Nonlinear Optical Engineering

Self-Phase Modulation (1)
(NFO 5th ed: 4.1 ~ 4.2)

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SPM-Induced Spectral Changes (1)

Nonlinear phase shift:

$$\rightarrow \frac{\partial U}{\partial z} = \frac{ie^{-\alpha z}}{L_{NL}} |U|^2 U \quad \leftarrow \beta_2 = 0 \quad \leftarrow L_{NL} = (\gamma P_0)^{-1}$$

$$\rightarrow U = V \exp(i\phi_{NL}) \quad \rightarrow \frac{\partial V}{\partial z} = 0, \quad \frac{\partial \phi_{NL}}{\partial z} = \frac{e^{-\alpha z}}{L_{NL}} V^2$$

$$\rightarrow U(L,T) = U(0,T)\exp[i\phi_{NL}(L,T)] \quad \leftarrow L_{eff} = [1-\exp(-\alpha L)]/\alpha$$

$$\rightarrow \phi_{NL}(L,T) = |U(0,T)|^2 (L_{eff}/L_{NL}) \quad \leftarrow |U(0,0)| = 1$$

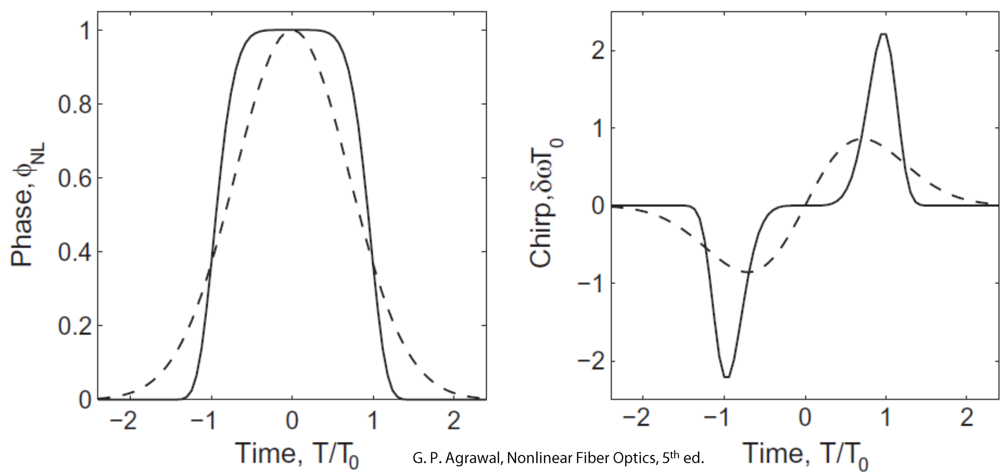
Maximum phase shift: $\rightarrow \phi_{\max} = L_{eff}/L_{NL} = \gamma P_0 L_{eff}$

$$\rightarrow \delta\omega(T) = -\frac{\partial \phi_{NL}}{\partial T} = -\left(\frac{L_{eff}}{L_{NL}}\right)\frac{\partial}{\partial T}|U(0,T)|^2$$

Gaussian/Super-Gaussian pulses:

$$\rightarrow \delta\omega(T) = \frac{2m}{T_0}\left(\frac{L_{eff}}{L_{NL}}\right)\left(\frac{T}{T_0}\right)^{2m-1} \exp\left[-\left(\frac{T}{T_0}\right)^{2m}\right]$$

$$\leftarrow m = 1, 3$$



G. P. Agrawal, Nonlinear Fiber Optics, 5th ed.

SPM-Induced Spectral Changes (2)

Changes in pulse spectra:

$$\rightarrow \delta\omega(T) = \frac{2m}{T_0}\left(\frac{L_{eff}}{L_{NL}}\right)\left(\frac{T}{T_0}\right)^{2m-1}\exp\left[-\left(\frac{T}{T_0}\right)^{2m}\right]$$

$$\rightarrow \delta\omega_{\max} = \frac{mf(m)}{T_0}\phi_{\max} \quad \leftarrow f(m) = 2\left(1-\frac{1}{2m}\right)^{1-1/2m}\exp\left[-\left(1-\frac{1}{2m}\right)\right]$$

