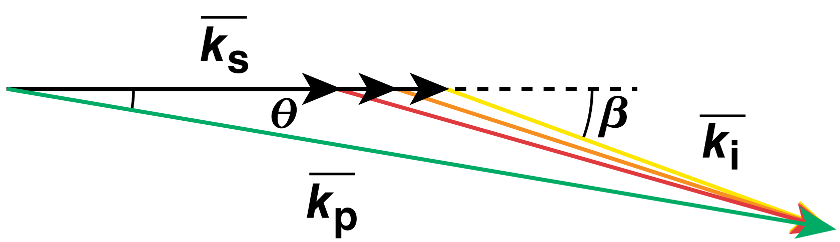

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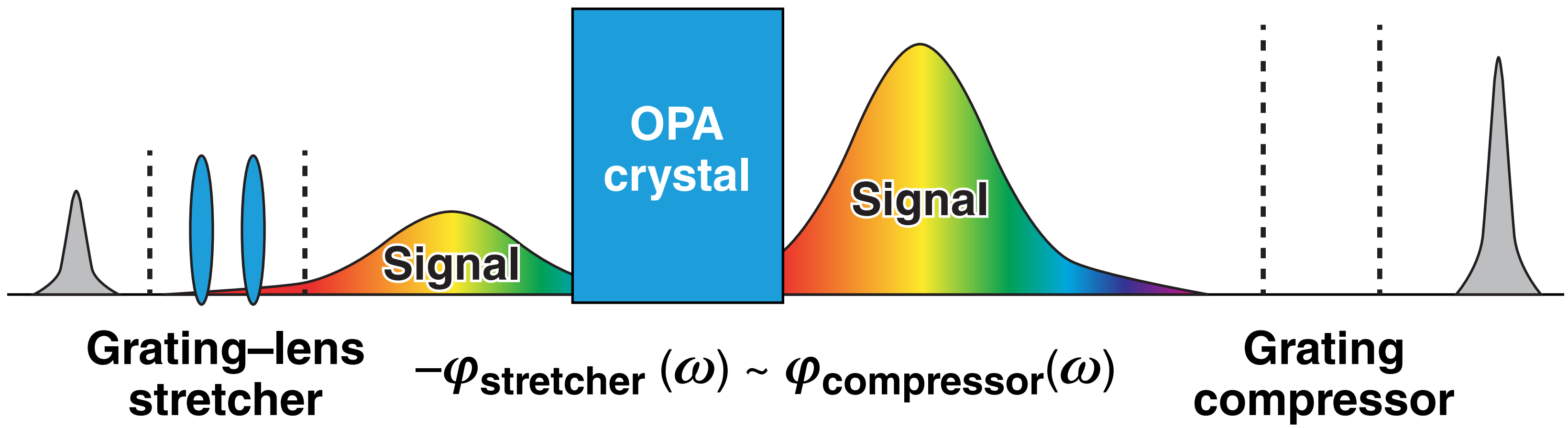

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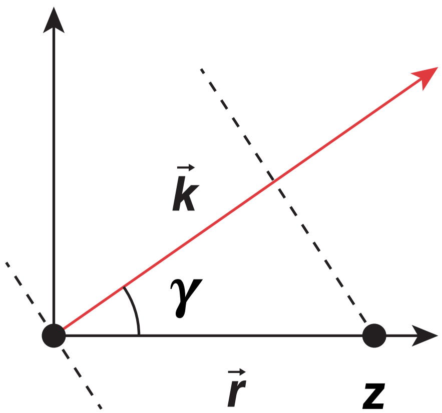

