Резонансное взаимодействие квазилинейных волн с оптическими солитонами и генерация оптического суперконтинуума в нелинейных световодах

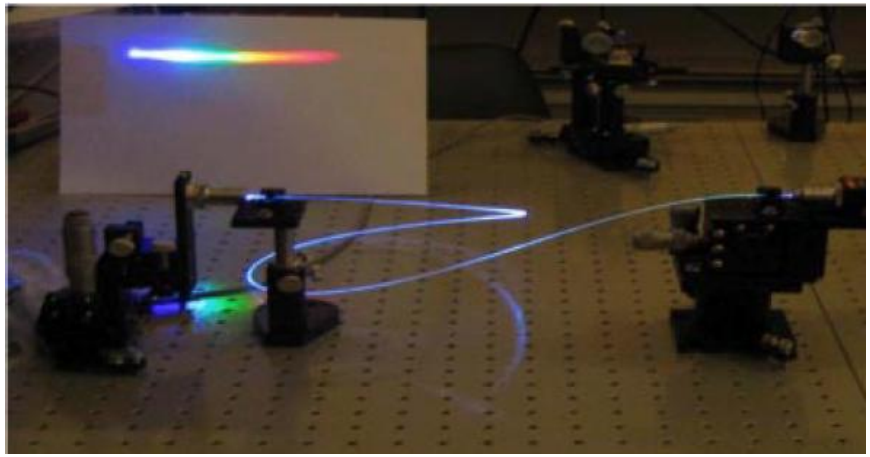
А. Юлин

физико-технический факультет,
международный исследовательский центр нанофотоники и метаматериалов

ITMO UNIVERSITY

Очень краткое введение…

Генерация оптического суперконтинуума



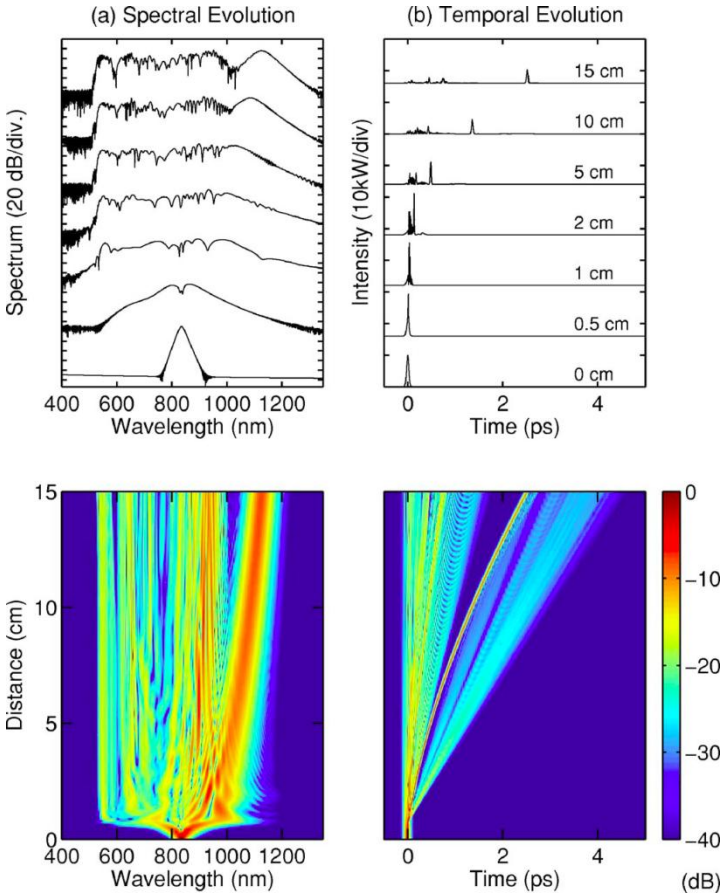
Июнь 2006 г. УСПЕХИ ФИЗИЧЕСКИХ НАУК *Том 176, № 6*

ОБЗОРЫ АКТУАЛЬНЫХ ПРОБЛЕМ

Да будет белый свет: генерация суперконтинуума сверхкороткими лазерными импульсами

А.М. Желтиков

The input sech2 input pulse at 835 nm has 10 kW peak power and 50 fs FWHM



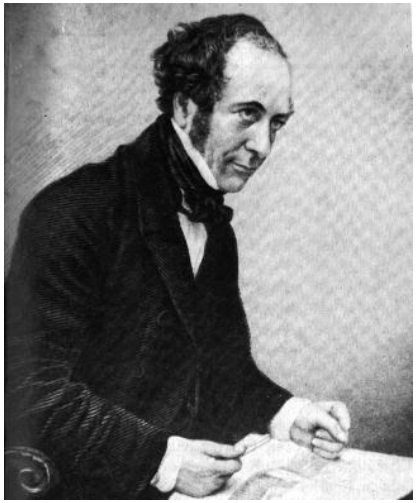
REVIEWS OF MODERN PHYSICS, VOLUME 78, OCTOBER–DECEMBER 2006

Supercontinuum generation in photonic crystal fiber

John M. Dudley Goëry Genty Stéphane Coen

Уединенные волны

"Wave of translation"



NATURE, V376, No. 6539,

3rd August 1995, p373

John Scott Russell (1808-1882)

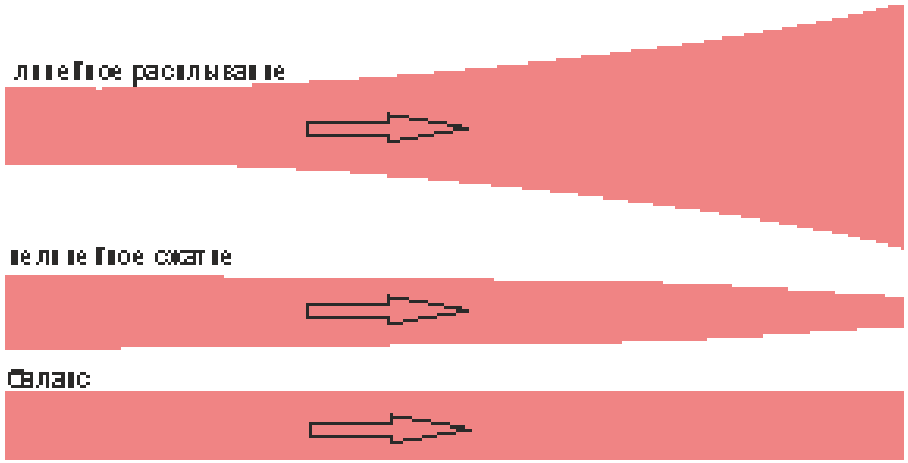
"Report on Waves": (Report of the fourteenth meeting of the British Association for the Advancement of Science, York, September 1844 (London 1845), pp 311-390, Plates XLVII-LVII).

Эффекты, ведущие к расплыванию волнового пакета

Эффекты, ведущие к сжатию волнового пакета

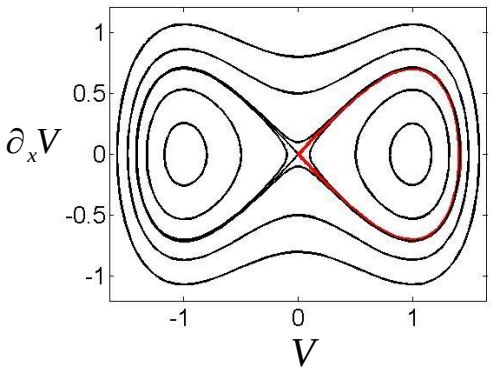
баланс

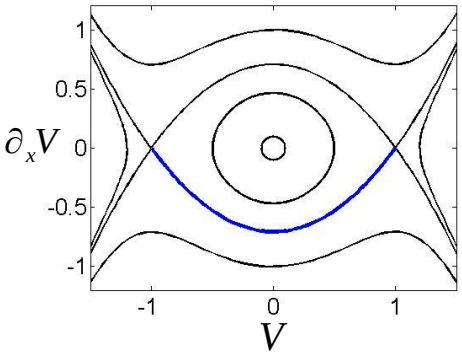
Уединенная волна

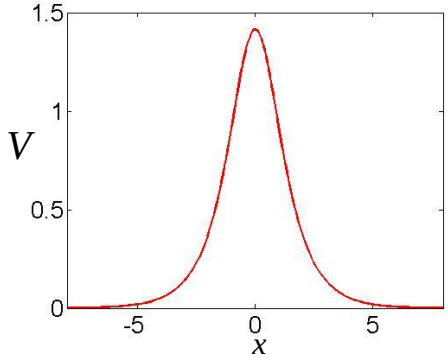


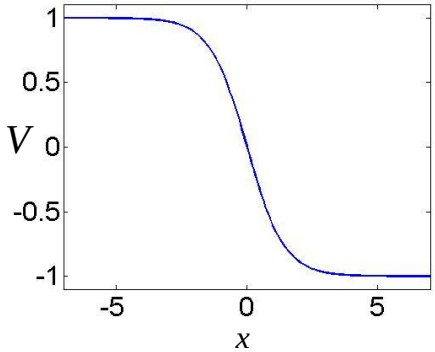
$$i\partial_t U + \partial_x^2 U + \alpha |U|^2 U = 0$$

$$U = V(x)e^{i\delta t} \qquad \partial_x^2 V - \delta V + \alpha V^3 = 0$$



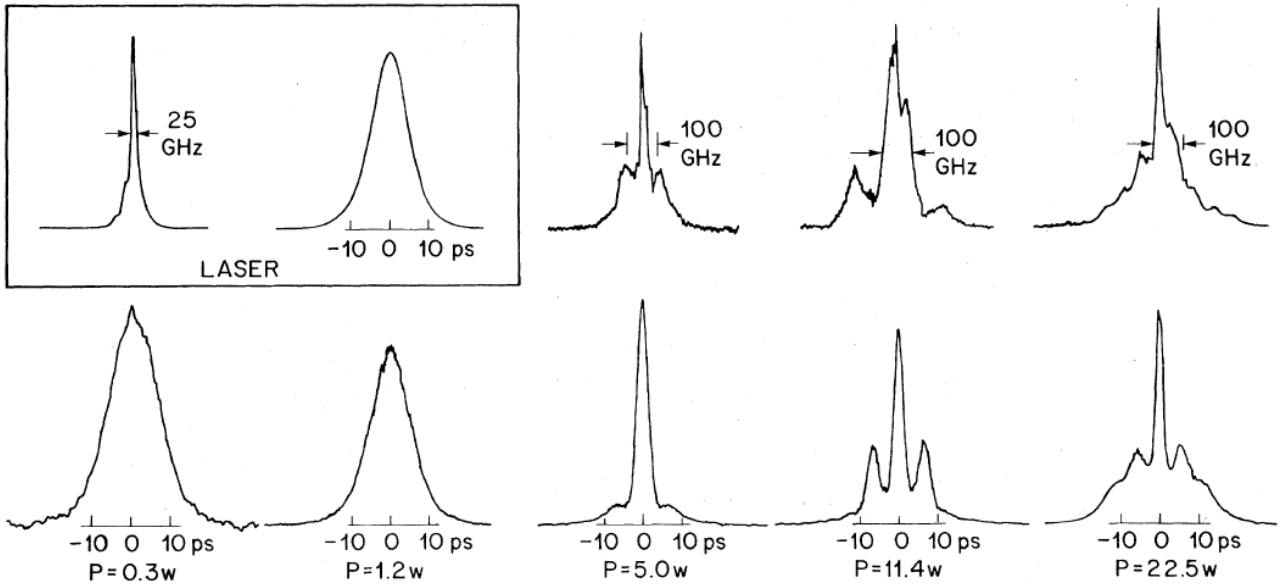






Солитоны в пассивных оптических волноводах

Баланс дисперсионного расплывания и нелинейной самфокусировки



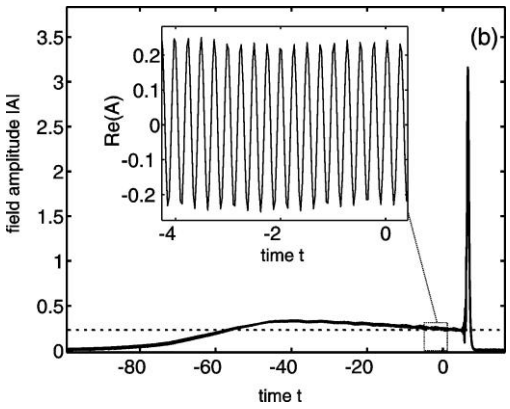
VOLUME 45, NUMBER 13 PHYSICAL REVIEW LETTERS 29 SEPTEMBER 1980

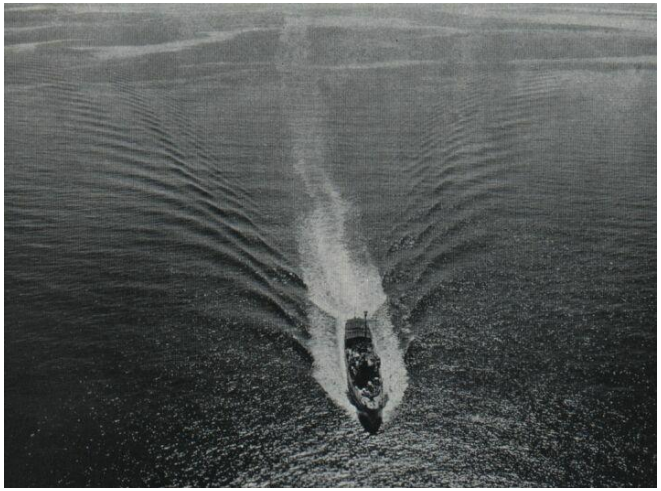
Experimental Observation of Picosecond Pulse Narrowing and Solitons in Optical Fibers