For an unchirped Gaussian pulse: $\rightarrow \delta\omega_{\max} = 0.86\Delta\omega_0\phi_{\max}$

Pulse spectrum:

$$\rightarrow S(\omega) = \left|\tilde{U}(L,\omega)\right|^2$$

$$\rightarrow \phi_{\max} \approx \left(M - \frac{1}{2}\right)\pi$$

$\leftarrow M$: # of peaks

$(\phi_{\max} >> 1)$

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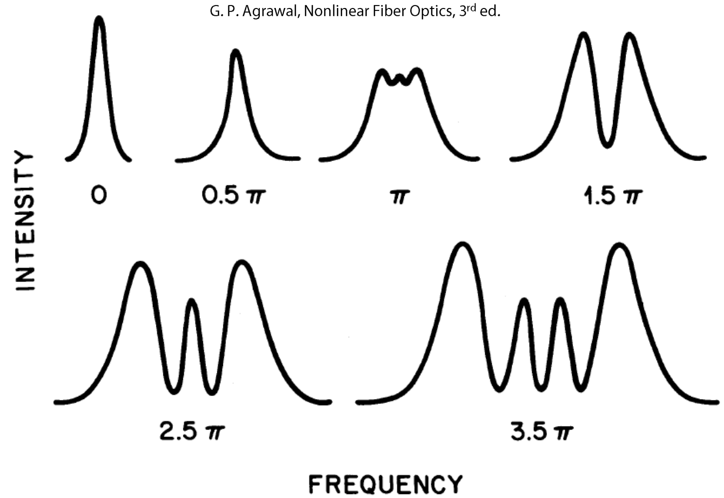


RMS spectral width:

$$\rightarrow \Delta\omega_{\text{rms}}^2 = \left\langle(\omega-\omega_0)^2\right\rangle - \left\langle(\omega-\omega_0)\right\rangle^2$$

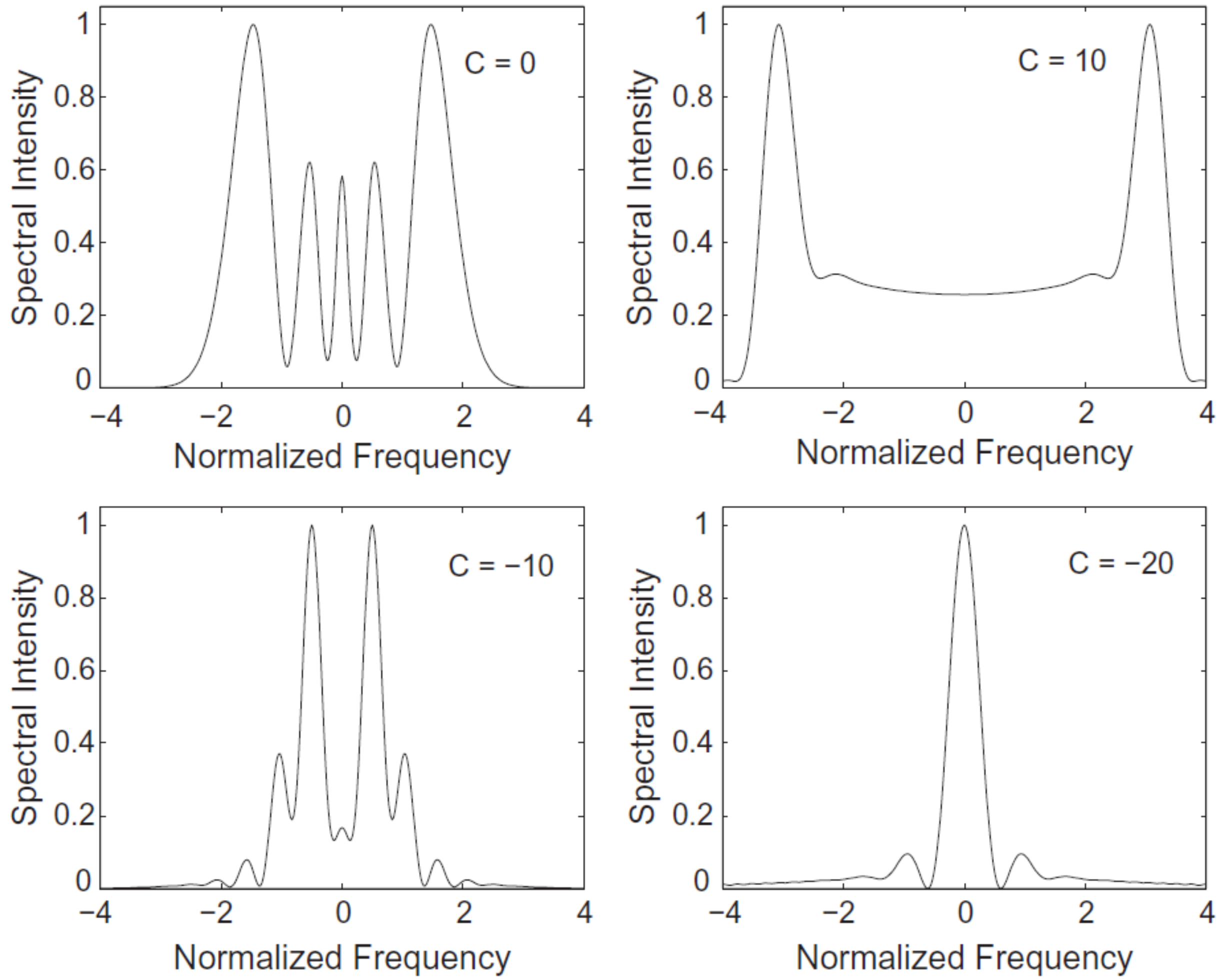
$$\leftarrow \left\langle(\omega-\omega_0)^n\right\rangle = \frac{\int_{-\infty}^{\infty}(\omega-\omega_0)^n S(\omega)d\omega}{\int_{-\infty}^{\infty}S(\omega)d\omega}$$

