The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2286-5

Workshop on New Materials for Renewable Energy

31 October - 11 November 201

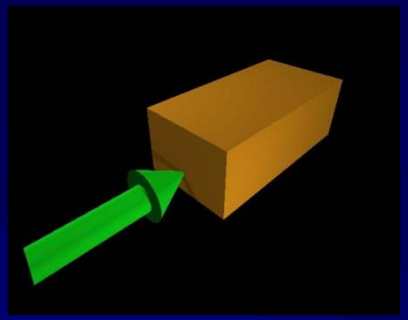
Spatial dispersion and solitons

Yuri S. Kivshar

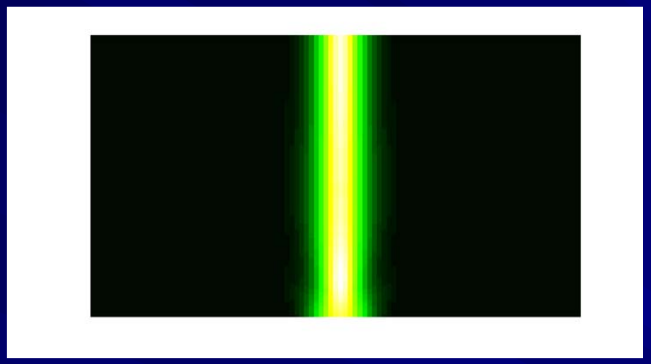
Nonlinear Physics Centre
Research School of Physics and Engineering
The Australian National University
Canberra ACT 0200
Australia