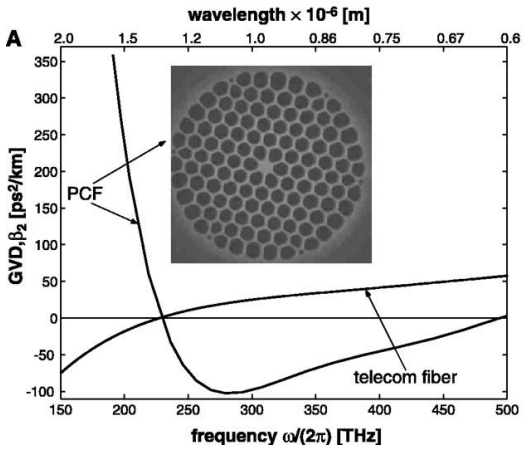
L. F. Mollenauer, R. H. Stolen, and J. P. Gordon

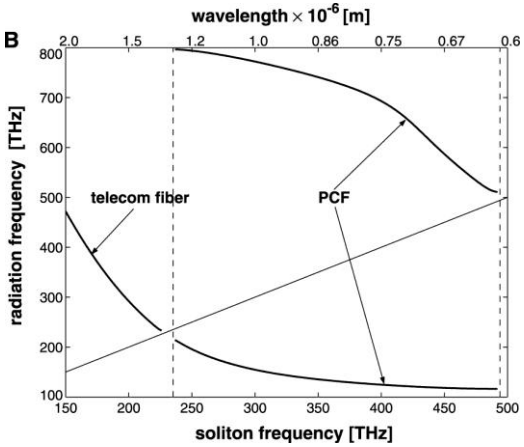
Черенковское излучение солитонов

Распространение оптического импульса на частоте близкой к частоте нулевой дисперсии







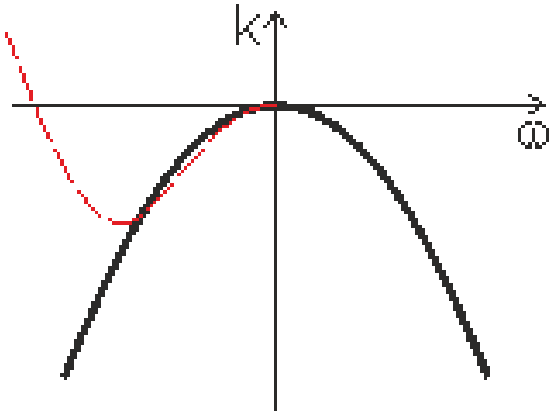


Математическая модель

$$i\partial_z E + \hat{D}_t E + \hat{N}(E) = 0$$

$$i\partial_z E + \frac{1}{2}\partial_t^2 E + |E|^2 E = 0$$

$$\hat{D}_t = \frac{1}{2}\partial_{tt} - i\beta_3\partial_{ttt} + \ldots$$



$$\hat{N}(E) = (1-\Theta)|E|^2 E + E\int_{-\infty}^{t} R(t')|E(t-t')|^2 dt'$$

$$R(t) = \Theta\frac{\tau_1^2 + \tau_2^2}{\tau_1\tau_2^2} e^{-t/\tau_2} \sin\frac{t}{\tau_1}$$

Резонансное излучение

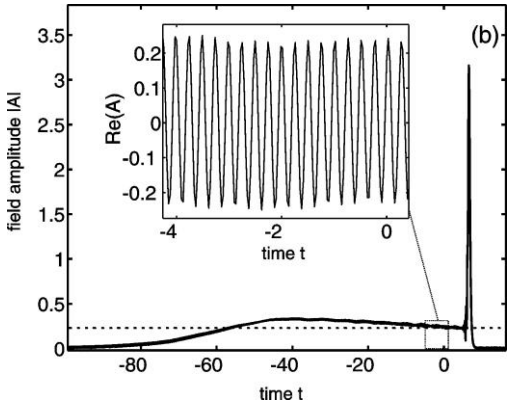
P. K. A. Wai, C. R. Menyuk,* Y. C. Lee, and H. H. Chen
464 OPTICS LETTERS / Vol. 11, No. 7 / July 1986

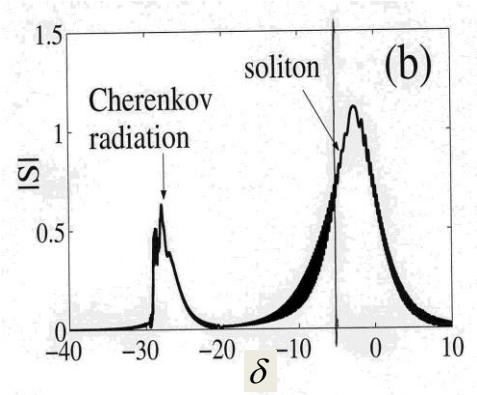
$$\partial_z\psi - i\hat{D}\psi - 2iF^2\psi - iF^2\psi^* e^{2iqz} = i(\hat{D} - \frac{1}{2}\partial_t^2)Fe^{iqz}$$

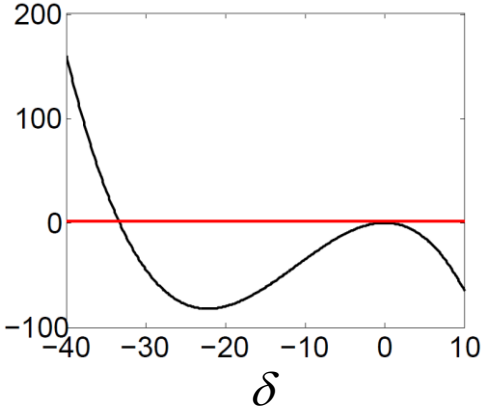
$$F(\xi) = \sqrt{2q}\ \mathrm{sech}\left(\frac{\xi}{w}\right), \quad w = \sqrt{\frac{-D_s''}{2q}},$$

$$q + D_s - [\delta_s - \delta_r]D_s' = D(\delta_r) \qquad D_s = D(\delta_s) \qquad D_s' = \partial_\delta D(\delta_s) \qquad D_s'' = \partial_\delta^2 D(\delta_s)$$

$$D = \frac{1}{2}\delta^2 + \beta_3\delta^3$$







Влияние излучения на динамику солитонов

Science 19 Sep 2003:Vol. 301, Issue 5640, pp. 1705-1708

D. V. Skryabin,* F. Luan, J. C. Knight, P. St. J. Russell

Adiabatic theory

PHYSICAL REVIEW E **70**, 016615 (2004)

F. Biancalana, D. V. Skryabin,* and A. V. Yulin

$$Q=\int |E|^2\,dt \qquad M=\frac{1}{2i}\int (E^*\partial_t E - c.c.)dt \qquad E_s=\sqrt{2q}\,\mathrm{sech}\left(\sqrt{\frac{2q}{-D_s''}}\cdot(t-D_s' z)\right)\cdot e^{-i\delta_s t+i(D_s+q)z}$$

$$\partial_z q = -\frac{|\mathcal{I}|^2}{\partial_q Q_s |D_s' - D_r'|}.$$

$$Q_s \partial_z \delta_s = [\delta_s - \delta_r]\partial_z Q_r - \alpha.$$

$$\alpha \equiv 4\tau_r (2q)^{5/2}/[15|D_s''|^{1/2}]$$

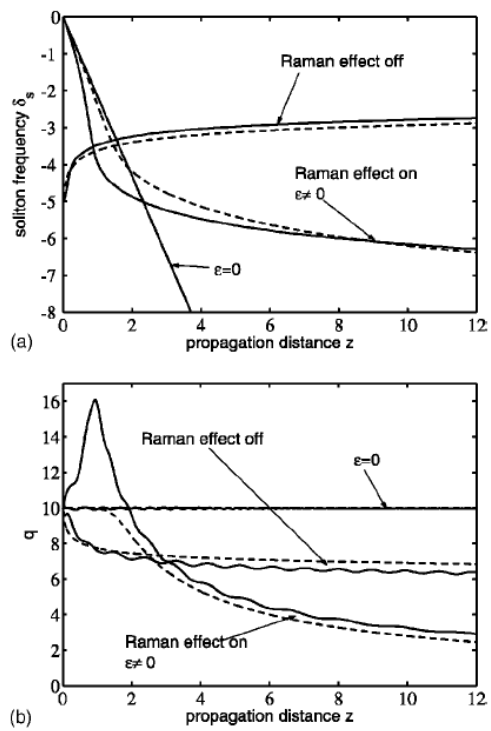
$$Q_r = z|\mathcal{I}|^2/|D_s' - D_r'|$$

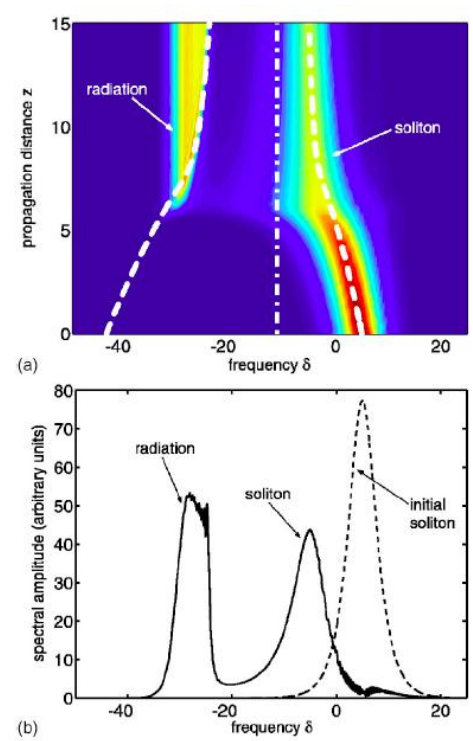
$$Q_s = \int d\xi |F|^2 = 2\sqrt{2q|D_s''|}$$

$$F(\xi)=\sqrt{2q}\,\mathrm{sech}\left(\frac{\xi}{w}\right), \quad w=\sqrt{\frac{-D_s''}{2q}},$$

$$\mathcal{I}(\Omega) \simeq -\pi\sqrt{-D_s''}[D(\Omega+\delta_s)-D_2(\Omega)]\mathrm{sech}\left(\frac{\pi w}{2}\Omega\right)$$

$$\Omega = \delta_r - \delta_s + \frac{4q}{D_s' - D_r'}$$





Резонансное рассеяние волн малой интенсивности на солитонах

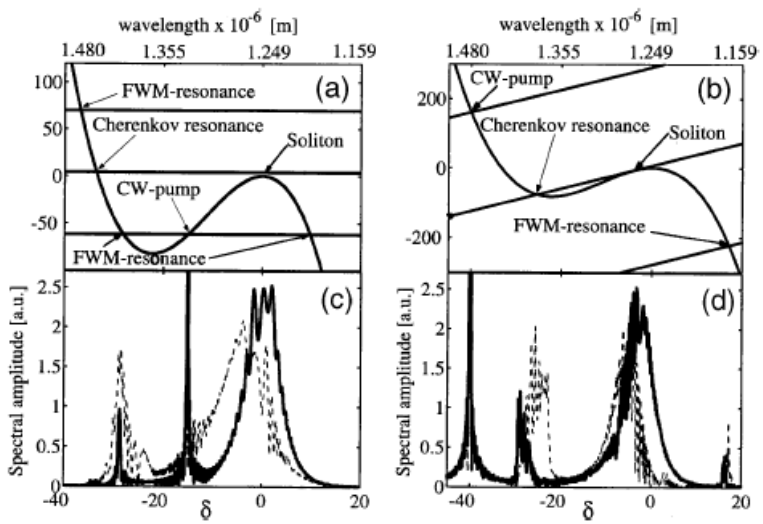
$$i\partial_z E + \hat{D}_t E + \hat{N}(E) = 0$$

$$\hat{D}_t = \frac{1}{2}\partial_{tt} - i\beta_3\partial_{ttt} + \ldots \qquad \hat{N}(E) = i(1-\Theta)\,|E|^2\,E + iE\int_{-\infty}^{t} R(t')\,|E(t-t')|^2\,dt'$$

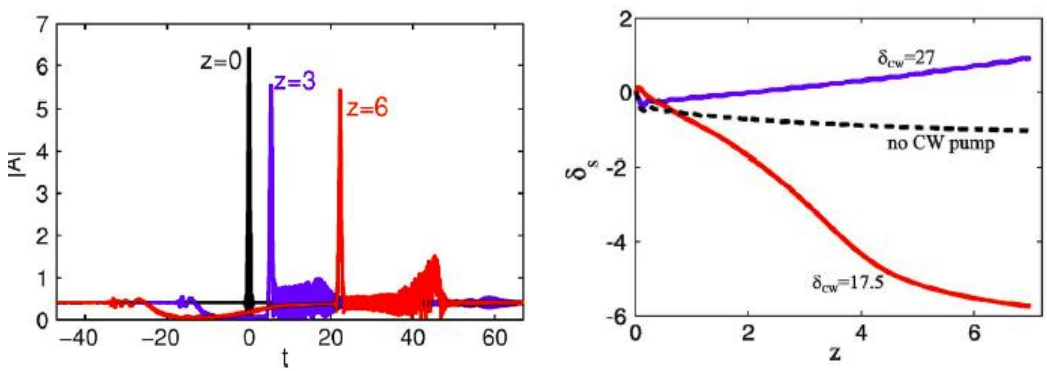
$$R(t) = \Theta\frac{\tau_1^2+\tau_2^2}{\tau_1\tau_2^2}e^{-t/\tau_2}\sin\frac{t}{\tau_1}$$

$$\partial_z\psi - i\hat{D}\psi - 2iF^2\psi - iF^2\psi^* e^{2iqz} = i(\hat{D} - \frac{1}{2}\partial_t^2)Fe^{iqz} + 2iF^2\eta e^{iD_{cw}z - i\delta_{cw}t} + iF^2\eta e^{2iqz - iD_{cw}z + i\delta_{cw}t}$$

$$q + J[D_{cw} - q] = D(\delta), \quad J = -1, 0, +1$$



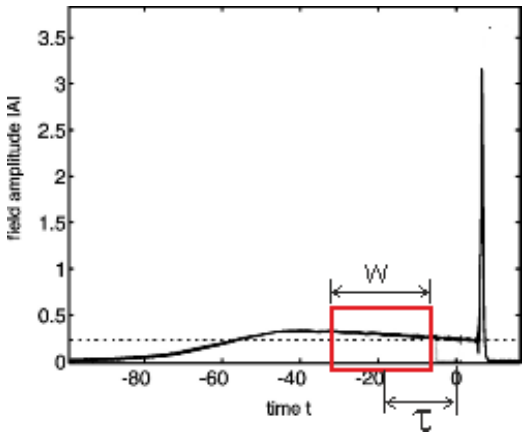
2004 / Vol. 29, No. 20 / OPTICS LETTERS 2411
A. V. Yulin, D. V. Skryabin, and P. St. J. Russell