For an unchirped Gaussian pulse:

$$\rightarrow \frac{\Delta\omega_{\text{rms}}}{\Delta\omega_0} = \left(1+\frac{4}{3\sqrt{3}}\phi_{\max}^2\right)^{1/2}$$

SPM-Induced Spectral Changes (3)

Effect of pulse shape and initial chirp (Gaussian pulses):



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SPM-Induced Spectral Changes (4)

Effect of partial coherence:

→ H.W.

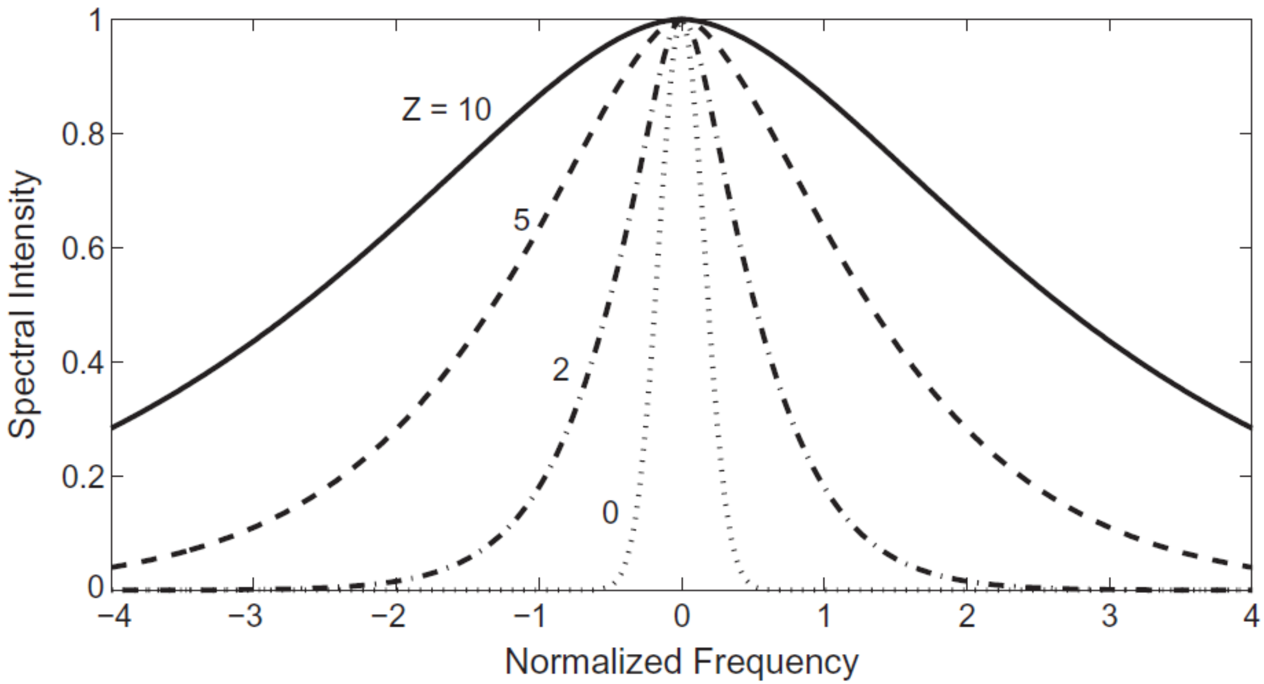
Optical spectrum: $\rightarrow S(\omega)=\int_{-\infty}^{\infty}\Gamma(z,\tau)\exp(i\omega\tau)d\tau$ ← Wiener-Khintchine theorem

