Nonlinear Optical Engineering

Optical Solitons (4)
(NFO 5th ed: 5.5)

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Higher-Order Effects (1)

Moment equations for pulse parameters:

NLSE: $\rightarrow \dfrac{\partial U}{\partial z} + \dfrac{i\beta_2}{2}\dfrac{\partial^2 U}{\partial T^2} - \dfrac{\beta_3}{6}\dfrac{\partial^3 U}{\partial T^3} = i\gamma P_0 e^{-\alpha z}\left(|U|^2 U + \dfrac{i}{\omega_0}\dfrac{\partial}{\partial T}(|U|^2 U) - T_R U \dfrac{\partial |U|^2}{\partial T}\right)$

Solution form: $\rightarrow U(z,T) = a_p \mathrm{sech}\left(\dfrac{T-q_p}{T_p}\right)\exp\left[-i\Omega_p(T-q_p) - iC_p\dfrac{(T-q_p)^2}{2T_p^2} + i\phi_p\right]$

By the moment method: $\rightarrow \dfrac{dT_p}{dz} = (\beta_2 + \beta_3\Omega_p)\dfrac{C_p}{T_p}$

$$\rightarrow \frac{dC_p}{dz} = \left(\frac{4}{\pi^2} + C_p^2\right)\frac{(\beta_2 + \beta_3\Omega_p)}{T_p^2} + \frac{4T_0}{\pi^2 T_p}(\bar{\gamma} + \Omega_p/\omega_0)P_0$$

$$\rightarrow \frac{dq_p}{dz} = \beta_2\Omega_p + \frac{\beta_3}{2}\Omega_p^2 + \frac{\beta_3}{6T_p^2}\left(1 + \frac{\pi^2}{4}C_p^2\right) + \frac{\bar{\gamma}P_0}{\omega_0}\frac{T_0}{T_p}$$

$$\rightarrow \frac{d\Omega_p}{dz} = -\frac{8T_R\bar{\gamma}P_0}{15}\frac{T_0}{T_p^3} + \frac{2\bar{\gamma}P_0}{3\omega_0}\frac{T_0C_p}{T_p^3} \qquad \leftarrow \bar{\gamma} = \gamma\exp(-\alpha z)$$

$$\rightarrow E_0 = 2P_0T_0 = 2a_p^2(z)T_p(z)$$

Simplified chirp parameter:

$$\rightarrow \frac{dC_p}{dz} = \left(\frac{4}{\pi^2} + C_p^2\right)\frac{\beta_2}{T_p^2} + \frac{4P_0\gamma}{\pi^2}\frac{T_0}{T_p} \qquad \begin{array}{l} \leftarrow \alpha = 0 \\ \leftarrow \beta_2 = -\gamma P_0 T_0^2 \\ \leftarrow N = 1 \end{array}$$

Higher-Order Effects (2)

Moment equations for pulse parameters:

NLSE: $\rightarrow\ i\dfrac{\partial u}{\partial \xi}+\dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2}+|u|^2u=i\delta_3\dfrac{\partial^3 u}{\partial \tau^3}-is\dfrac{\partial}{\partial \tau}(|u|^2u)+\tau_R u\dfrac{\partial |u|^2}{\partial \tau}$

$$\leftarrow \delta_3=\frac{\beta_3}{6|\beta_2|T_0},\quad s=\frac{1}{\omega_0 T_0},\quad \tau_R=\frac{T_R}{T_0}$$

Third-order dispersion:

Based on the moment method: $\rightarrow s=0,\ \tau_R=0\ \ \rightarrow \Omega_p=0$

$$\rightarrow C_p=0,\ T_p=T_0$$

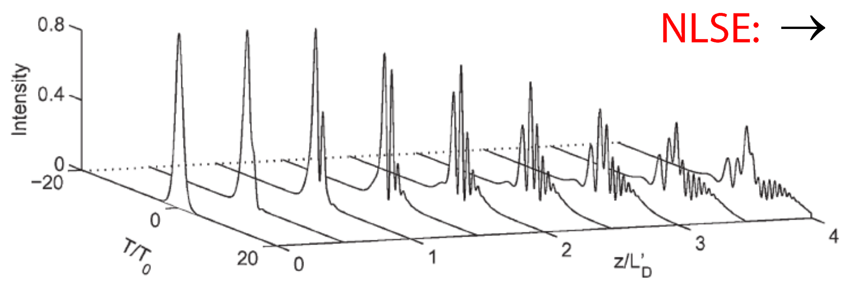
$$\rightarrow q_p(z)=(\beta_3/6T_0^2)z\equiv\delta_3(z/L_D)$$

