

Nonlinear Optical Engineering

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

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Higher-Order Effects (1)

Moment equations for pulse parameters:

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

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

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

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

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

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

$$\rightarrow E_0 = 2P_0 T_0 = 2a_p^2(z) T_p(z)$$

Simplified chirp parameter:

$$\rightarrow \frac{dC_p}{dz} = \left(\frac{4}{\pi^2} + C_p^2 \right) \frac{\beta_2}{T_p^2} + \frac{4P_0 \gamma T_0}{\pi^2 T_p} \quad \leftarrow \alpha = 0$$

$$\leftarrow \beta_2 = -\gamma P_0 T_0^2 \quad 2$$

$$\leftarrow N = 1$$

Higher-Order Effects (2)

Moment equations for pulse parameters:

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

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

Third-order dispersion:

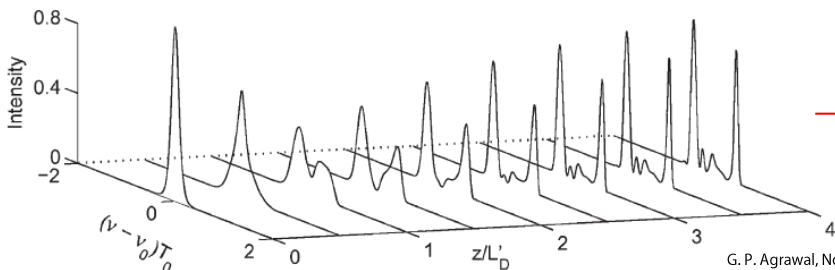
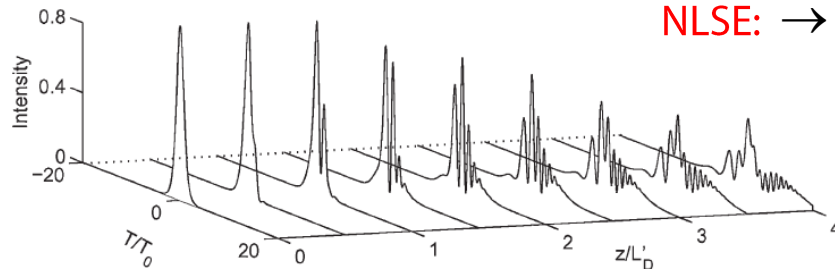
Based on the moment method: $\rightarrow s = 0, \tau_R = 0 \rightarrow \Omega_p = 0$
 $\rightarrow C_p = 0, T_p = T_0$
 $\rightarrow q_p(z) = (\beta_3/6T_0^2)z \equiv \delta_3(z/L_D)$

Near the dispersion-zero wavelength:

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

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

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



→ Splitting of the spectrum

Higher-Order Effects (3)

Fourth-order dispersion:

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

\leftarrow Dispersion-flattened fibers

Solution form:

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

\leftarrow Autosolitons

Other TOD effect: \rightarrow Soliton fission

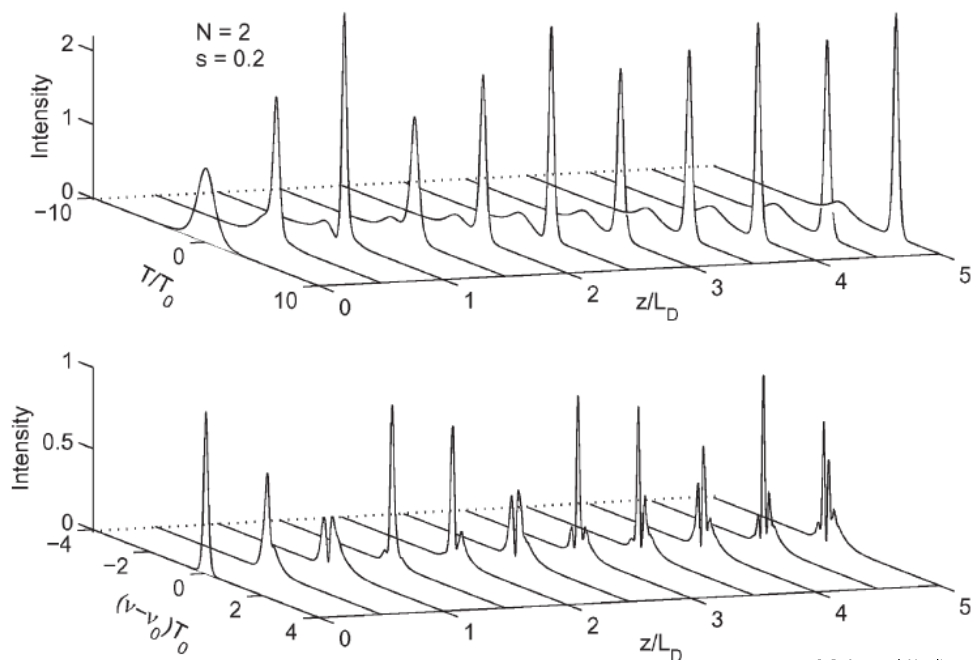
Higher-Order Effects (4)