$$\leftarrow \Gamma(z,\tau)=\left\langle U^{*}(z,T)U(z,T+\tau)\right\rangle$$

← Coherent function

Gaussian form for the input coherent function:

$$\rightarrow \Gamma(0,\tau)=\exp[-\tau^{2}/(2T_{c}^{2})]$$



$\leftarrow Z = L_{eff} / L_{NL}$

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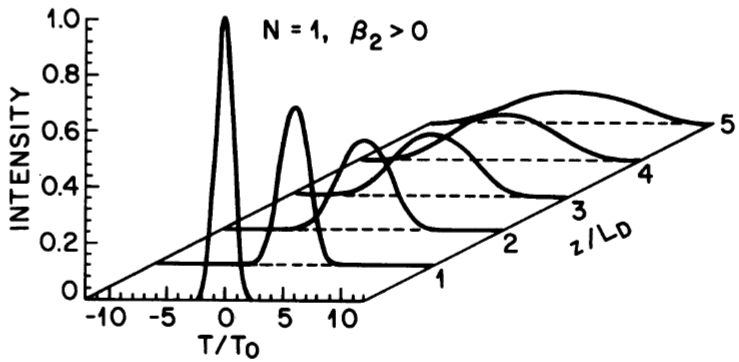
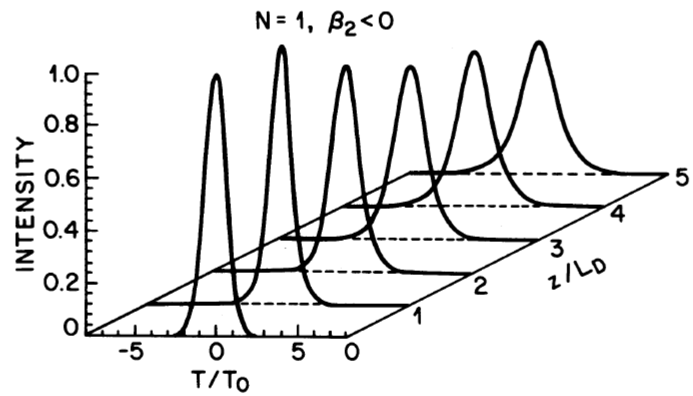
Effect of Group-Velocity Dispersion (1)

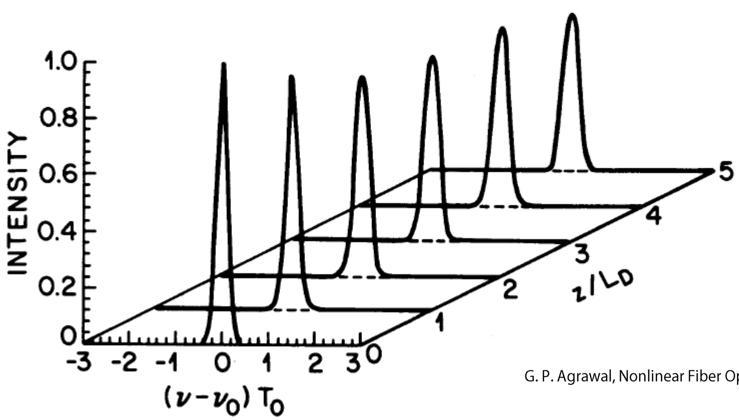
Pulse evolution:

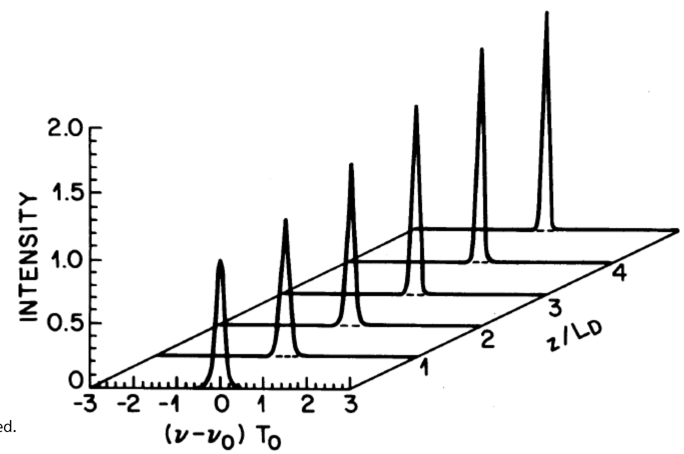
$$\rightarrow i\frac{\partial U}{\partial \xi} = \mathrm{sgn}(\beta_2)\frac{1}{2}\frac{\partial^2 U}{\partial \tau^2} - N^2 e^{-\alpha z}|U|^2 U$$

$$\leftarrow \xi = z/L_D, \quad \tau = T/T_0, \quad N^2 = \frac{L_D}{L_{NL}} \equiv \frac{\gamma P_0 T_0^2}{|\beta_2|}$$









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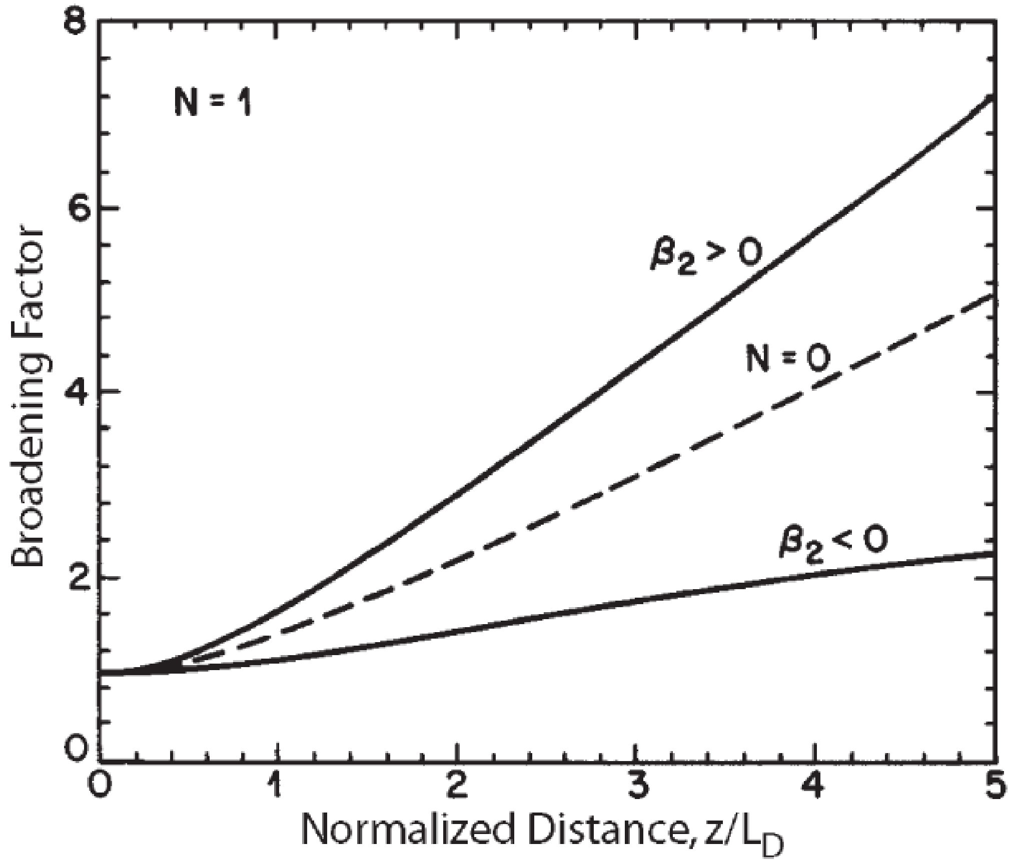
Effect of Group-Velocity Dispersion (2)