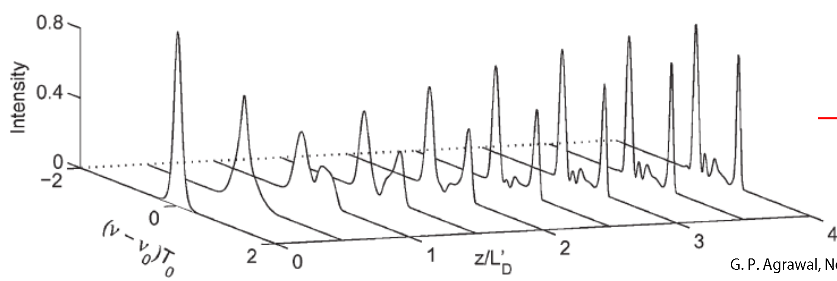
Near the dispersion-zero wavelength:

NLSE: $\rightarrow\ i\dfrac{\partial u}{\partial \xi'}-\mathrm{sgn}(\beta_3)\dfrac{i}{6}\dfrac{\partial^3 u}{\partial \tau^3}+|u|^2u=0$

$$\leftarrow \xi'=z/L_D'\ \ \leftarrow L_D'=T_0^3/|\beta_3|$$

$$\leftarrow u=\tilde{N}U\ \ \leftarrow \tilde{N}=\frac{L_D'}{L_{NL}}=\frac{\gamma P_0 T_0^3}{|\beta_3|}$$





$\rightarrow$ Splitting of the spectrum

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Higher-Order Effects (3)

Fourth-order dispersion:

NLSE: $\rightarrow\ i\dfrac{\partial u}{\partial \xi} + \dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2} + |u|^2 u = -\delta_4 \dfrac{\partial^4 u}{\partial \tau^4}$ $\leftarrow\ \delta_4 = \beta_4 / (24|\beta_2| T_0^2)$

$\leftarrow$ Dispersion-flatted fibers

Solution form:

$\rightarrow\ u(\xi,\tau) = 3b^2 \mathrm{sech}^2(b\tau)\exp(8ib^2\xi/5)$ $\leftarrow b = (40\delta_4)^{-1/2}$

$\leftarrow$ Autosolitons

Other TOD effect: $\rightarrow$ Soliton fission

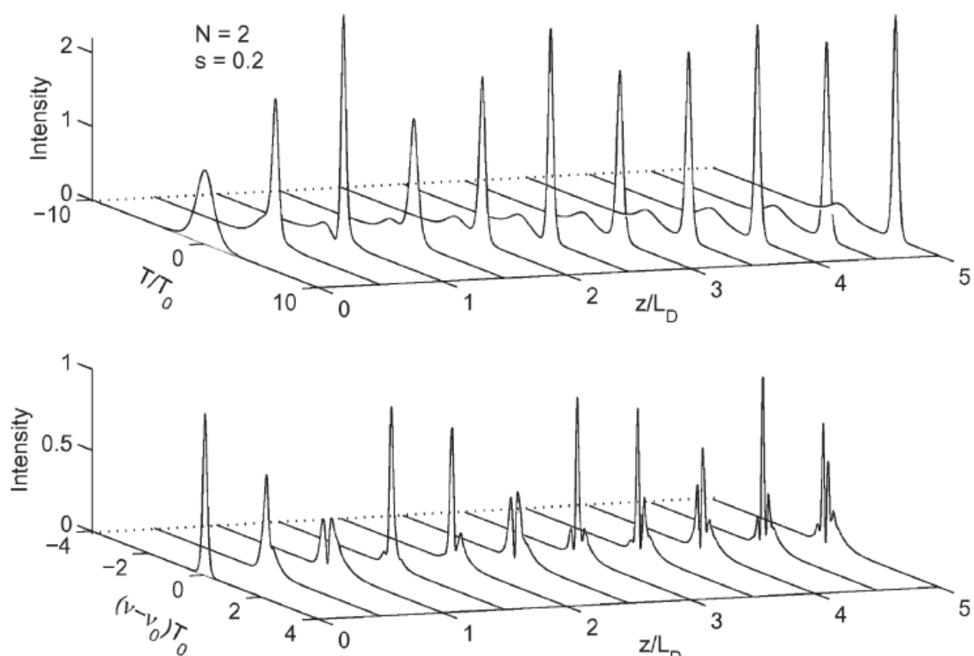
Higher-Order Effects (4)