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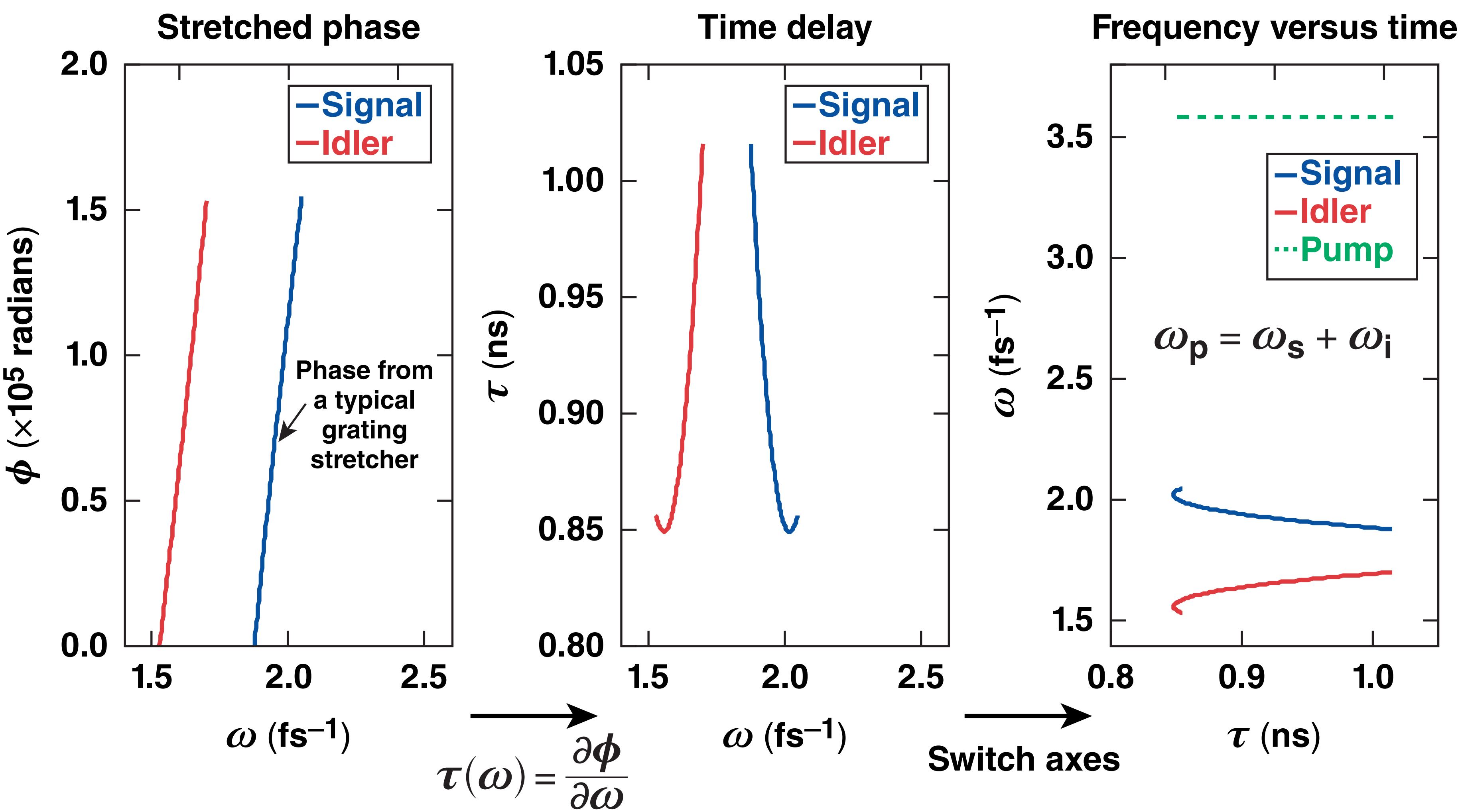