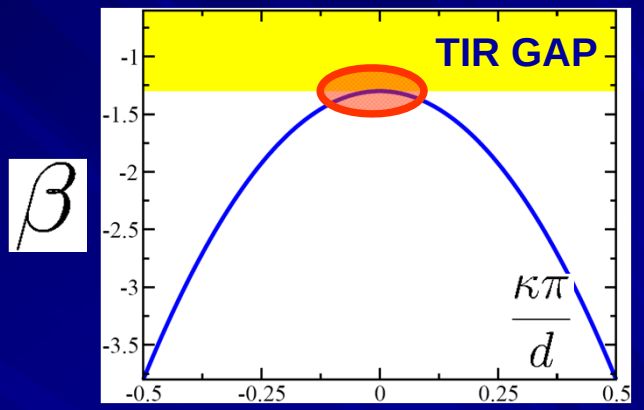
Spatial dispersion and solitons

Bulk media

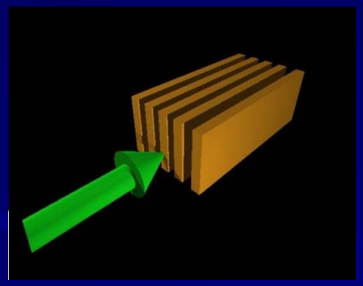


SPATIAL SOLITON

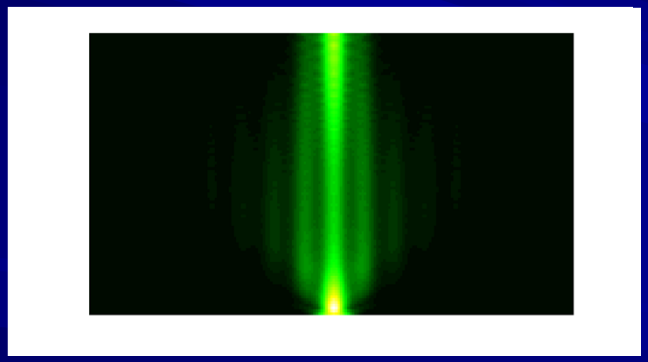


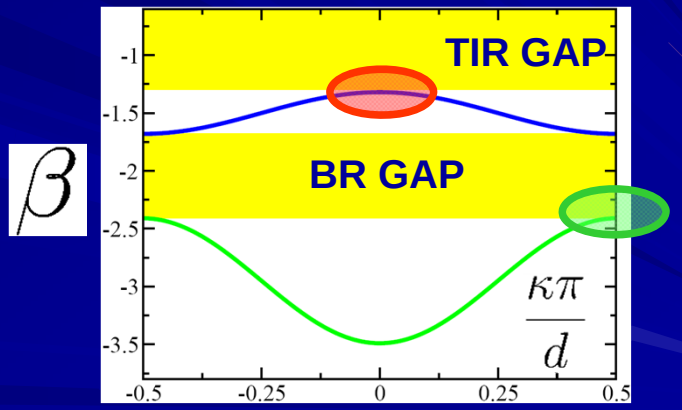


Waveguide array



LATTICE SOLITON

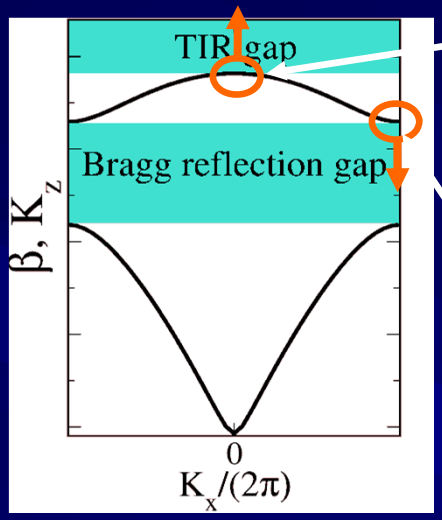




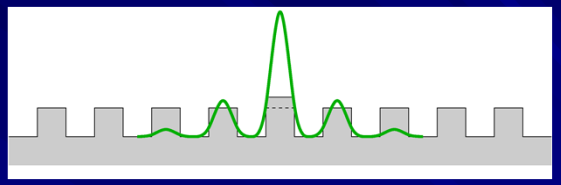
NONLINEAR PHYSICS CENTER

Theory: Christodoulides & Joseph (1988), Kivshar (1993)
Experiments: Eisenberg (1998), Fleischer (2003), Neshev (2003), Martin (2004)