Self-steepening:

Spectral shift: $\rightarrow \Omega_p(z) = \dfrac{\gamma E_0}{3\omega_0}\int_0^z \dfrac{C_p(z)}{T_p^3(z)} e^{-\alpha z} dz \quad \leftarrow T_R = 0$

Temporal shift: $\rightarrow \dfrac{dq_p}{dz} = \beta_2 \Omega_p + \dfrac{\beta_3}{2}\Omega_p^2 + \dfrac{\beta_3}{6T_p^2}\left(1 + \dfrac{\pi^2}{4}C_p^2\right) + \dfrac{\bar{\gamma} P_0}{\omega_0}\dfrac{T_0}{T_p}$

NLSE: $\rightarrow i\dfrac{\partial u}{\partial \xi} + \dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2} + |u|^2 u + is\dfrac{\partial}{\partial \tau}(|u|^2 u) = 0$



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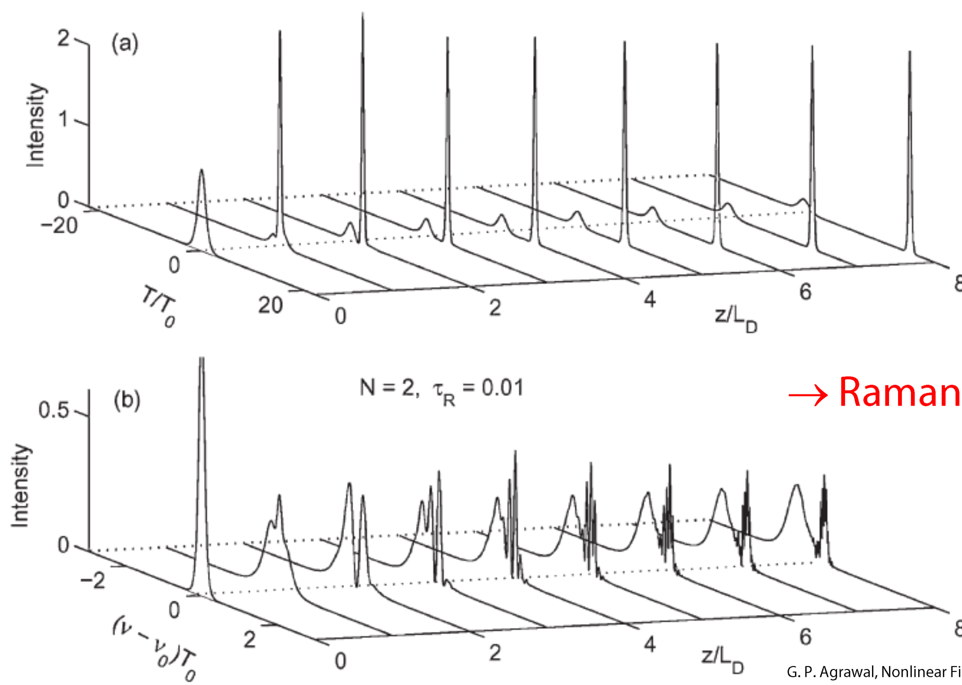
Higher-Order Effects (5)

Intrapulse Raman scattering:

Spectral shift: $\rightarrow \dfrac{d\Omega_p}{dz} = -\dfrac{8T_R\bar{\gamma}P_0}{15}\dfrac{T_0}{T_p^3} + \dfrac{2\bar{\gamma}P_0}{3\omega_0}\dfrac{T_0C_p}{T_p^3} \quad \leftarrow C_p \approx 0$

$$\rightarrow \Omega_p = -\frac{8T_R\gamma P_0}{15T_0^2}z = -\frac{8T_R|\beta_2|}{15T_0^4}z \quad \leftarrow N = \gamma P_0 T_0^2/|\beta_2| = 1$$

NLSE: $\rightarrow i\dfrac{\partial u}{\partial \xi} + \dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2} + |u|^2 u = \tau_R u \dfrac{\partial |u|^2}{\partial \tau}$



→ Raman-induced spectral red shift

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