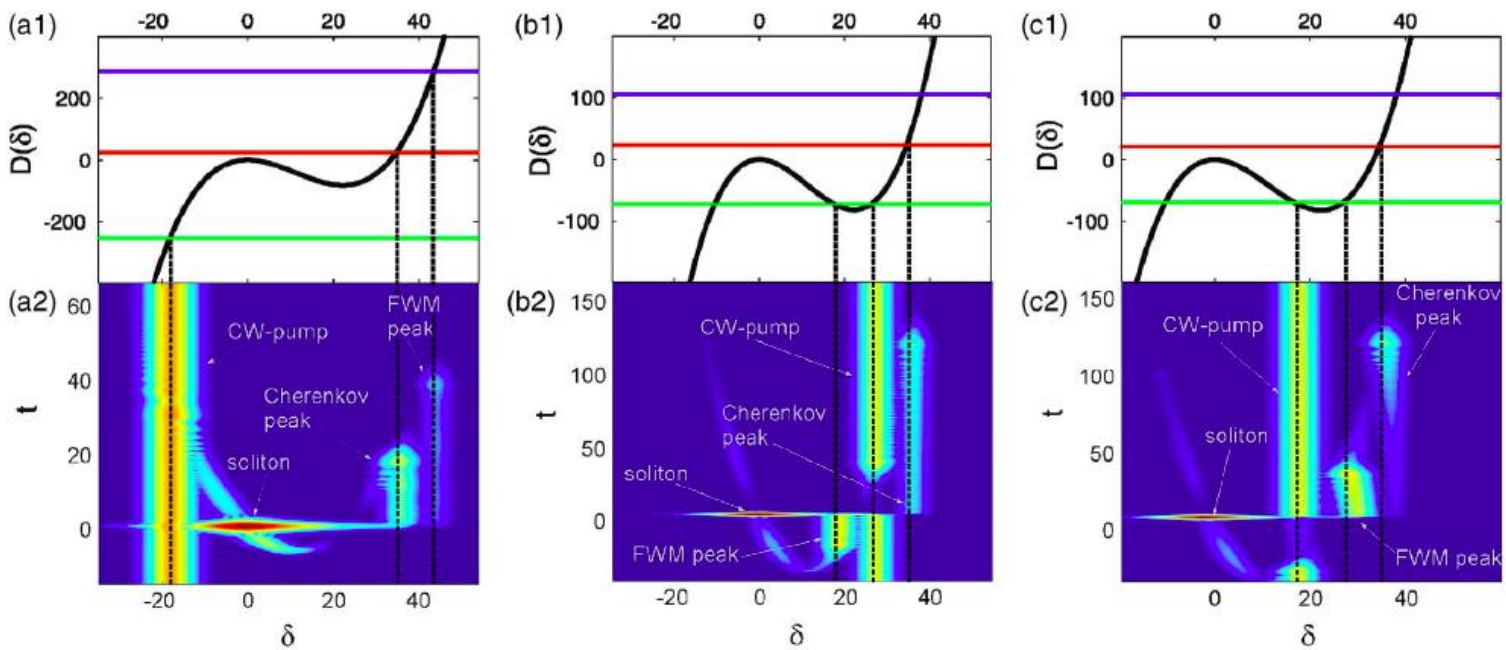
PHYSICAL REVIEW E **72**, 016619 (2005)
D. V. Skryabin* and A. V. Yulin

XFROG диаграммы

$$I(\tau,\omega)=\int f(t-\tau)E(t)e^{i\omega t}dt$$

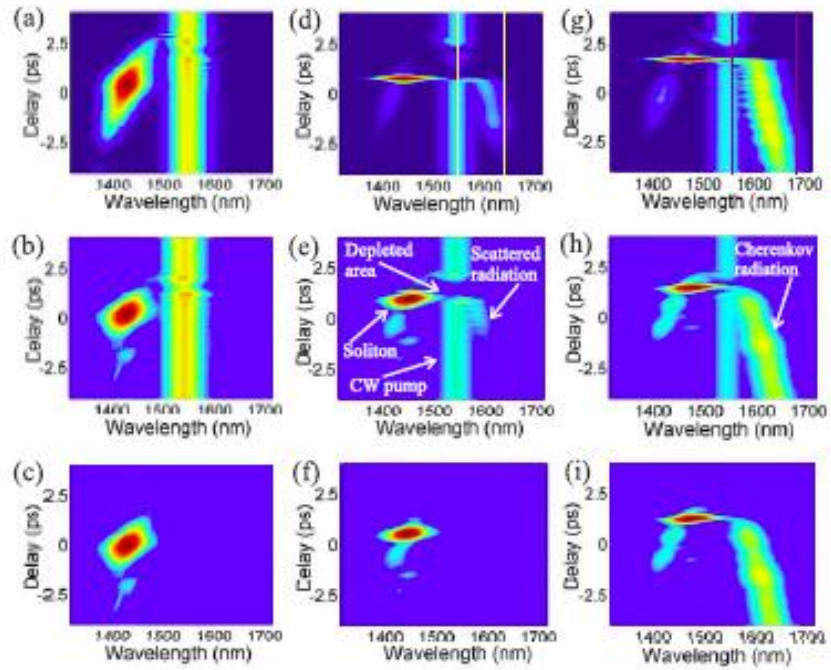


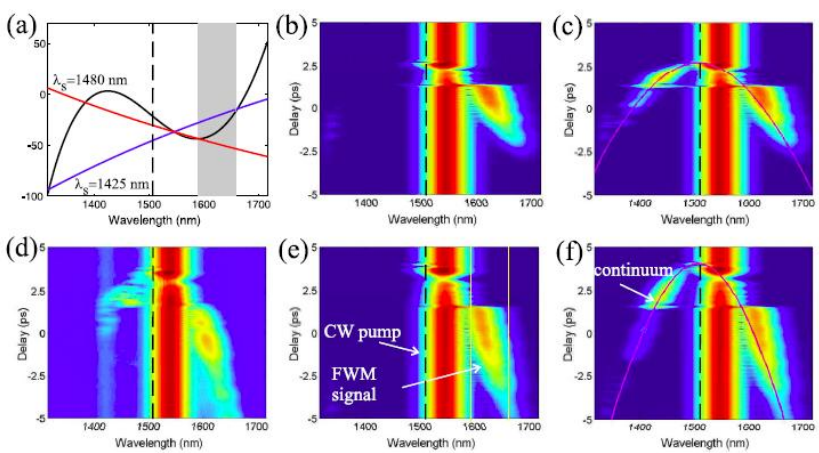
$$q+J[D_{cw}-q]=D(\delta),\quad J=-1,0,+1$$



PRL **95,** 213902 (2005) PHYSICAL REVIEW LETTERS

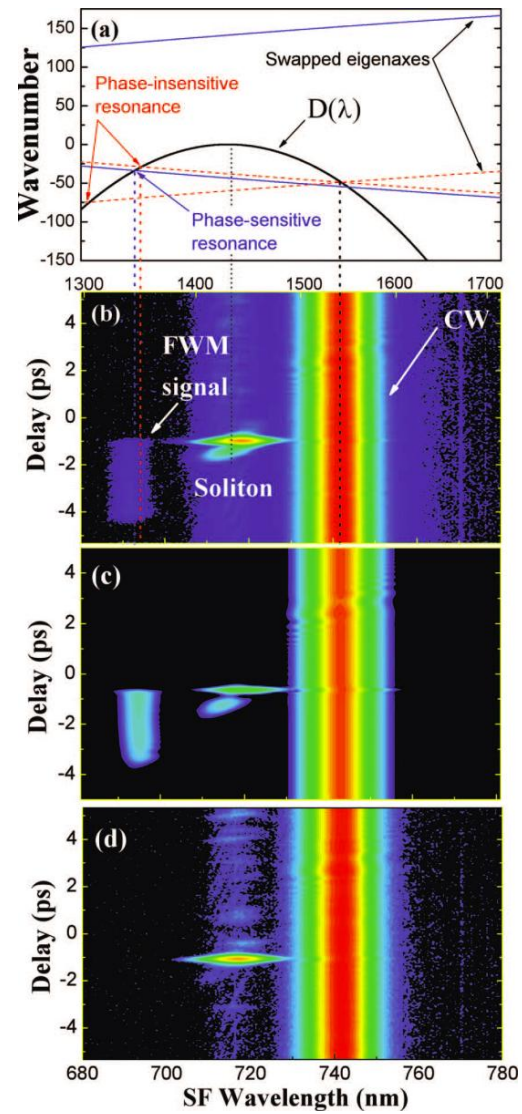
A. Efimov,[1] A. V. Yulin,[2] D. V. Skryabin,[2] J. C. Knight,[2] N. Joly,[2] F. G. Omenetto,[3] A. J. Taylor,[1] and P. Russell[2]





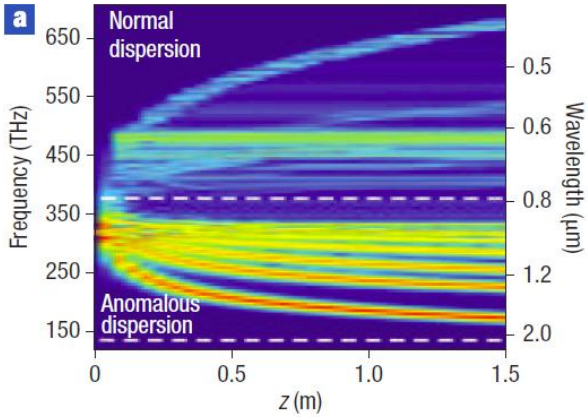
1624 OPTICS LETTERS / Vol. 31, No. 11

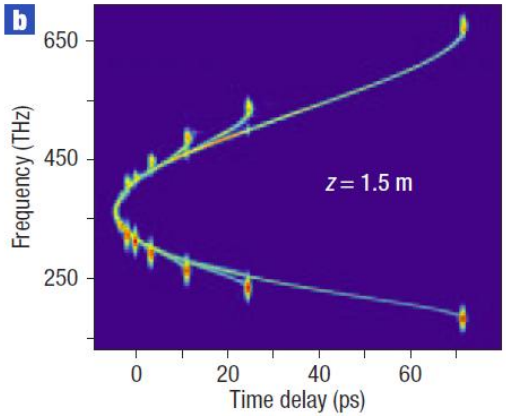
Anatoly Efimov and Antoinette I. Taylor
A. V. Yulin, D. V. Skryabin, and J. C. Knight

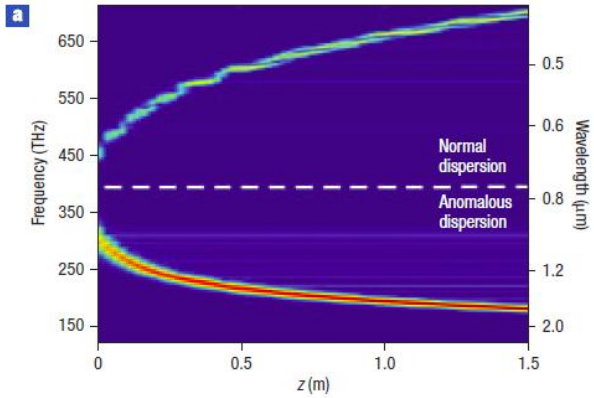


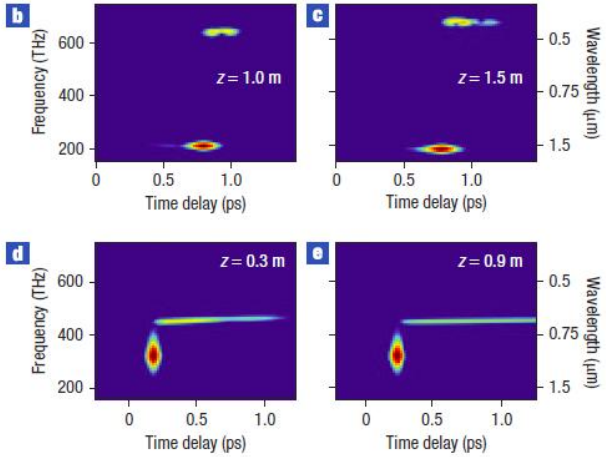
•*Nature Photonics* **volume1**, pages653–657 (2007) doi:10.1038/nphoton.2007.202