Effective discrete systems

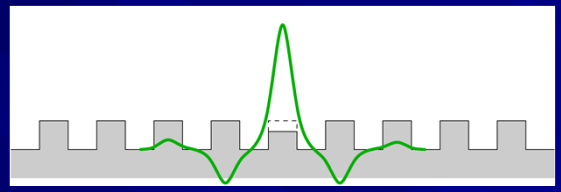


Self-focusing nonlinearity

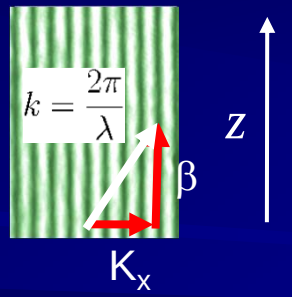


DISCRETE SOLITONS

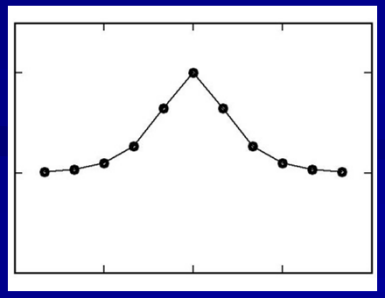
Defocusing nonlinearity

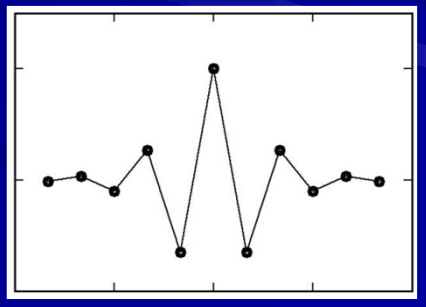


GAP SOLITONS



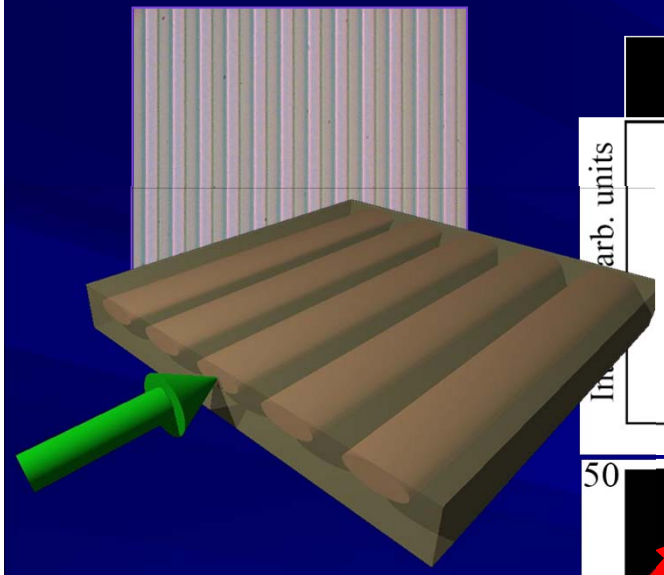
$$i\frac{\mathrm{d}E_n}{\mathrm{d}z} + \alpha E_n + (E_{n+1} + E_{n-1}) + \gamma|E_n|^2 E_n = 0, \qquad (1)$$