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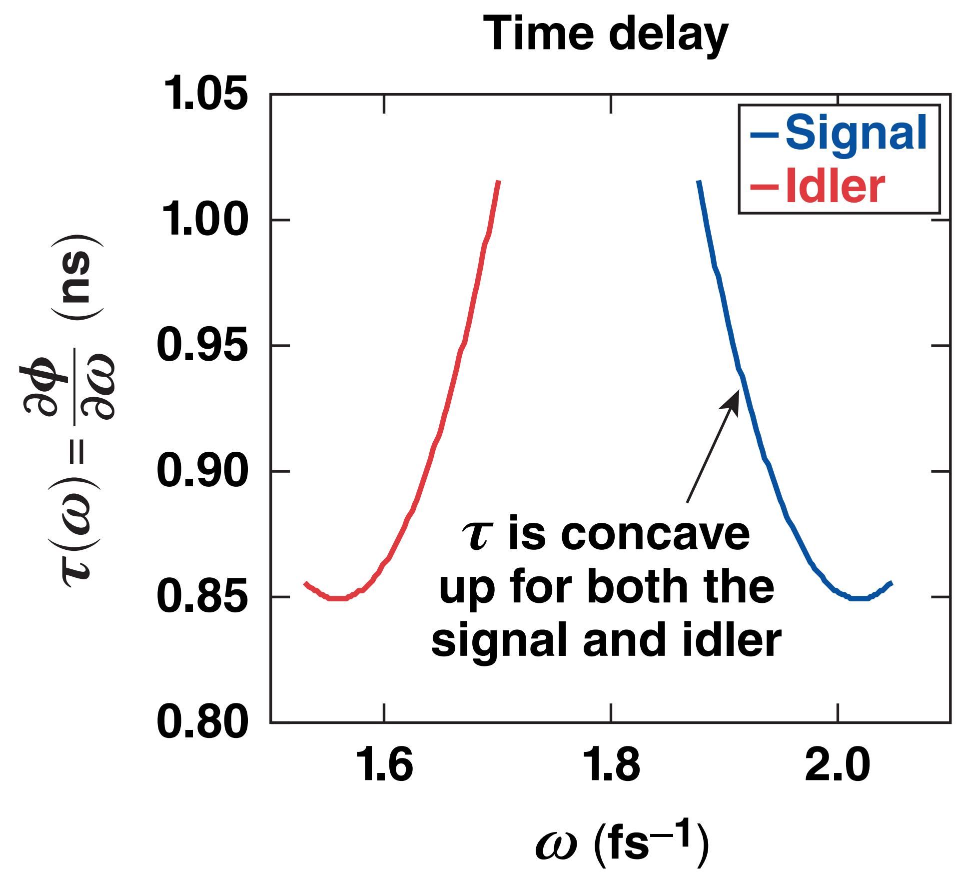

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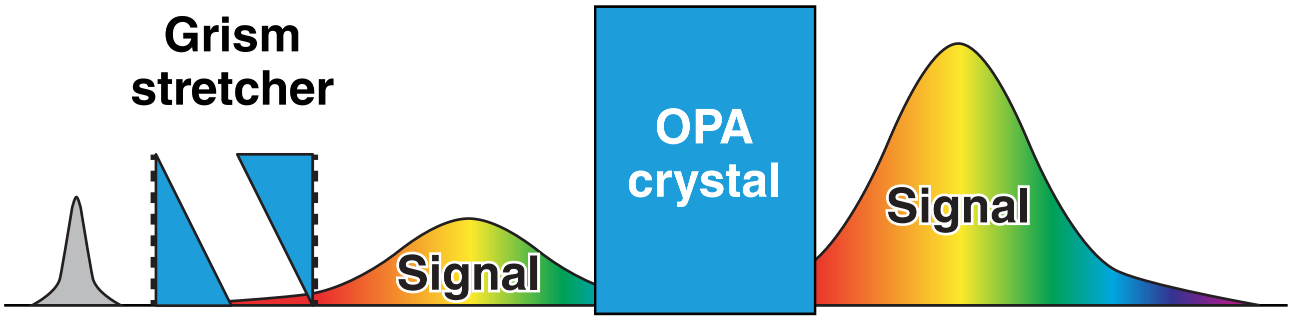