A. V. GORBACH AND D. V. SKRYABIN

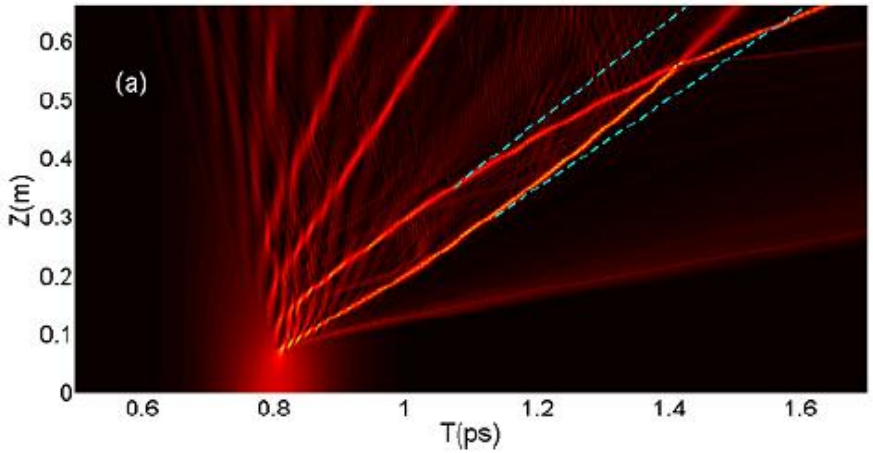






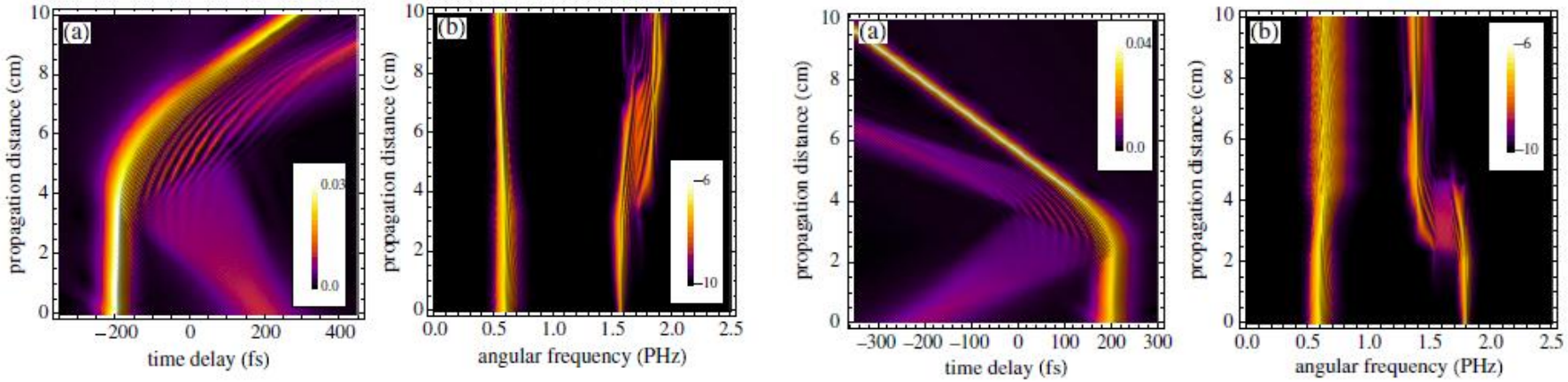


Захват излучения и взаимодействия солитонов



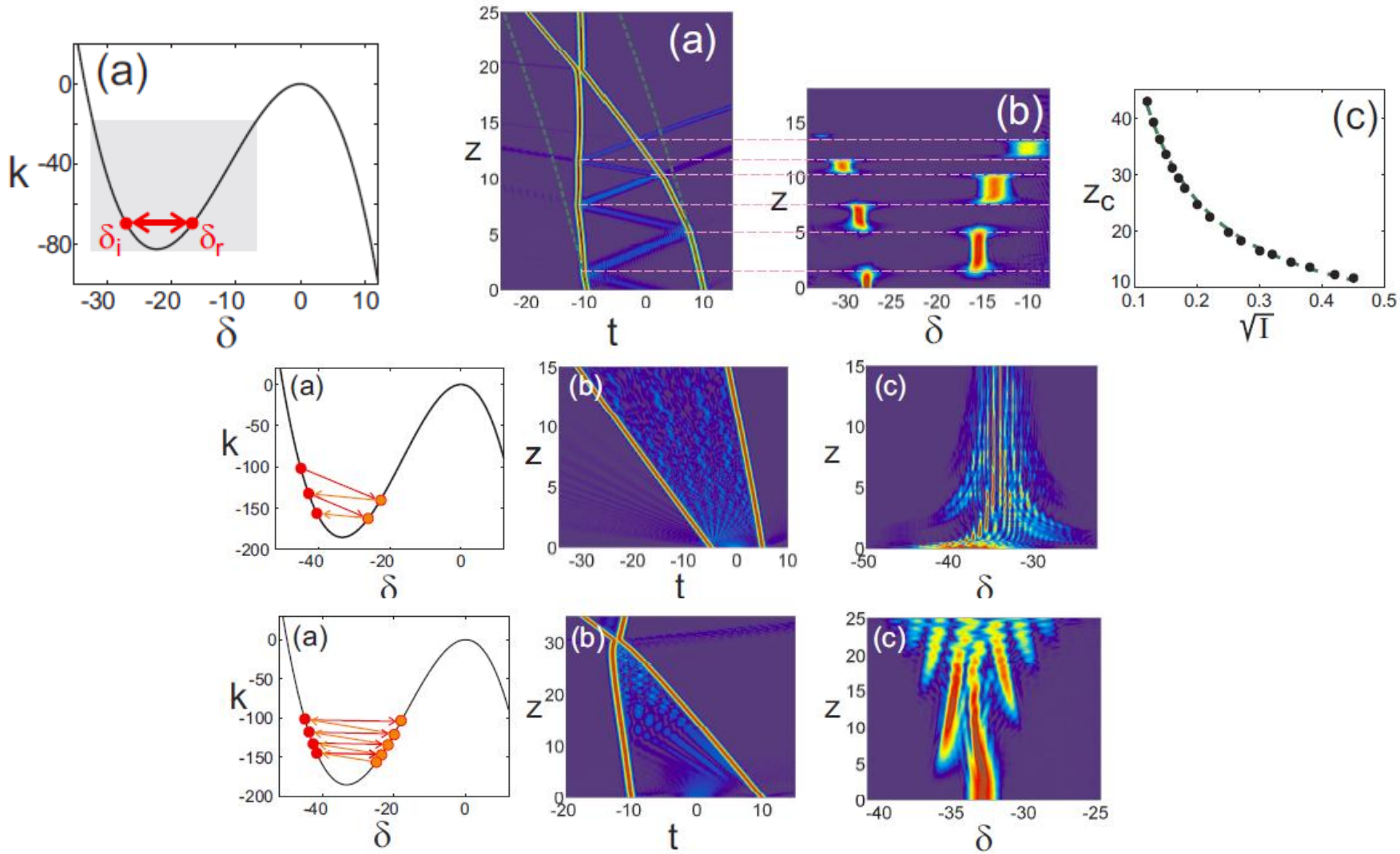
PRL **106,** 163901 (2011) PHYSICAL REVIEW LETTERS week ending 22 APRIL 2011

A. Demircan and Sh. Amiranashvili, G. Steinmeyer



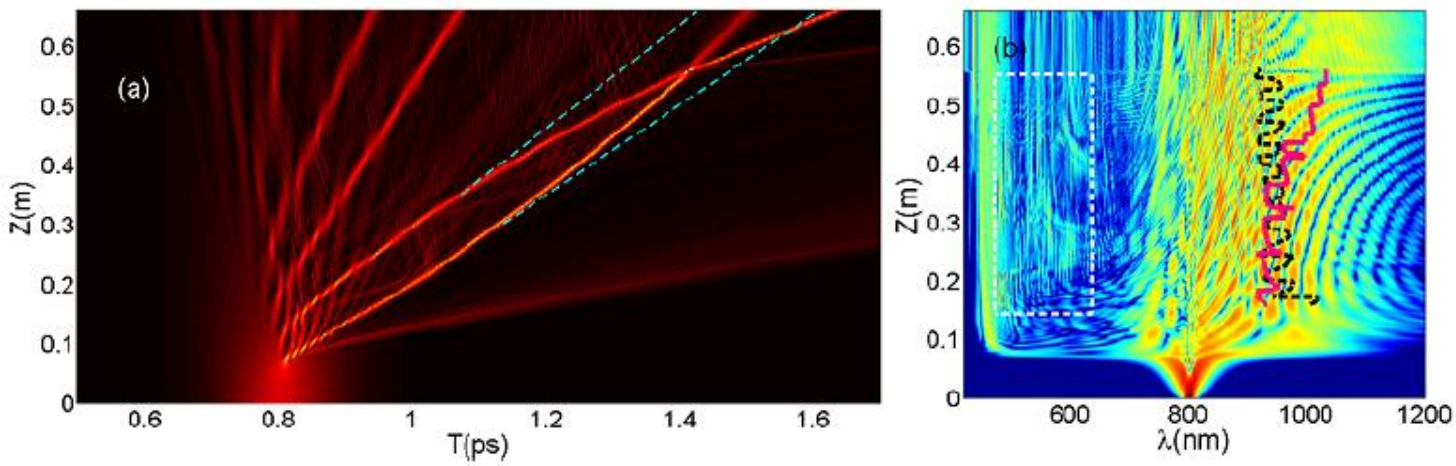
17 June 2013 | Vol. 21, No. 12 | DOI:10.1364/OE.21.014474 | OPTICS EXPRESS 14474

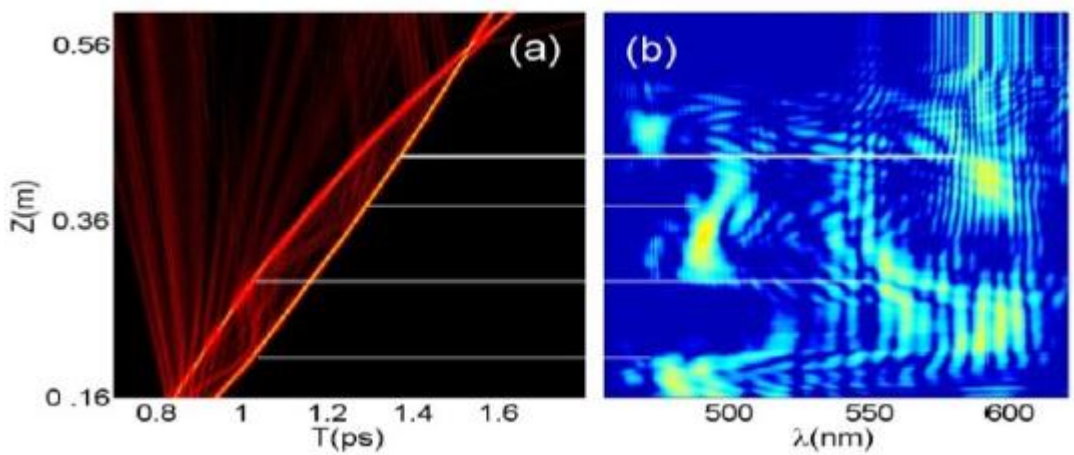
A. V. Yulin,[1] R. Driben,[2,3] B. A. Malomed,[2] and D. V. Skryabin[4,5]

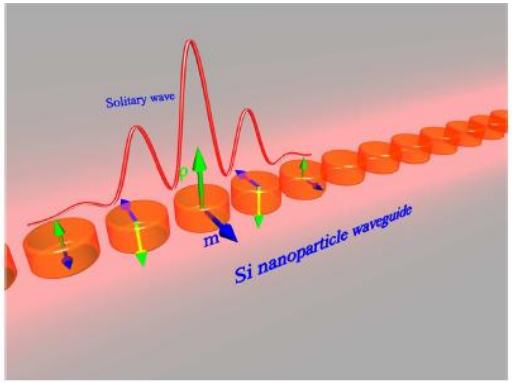


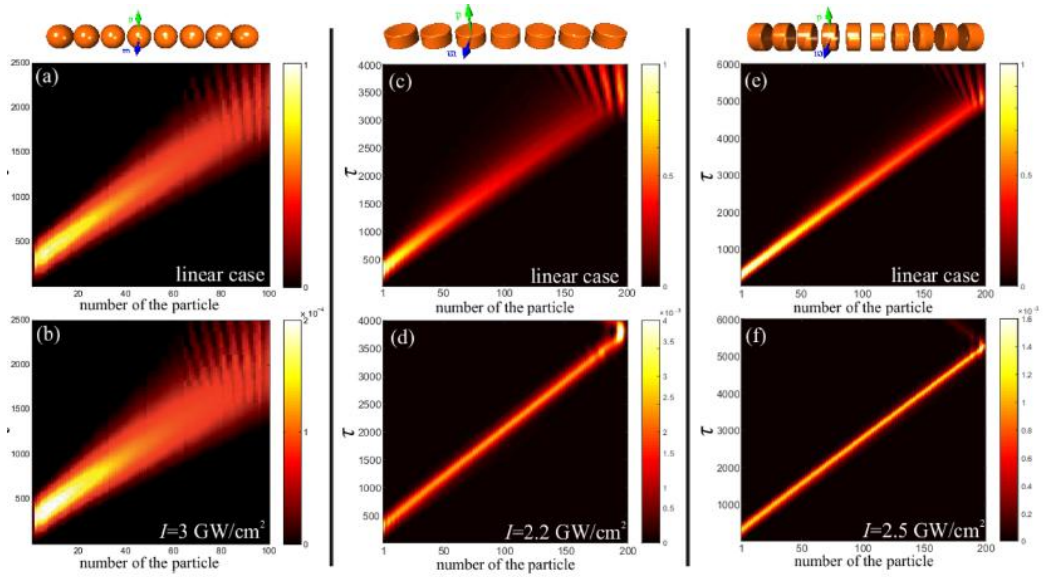
12 August 2013 | Vol. 21, No. 16 | DOI:10.1364/OE.21.019091 | OPTICS EXPRESS 19091