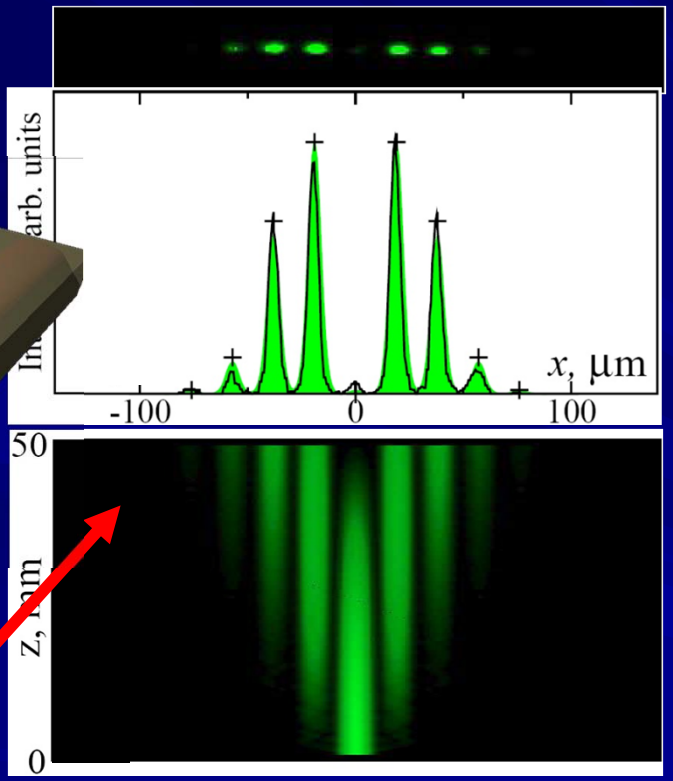


Gap Solitons - defocusing case

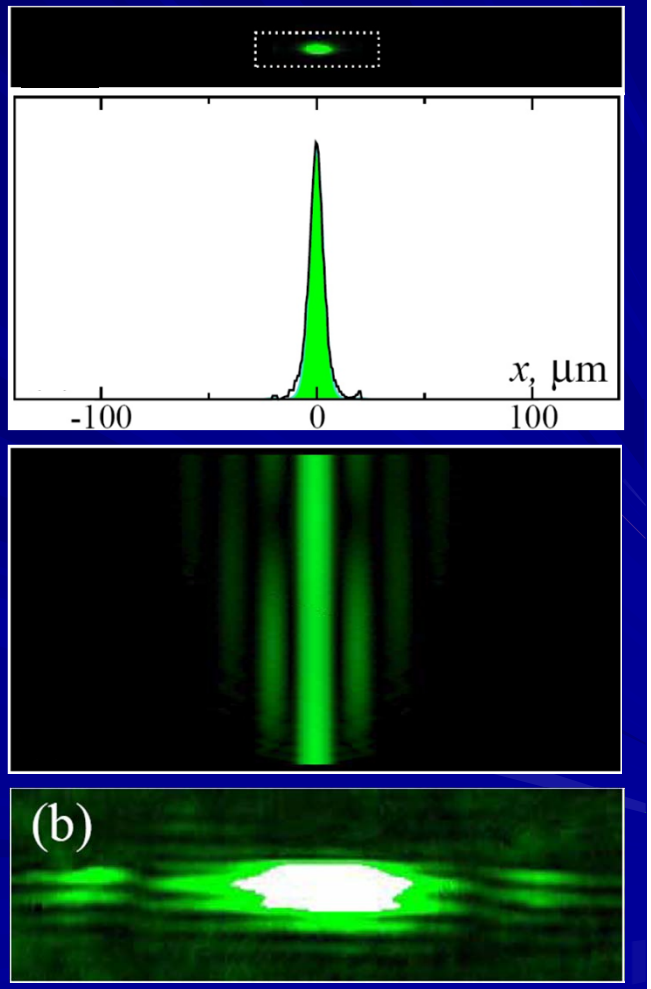
$LiNbO_3$ waveguide array

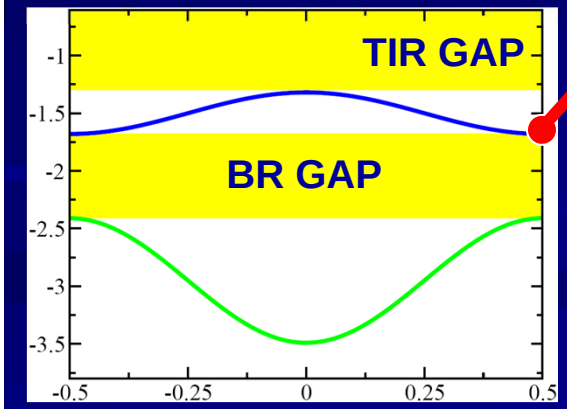


low power 10nW



high power 100μW



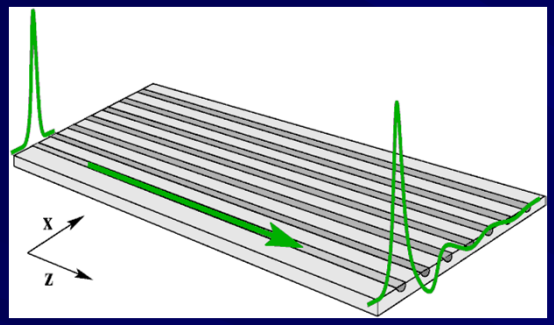


Opt. Exp. **14**, 254 (2006)