Self-steepening:

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

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

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



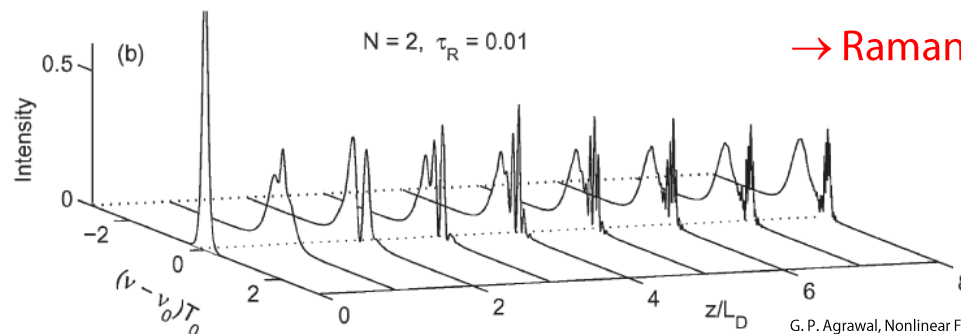
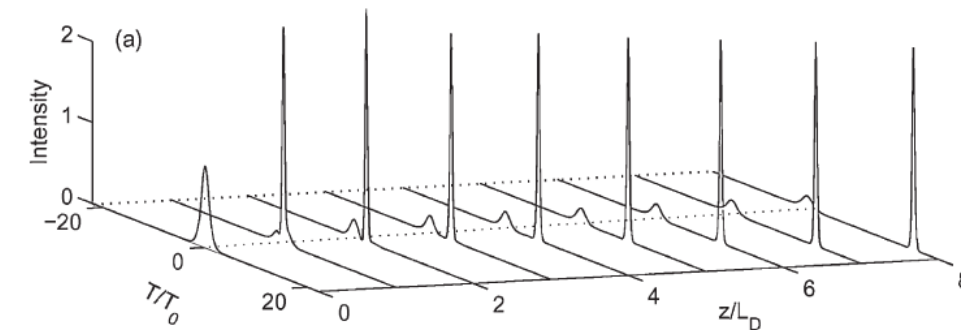
Higher-Order Effects (5)

Intrapulse Raman scattering:

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

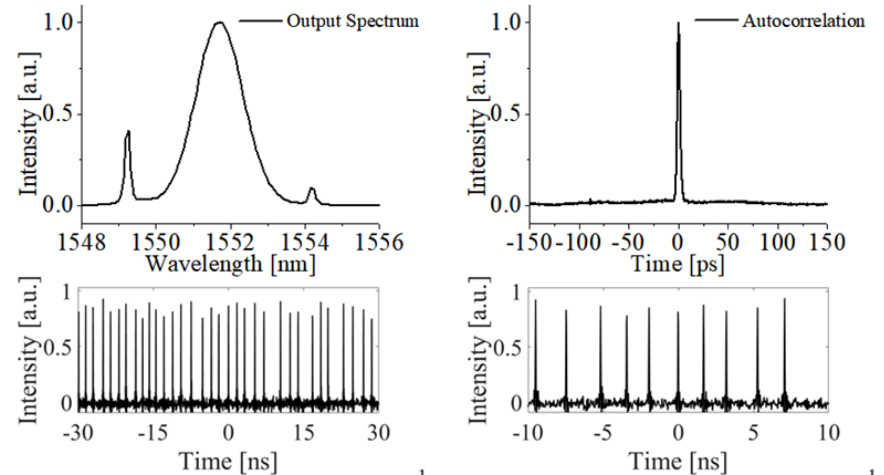
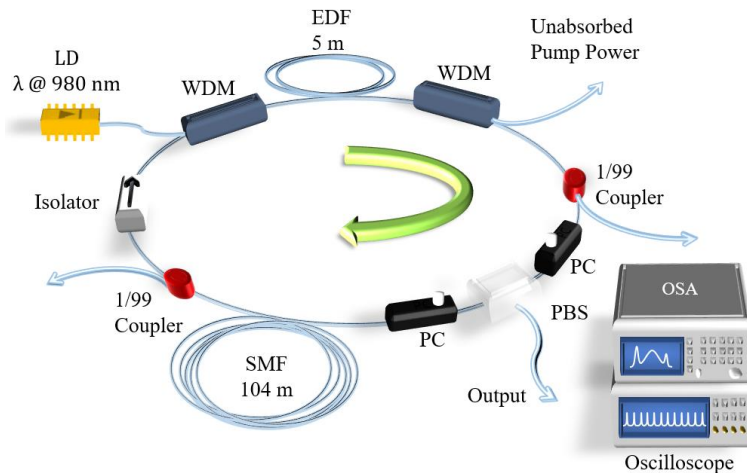
$$\rightarrow \Omega_p = -\frac{8T_R\bar{\gamma}P_0}{15T_0^2} z = -\frac{8T_R|\beta_2|}{15T_0^4} z \quad \leftarrow N = \gamma P_0 T_0^2 / |\beta_2| = 1$$