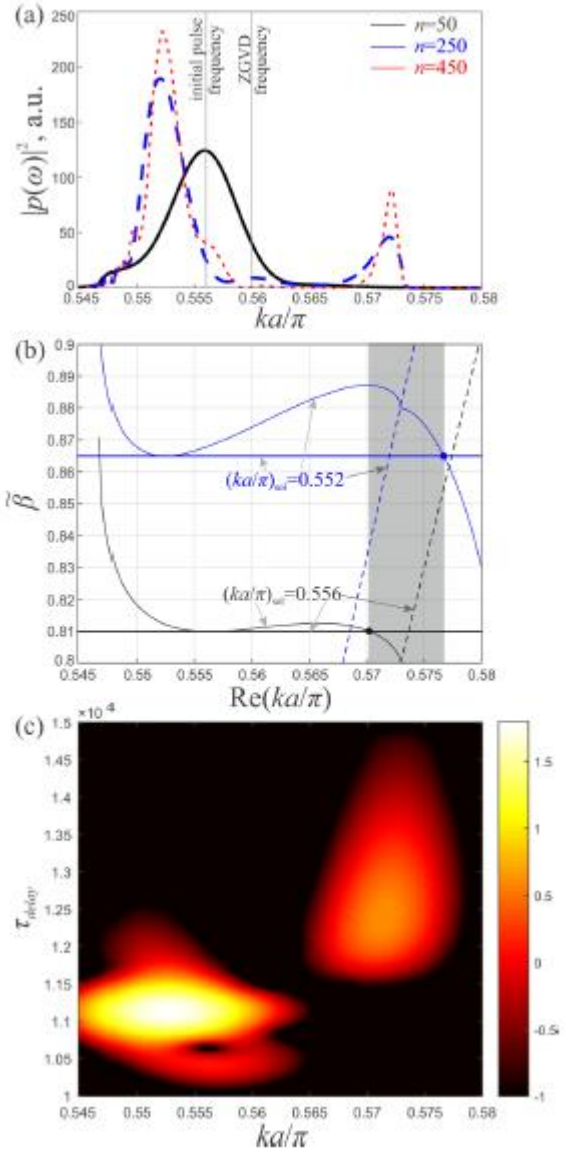
R. Driben,[1,2,*] A. V. Yulin,[3] A. Efimov,[4] and B. A. Malomed[2]











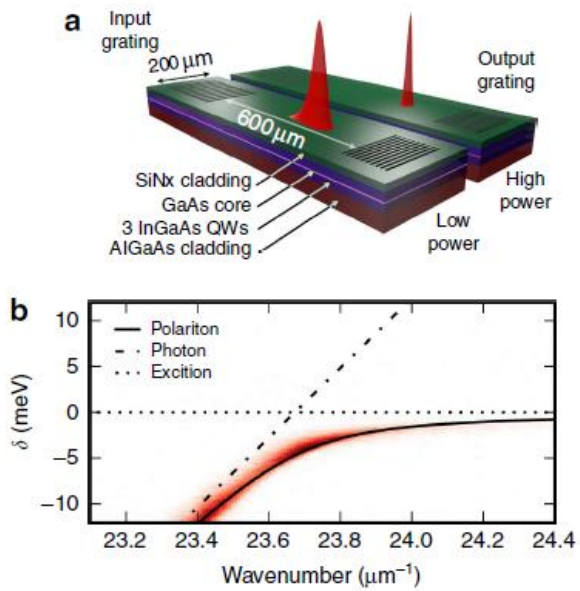
DOI: 10.1021/acsphotonics.6b00384
ACS Photonics 2016, 3, 1869−1876

Roman S. Savelev,*,† Alexey V. Yulin,† Alexander E. Krasnok,† and Yuri S. Kivshar†,‡

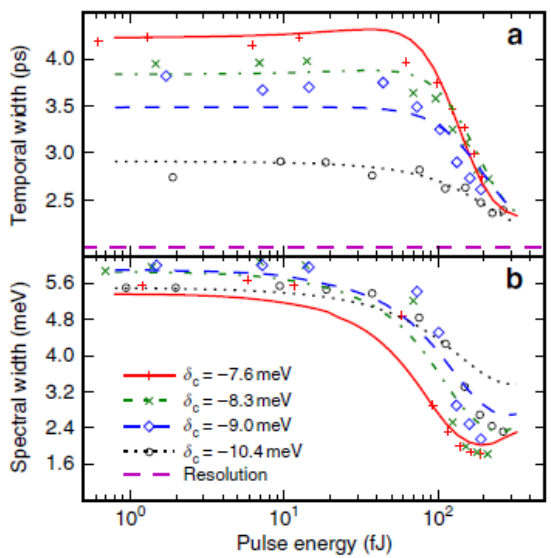
Излучение солитонов в экситон-поляритонных системах

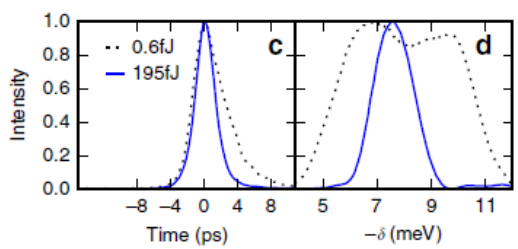
$$i\partial_t A = i\partial_x A + (\delta - i\gamma_p)A - \alpha\partial_{yy}A - \psi$$

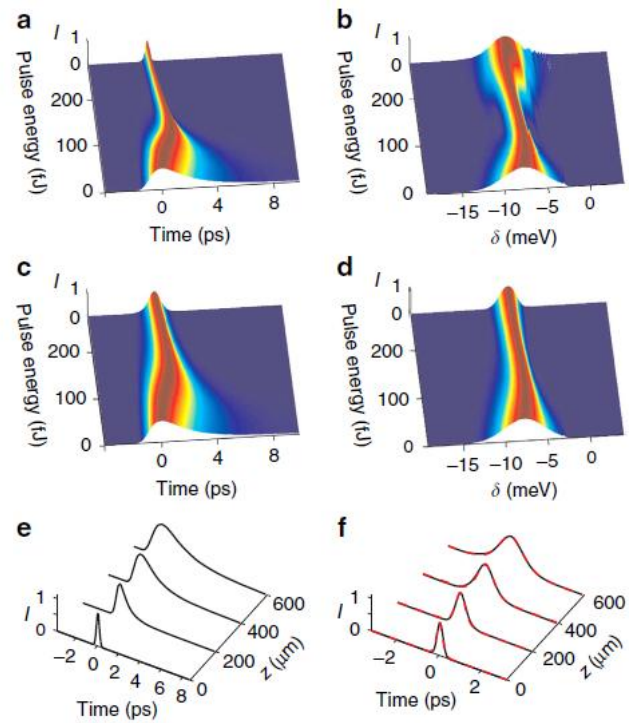
$$i\partial_t \psi = -i\gamma_p \psi + |\psi|^2 \psi - A$$



ω







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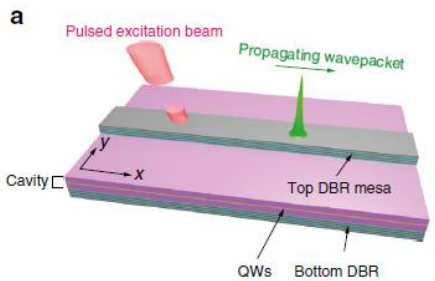
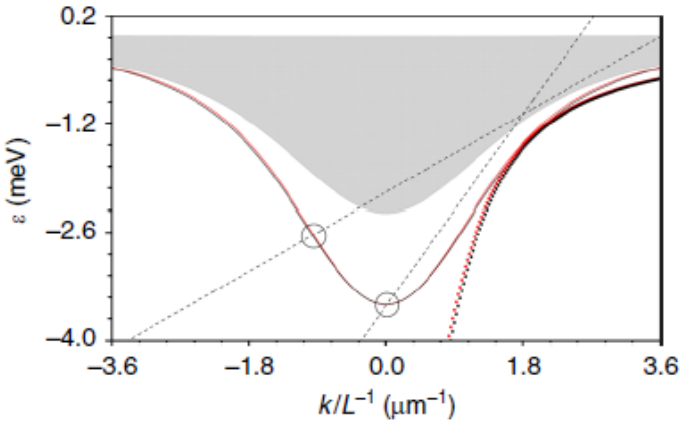
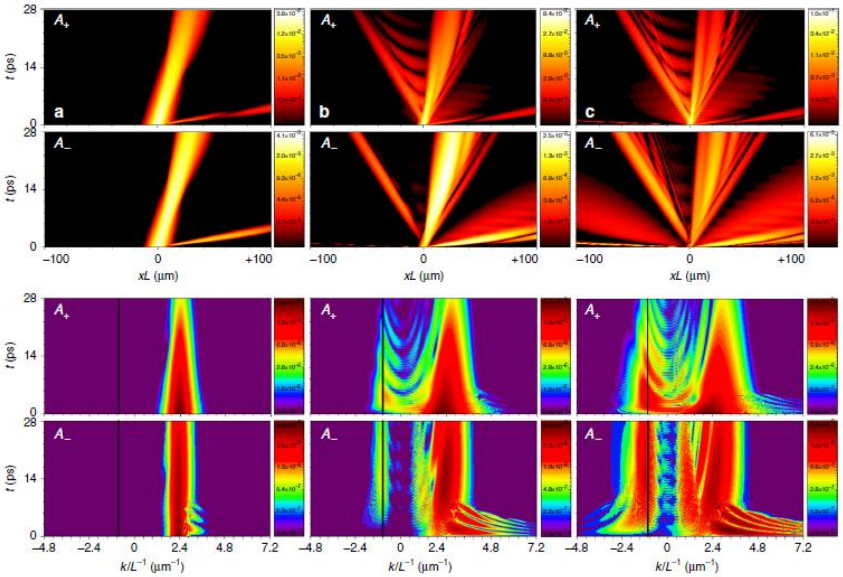
P.M. Walker[1], L. Tinkler[1], D.V. Skryabin[2,3], A. Yulin[3], B. Royall[1], I. Farrer[4,†], D.A. Ritchie[4], M.S. Skolnick[1] & D.N. Krizhanovskii[1]







$$i\partial_t A_+ + \left(\partial_x^2 + \partial_y^2\right)A_+ + (i\gamma_c + \delta_c + \delta + U(y))A_+ = -\psi_+ + \beta\left(\partial_x - i\partial_y\right)^2 A_-$$

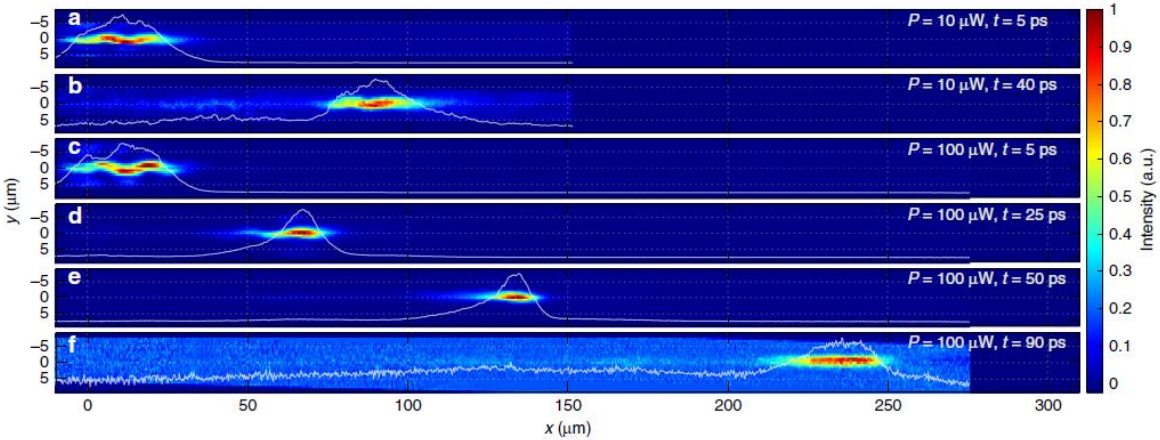
$$i\partial_t A_- + \left(\partial_x^2 + \partial_y^2\right)A_- + (i\gamma_c + \delta_c + \delta + U(y))A_- = -\psi_- + \beta\left(\partial_x + i\partial_y\right)^2 A_+$$

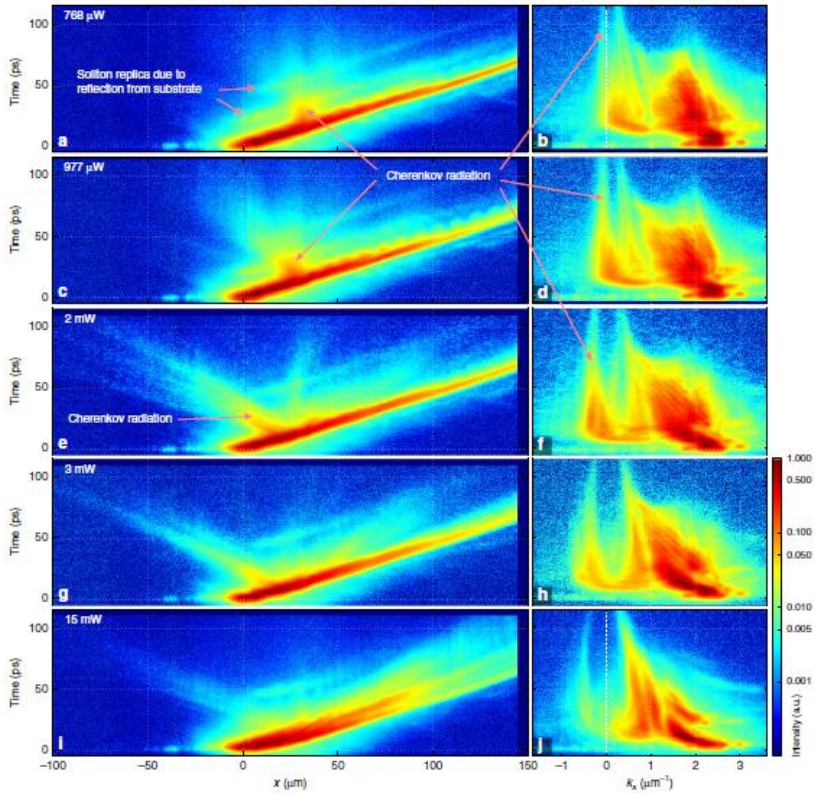
$$i\partial_t \psi_+ + \left(i\gamma_e + \delta - |\psi_+|^2 - g|\psi_-|^2\right)\psi_+ = -A_+$$