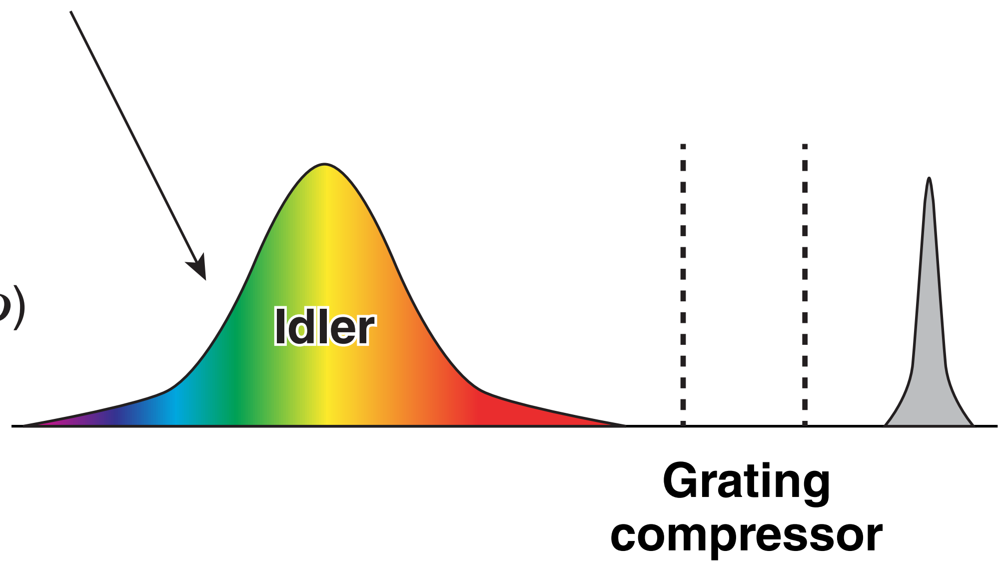

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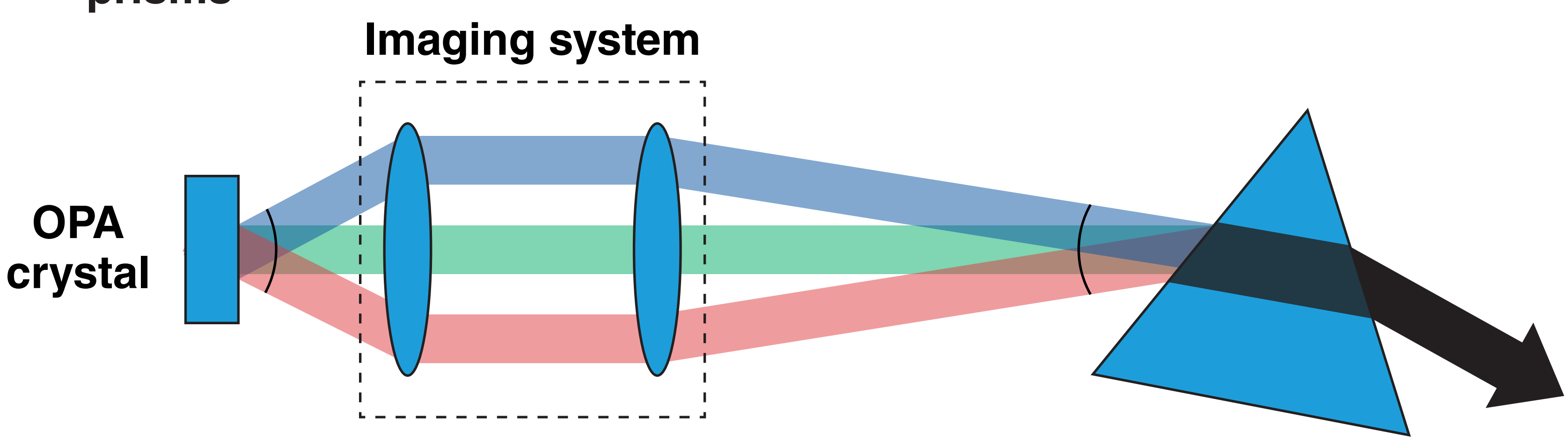