Broadening factor:

Gaussian pulses:



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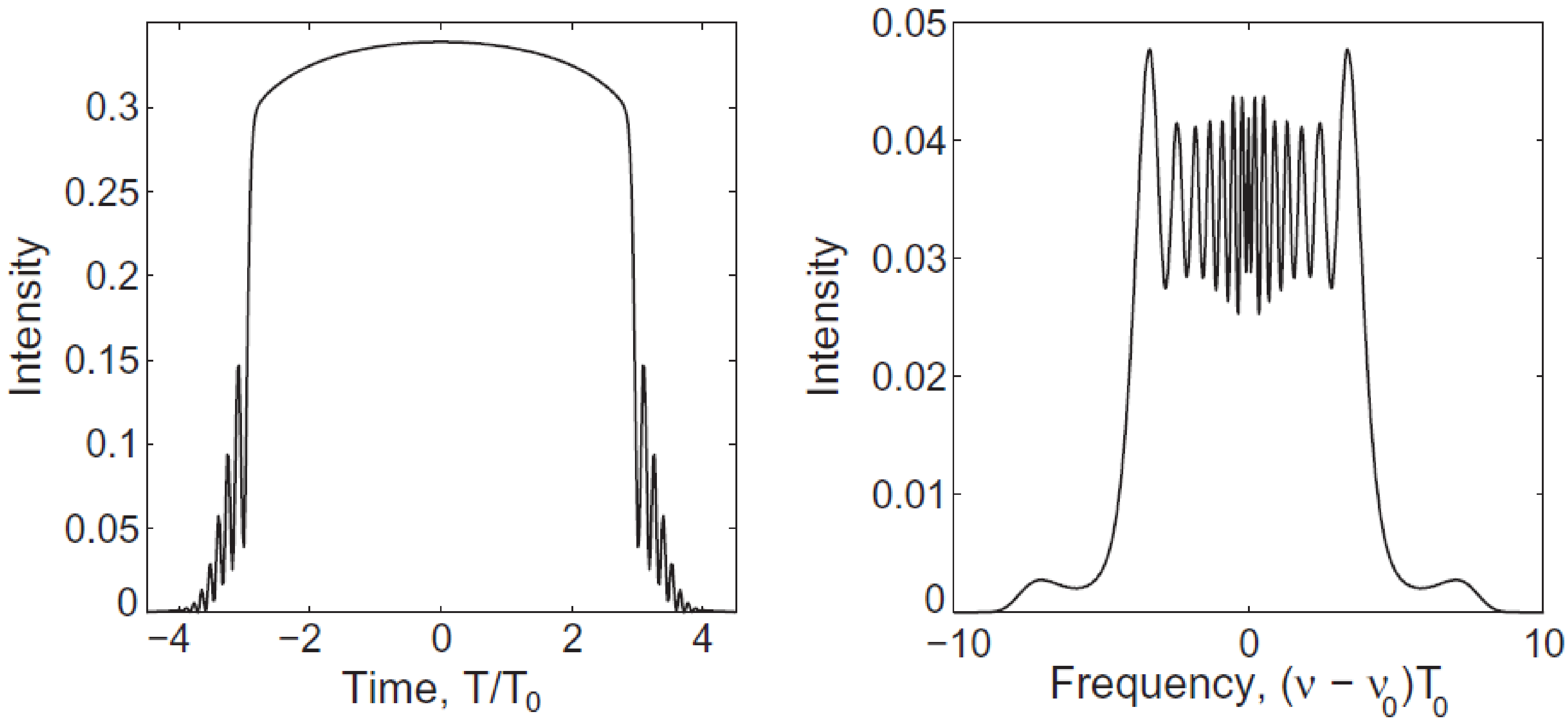
Effect of Group-Velocity Dispersion (3)