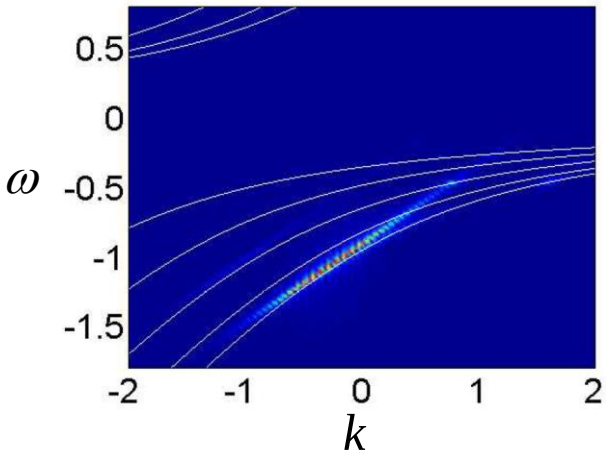
$$i\partial_t \psi_- + \left(i\gamma_e + \delta - |\psi_-|^2 - g|\psi_+|^2\right)\psi_- = -A_-$$

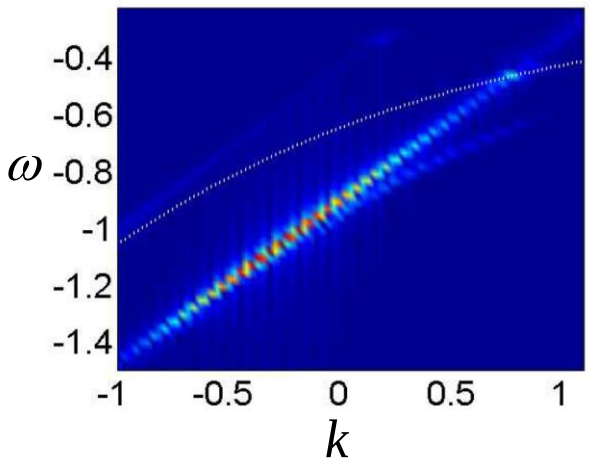
NATURE COMMUNICATIONS | 8: 1554 | DOI: 10.1038/s41467-017-01751-6 | www.nature.com/naturecommunications

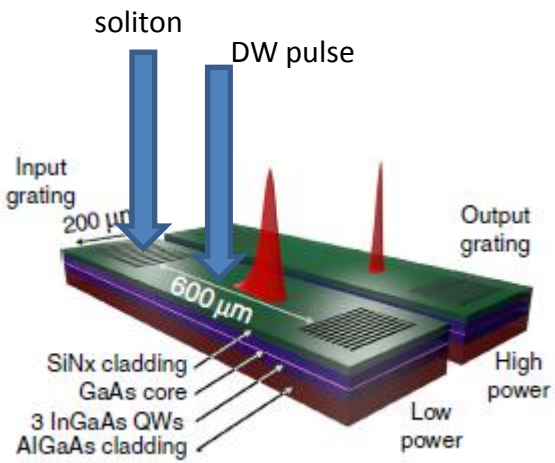
D.V. Skryabin[1,2], Y.V. Kartashov[1,3,4], O.A. Egorov[2,5], M. Sich[6], J.K. Chana[6,7], L.E. Tapia Rodriguez[6], P.M. Walker[6], E. Clarke[8], B. Royall[6], M.S. Skolnick[6] & D.N. Krizhanovskii[6]

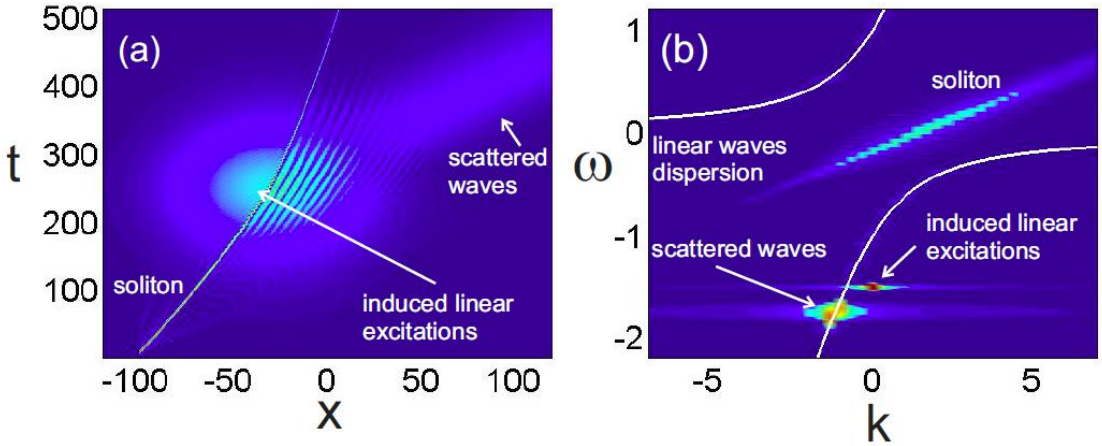

a
P = 10 μW, t = 5 ps
b
P = 10 μW, t = 40 ps
c
P = 100 μW, t = 5 ps
d
P = 100 μW, t = 25 ps
e
P = 100 μW, t = 50 ps
f
P = 100 μW, t = 90 ps
y (μm)
x (μm)
Intensity (a.u.)

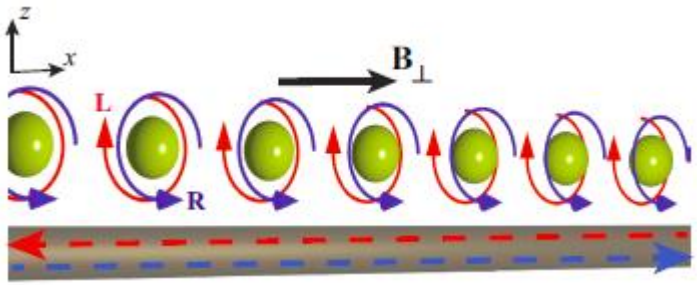

768 μW
Soliton replica due to reflection from substrate
977 μW
Cherenkov radiation
2 mW
Cherenkov radiation
3 mW
15 mW
Time (ps)
x (μm)
Intensity (a.u.)

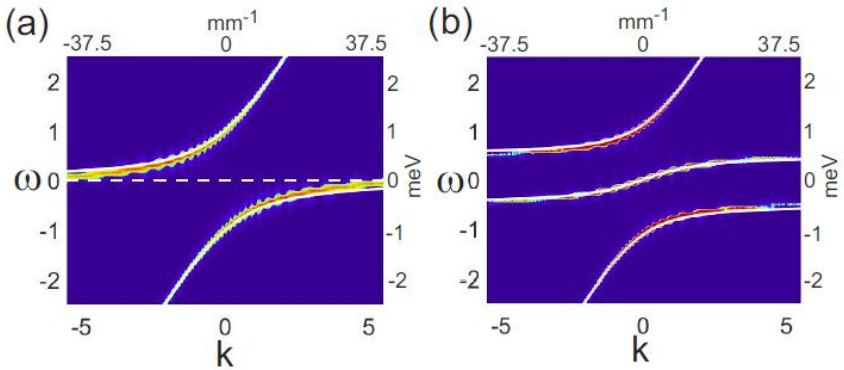

0.5
0
-0.5
-1
-1.5
ω
-2
-1
0
1
2
k

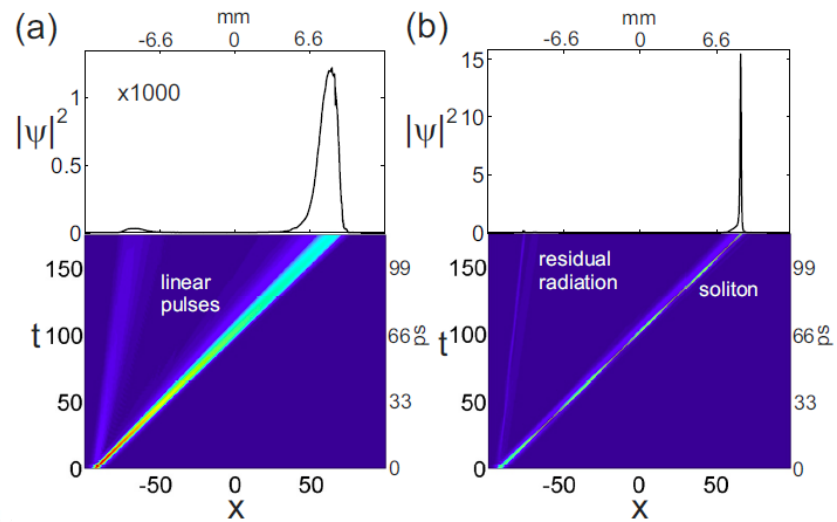

-0.4
-0.6
-0.8
-1
-1.2
-1.4
ω
-1
-0.5
0
0.5
1
k

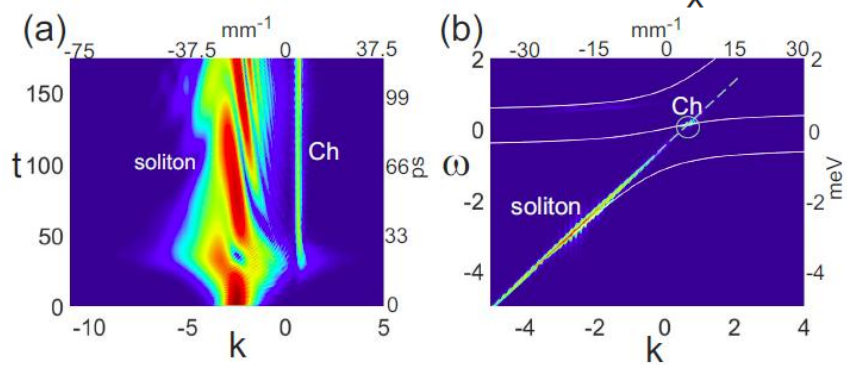

soliton
DW pulse
Input grating
200 μm
Output grating
600 μm
SiNx cladding
GaAs core
3 InGaAs QWs
AlGaAs cladding
High power
Low power


(a)
500
400
300
200
100
t
soliton
scattered waves
induced linear excitations
-100
-50
0
50
100
x
(b)
1
0
-1
-2
ω
soliton
linear waves dispersion
scattered waves
induced linear excitations
-5
0
5
k