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

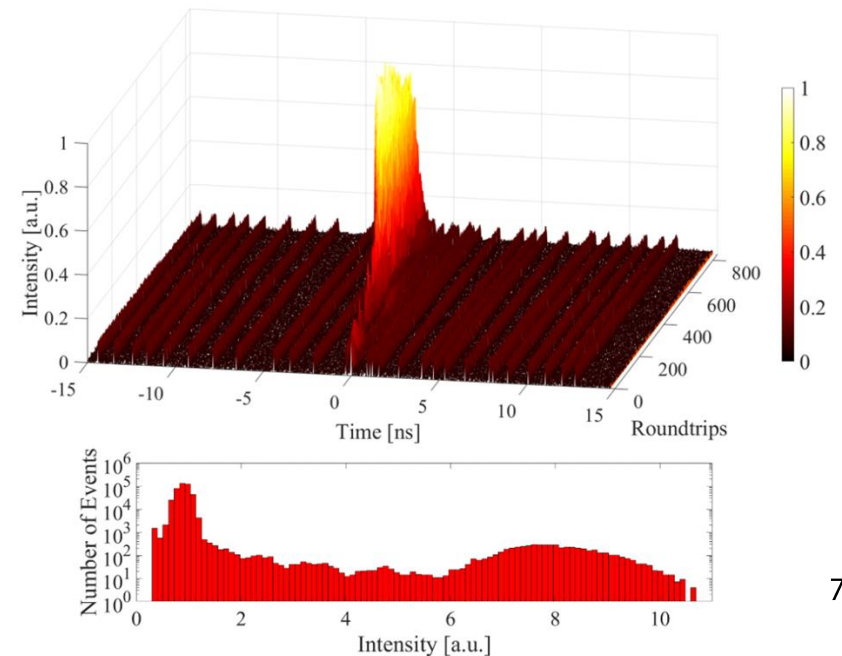
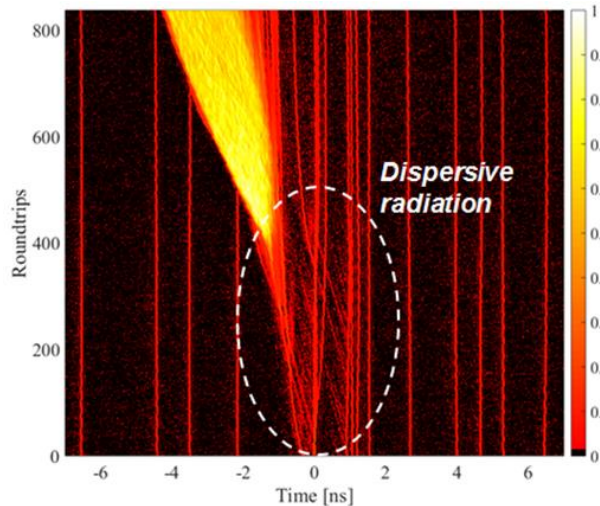


Generation of Solitons

Fiber ring cavity for generation of solitons:



Soliton interactions: → Dispersive waves



Burst of a Super Rogue Wave

Soliton interaction into the burst of a super rogue wave :