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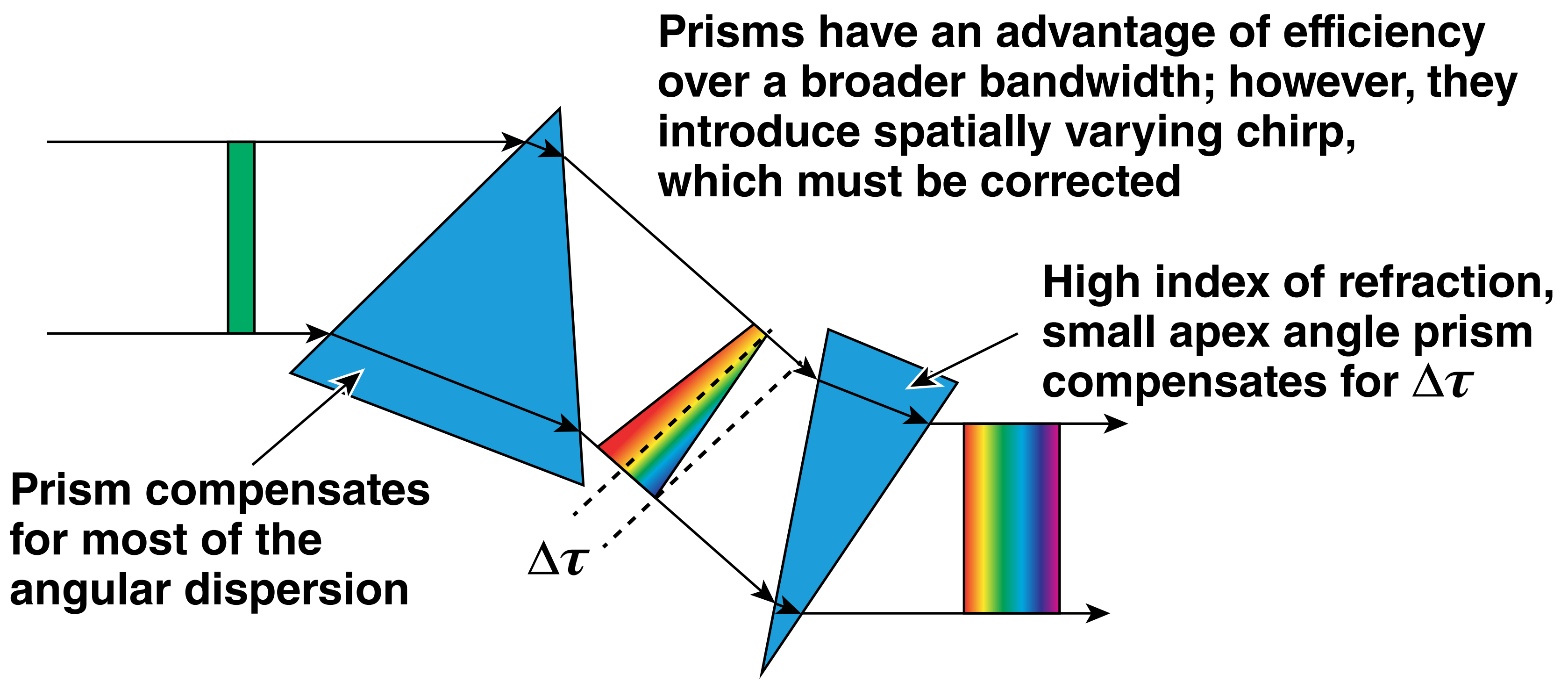

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