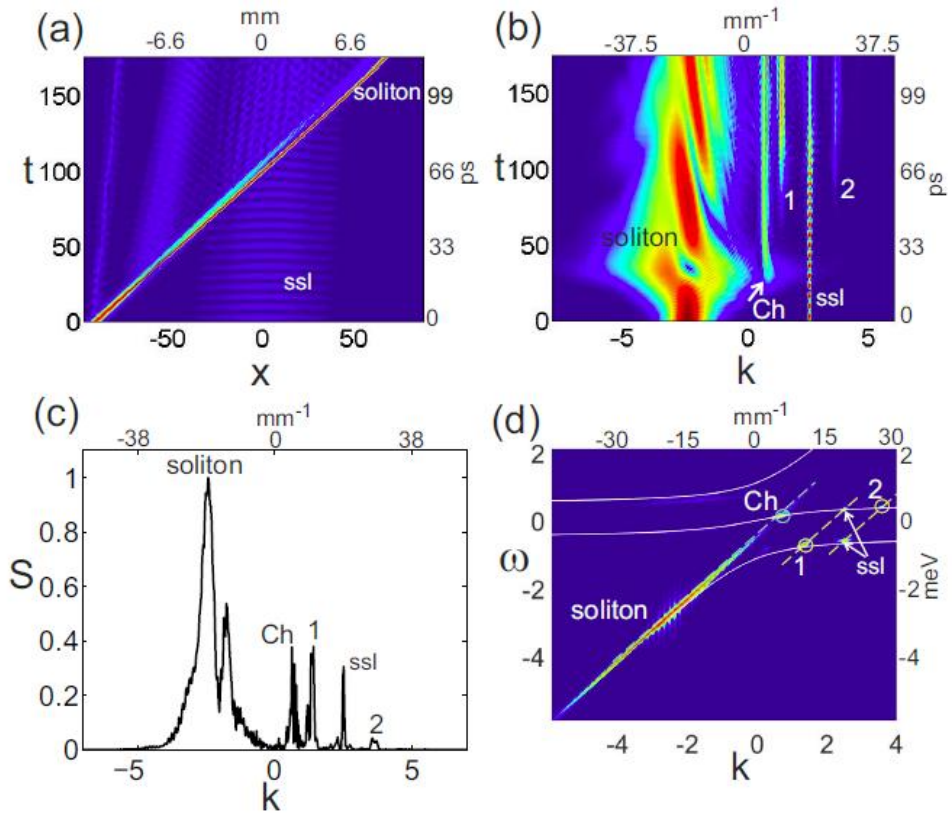


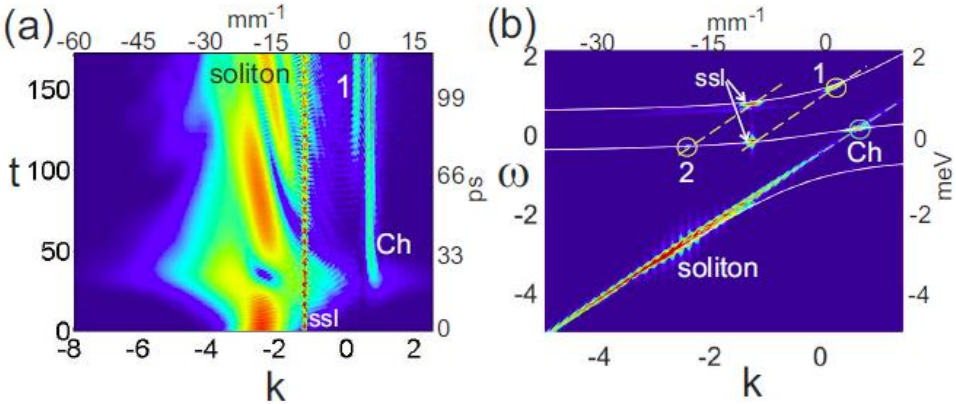






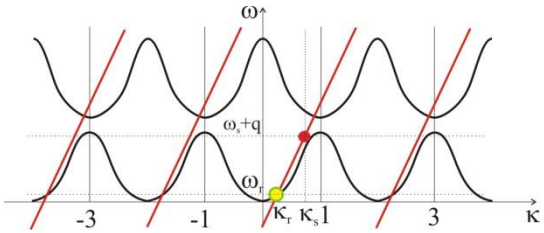
Yulin, Iorsh, Shelykh
Submitted to NJP

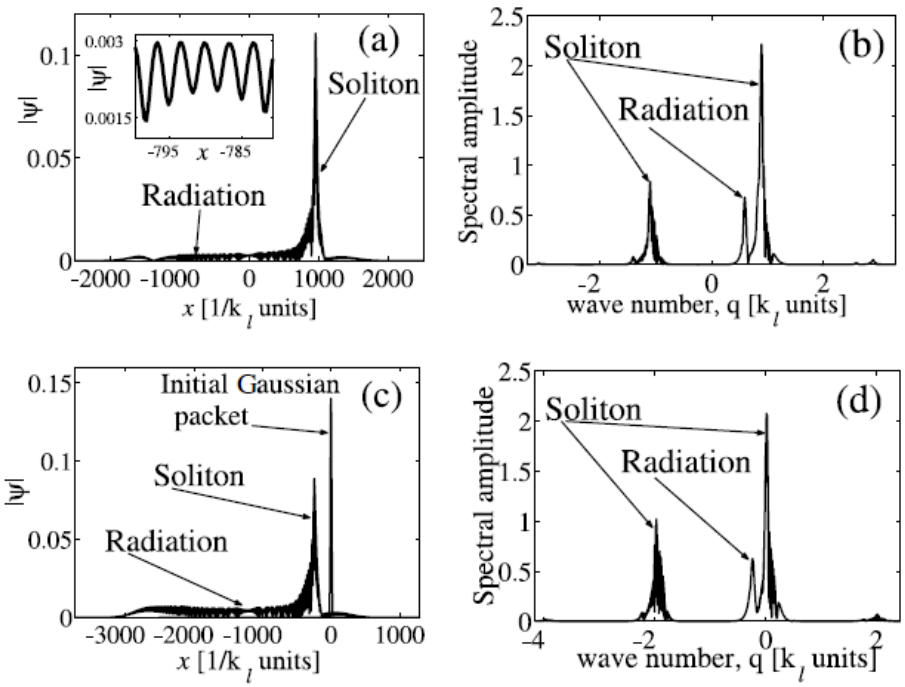

(a)
mm
-6.6
0
6.6
soliton
ssl
t
ps
x
(b)
mm-1
-37.5
0
37.5
soliton
1
2
Ch
ssl
k
(c)
mm-1
-38
0
38
soliton
Ch
1
ssl
2
S
k
(d)
mm-1
-30
-15
0
15
30
Ch
2
1
ssl
soliton
ω
meV
k


(a)
mm-1
-60
-45
-30
-15
0
15
soliton
1
Ch
ssl
t
ps
k
(b)
mm-1
-30
-15
0
ssl
1
2
Ch
soliton
ω
meV
k

Переходное излучение

$$i\partial_t\psi = -\partial_x^2\psi - \beta\psi\cos 2x + |\psi|^2\psi.$$



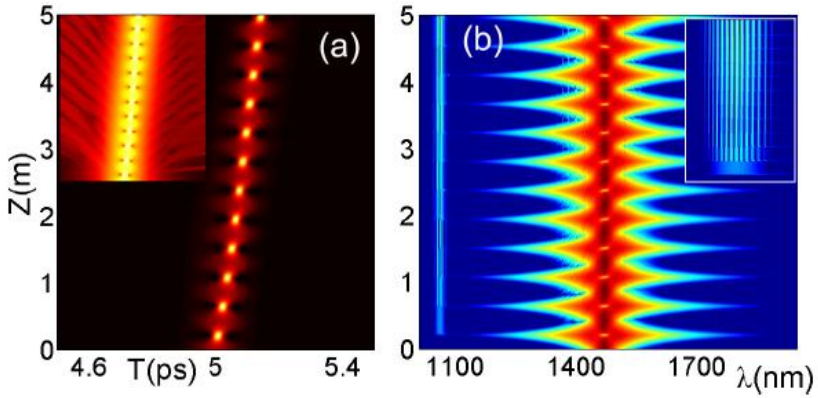


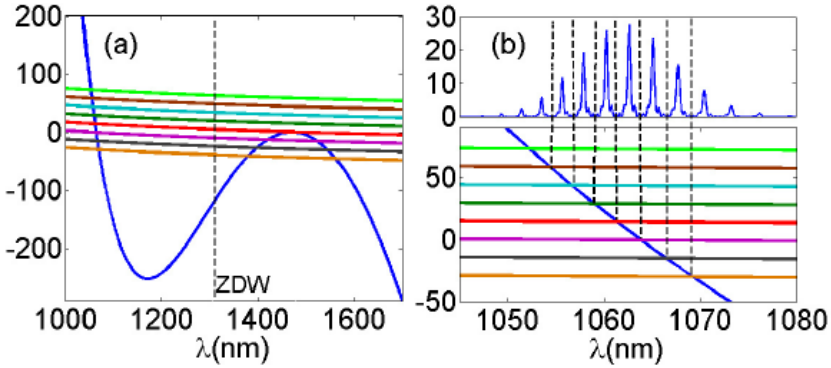
VOLUME 91, NUMBER 26 PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2003

A. V. Yulin, D. V. Skryabin, and P. St. J. Russell

Излучение осциллирующих солитонов

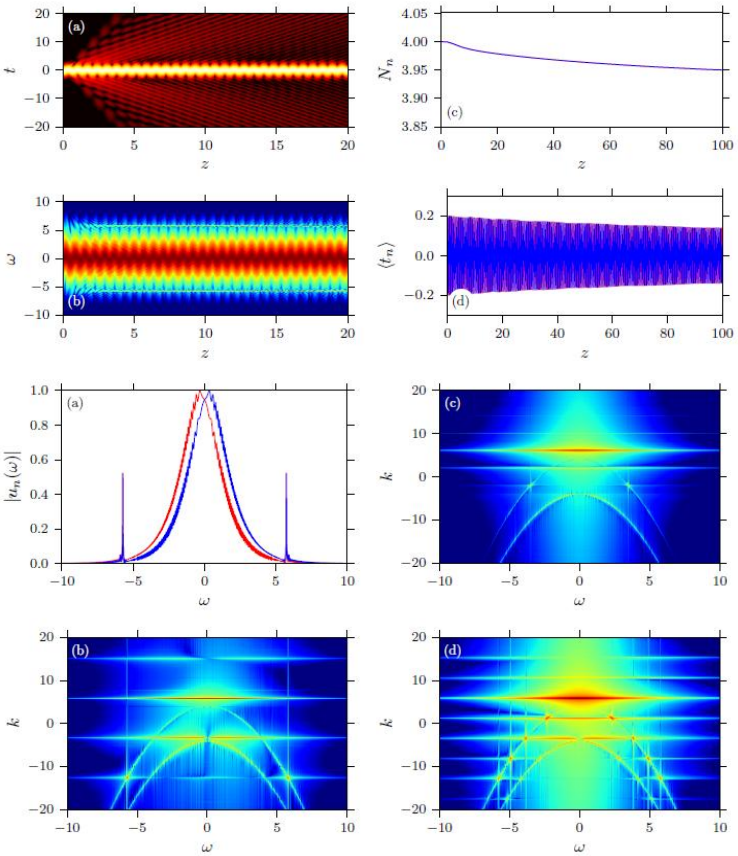
$$i\partial_z E + \frac{1}{2}\partial_{tt}E - i\beta_3\partial_{ttt}E + |E|^2 E = 0$$

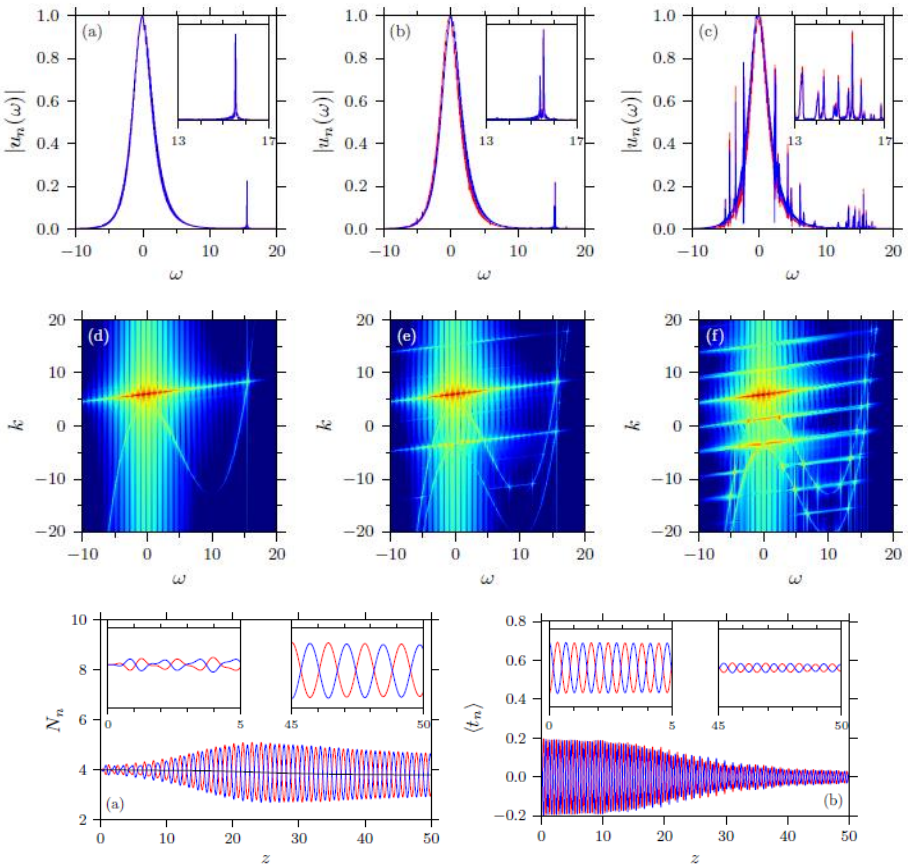




Vol. 23, No. 15 | DOI:10.1364/OE.23.019112 | OPTICS EXPRESS 19112 R. Driben,[1,2,*] A. V. Yulin,[1] and A. Efimov[3]

$$i\partial_z u_\pm + \hat{D}u_\pm + |u_\pm|^2 u_\pm + \kappa u_\mp = 0$$

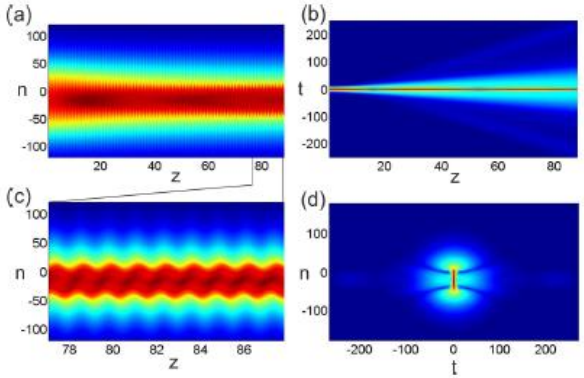


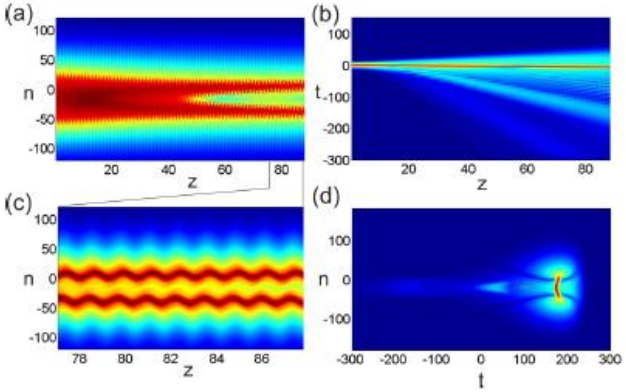


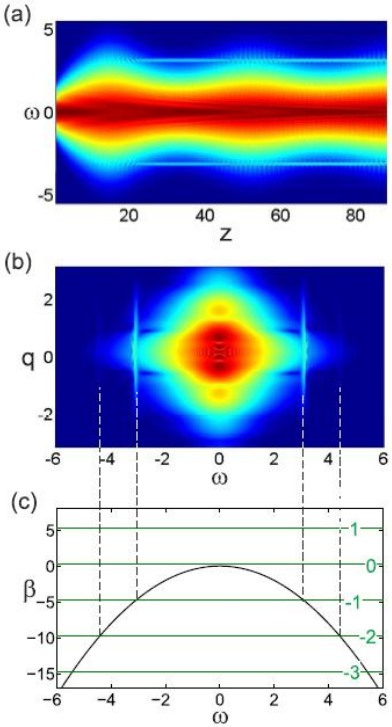
PHYSICAL REVIEW A **96**, 013809 (2017)