Optical wave breaking :

Sech pulse:



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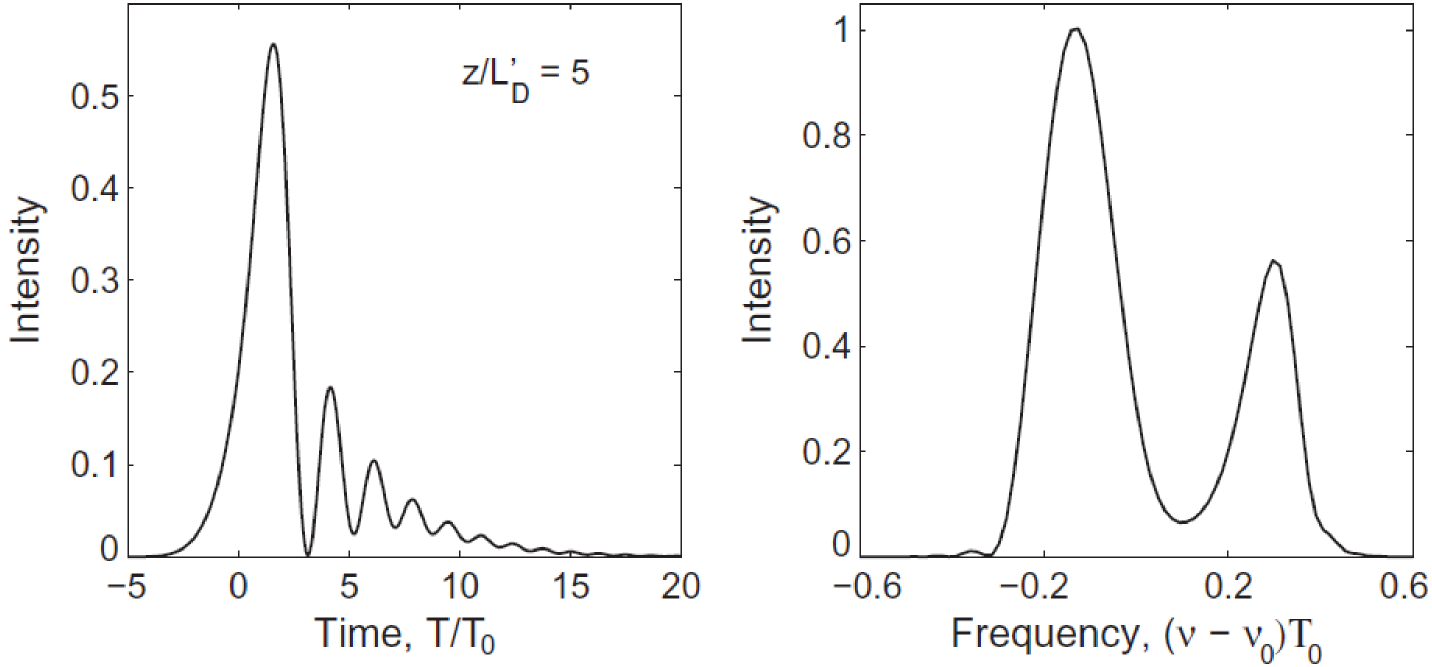
Effect of Group-Velocity Dispersion (4)

Effect of third-order dispersion:

$$\rightarrow i\frac{\partial U}{\partial \xi'} = \mathrm{sgn}(\beta_3)\frac{i}{6}\frac{\partial^3 U}{\partial \tau^3} - \bar{N}^2 e^{-\alpha z}|U|^2 U$$

$$\leftarrow \xi = z/L'_D, \quad \tau = T/T_0, \quad \bar{N}^2 = \frac{L'_D}{L_{NL}} \equiv \frac{\gamma P_0 T_0^3}{|\beta_3|}$$

Unchirped Gaussian pulse: $\rightarrow \beta_3 > 0$



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