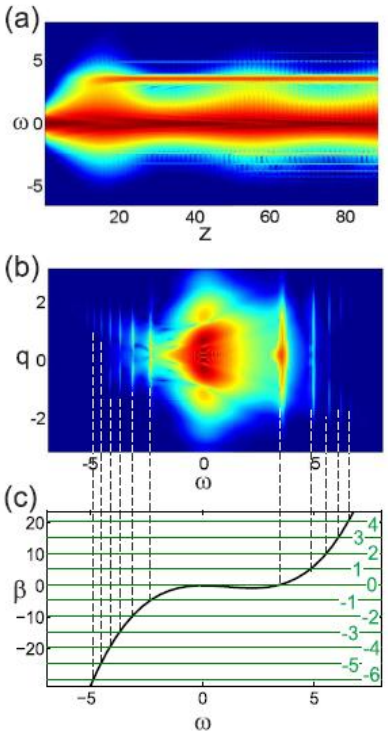
Ivan Oreshnikov,[1,*] Rodislav Driben,[2] and Alexey Yulin[1]

$$i\partial_z u_n + \hat{D}u_n + \sigma(u_{n+1} + u_{n-1} - 2u_n) + |u_n|^2 u_n + \varepsilon n u_n = 0$$







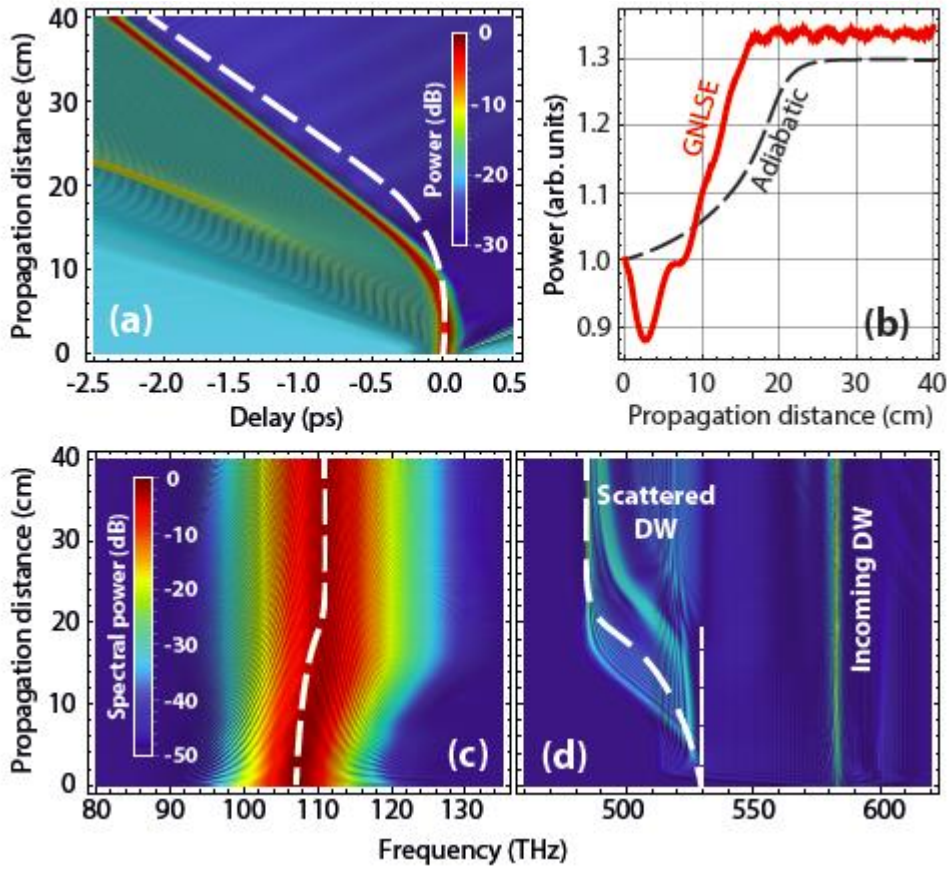


PHYSICAL REVIEW A **96**, 033827 (2017)

A. Yulin R. Driben and T. Meier

Управление солитонами посредством дисперионных волн малой интенсивности

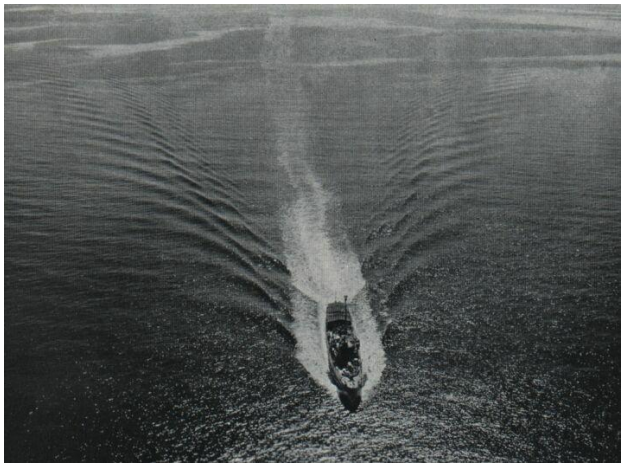
Asymptotically stable compensation of soliton self-frequency shift



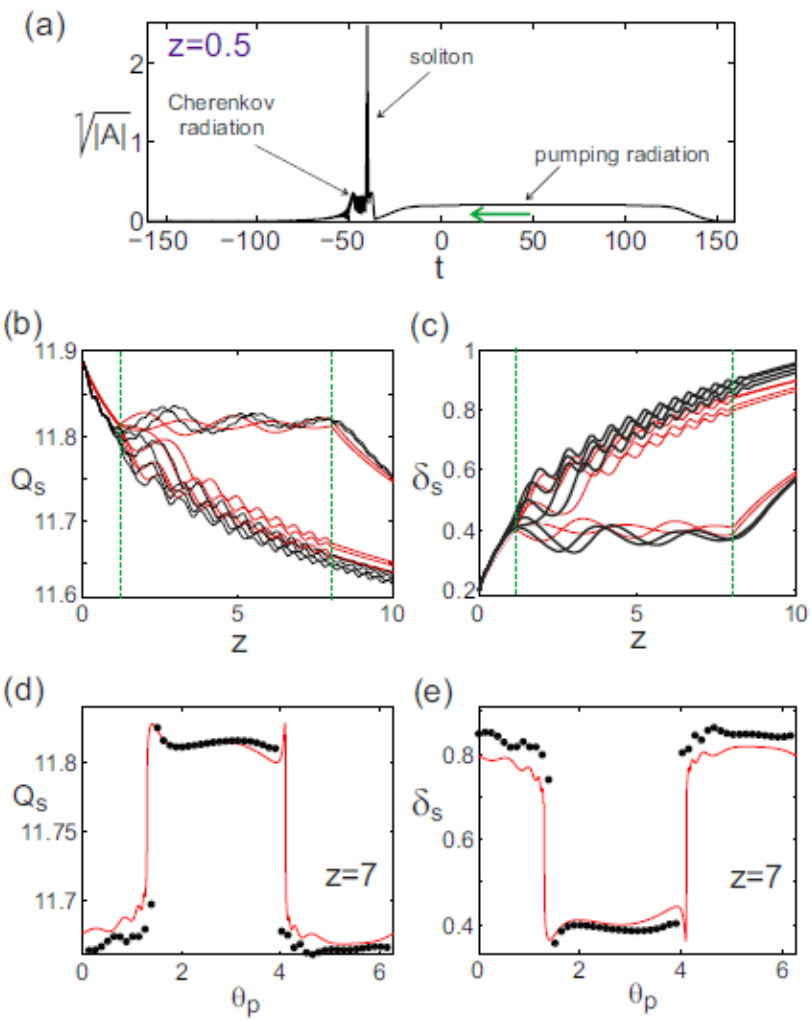
Optics Letters

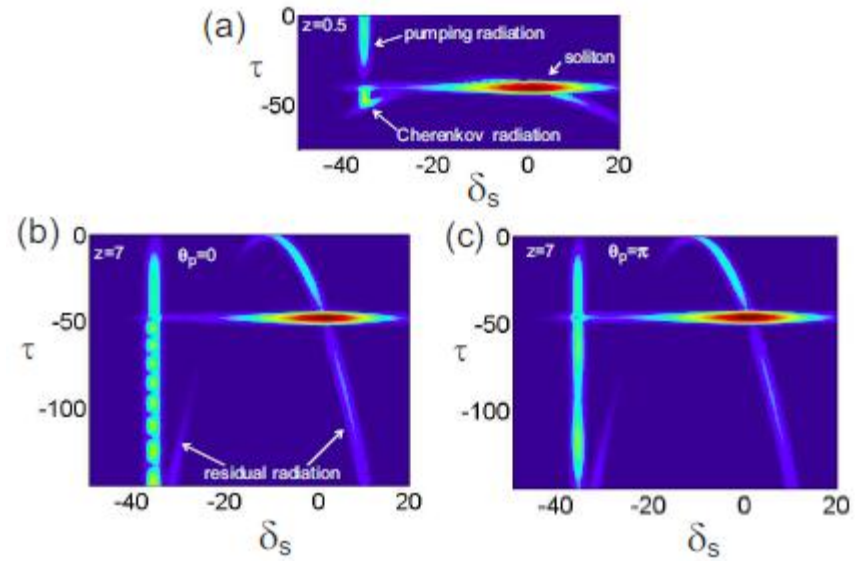
Sabrina Pickartz[1,*], Uwe Bandelow[1], and Shalva Amiranashvili[1]

Обратный эффект Черенкова



$$i\partial_z A + \frac{1}{2}\partial_t^2 A - i\beta\partial_t^3 A + |A|^2 A = 0,$$



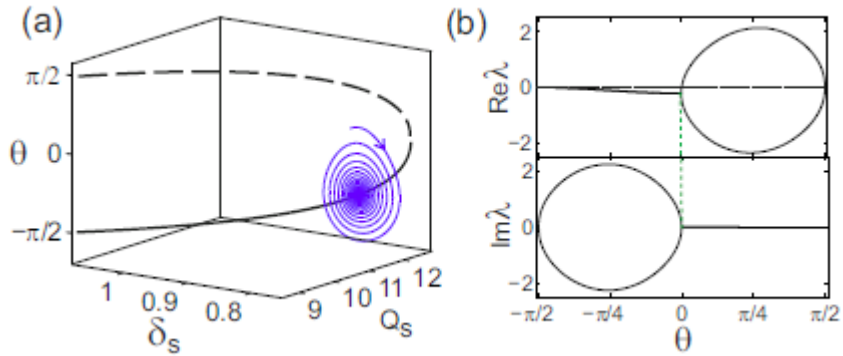


$$\partial_z Q_s = -\frac{\mu}{4\beta}$$

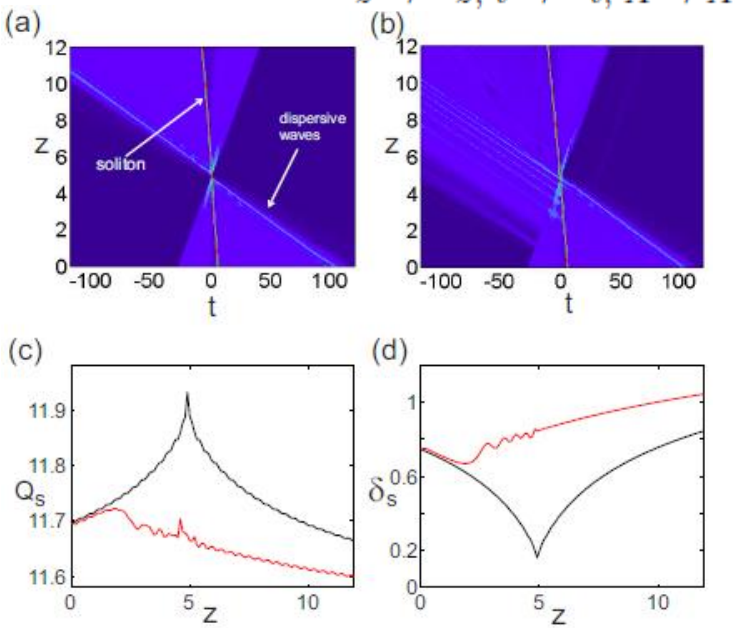
$$\partial_z \delta_s = \frac{\mu}{8\beta^2 Q_s}$$

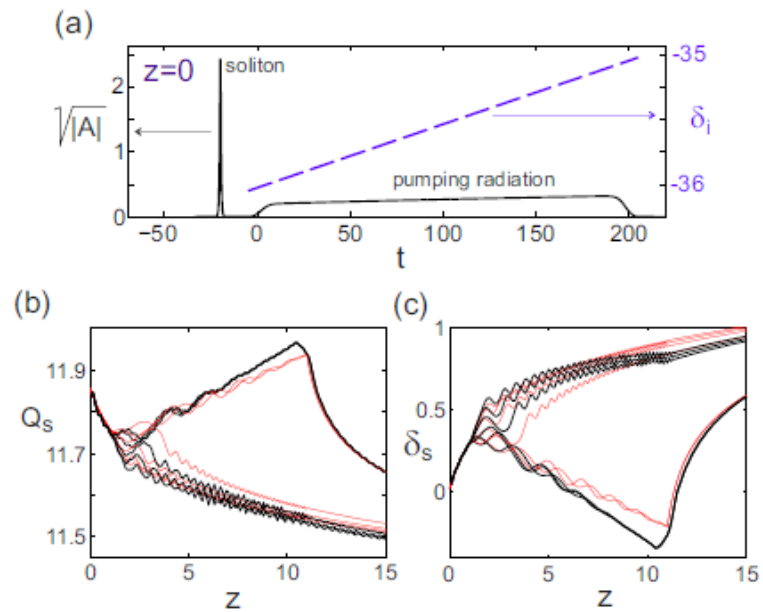
$$\partial_z \theta = \frac{Q_s^2}{8} - D_s'(\delta_p - \delta_s) - D_p.$$

$$a_r = \rho \exp[-\alpha \frac{|\delta_r - \delta_s|}{Q_s}] \quad \mu = a_r^2 + 2a_r a_p \cos(\theta)$$



$z \to -z,\ t \to -t,\ A \to A^*$





Спасибо за внимание!