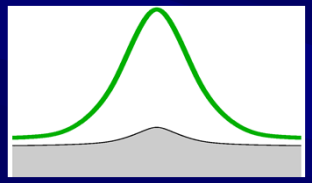
www.rsphysse.anu.edu.au/nonlinear

Surface solitons

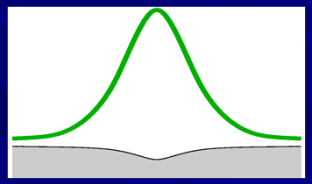
Optical surface waves

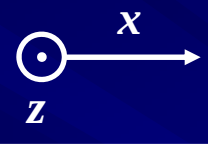


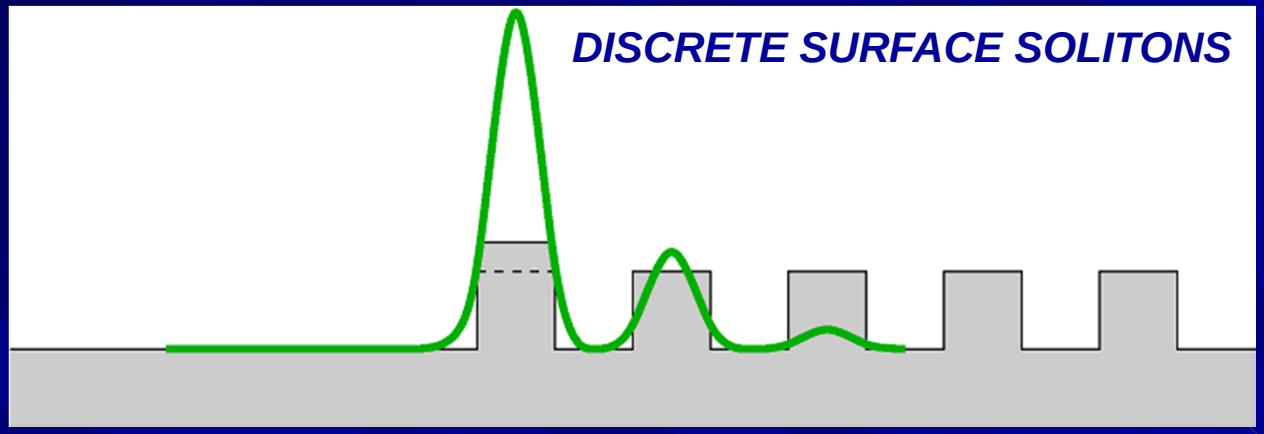
Self-focusing nonlinearity

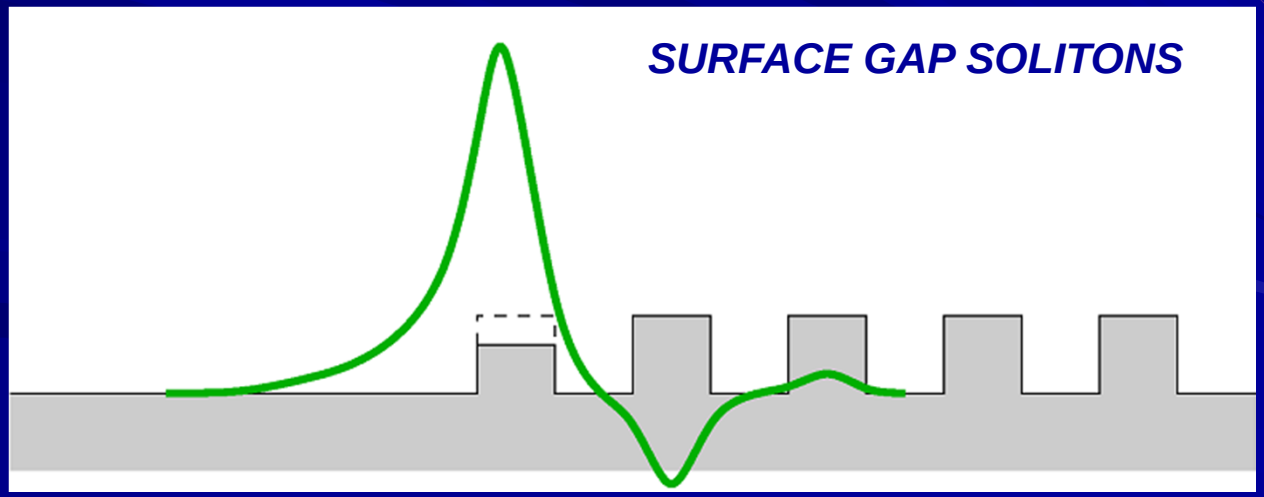


Defocusing nonlinearity





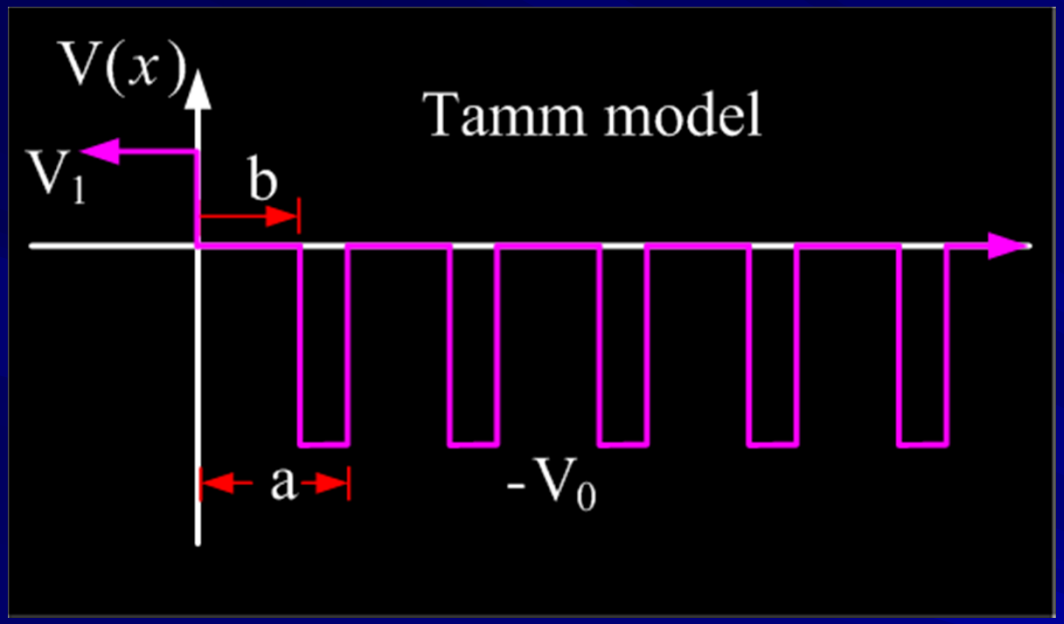


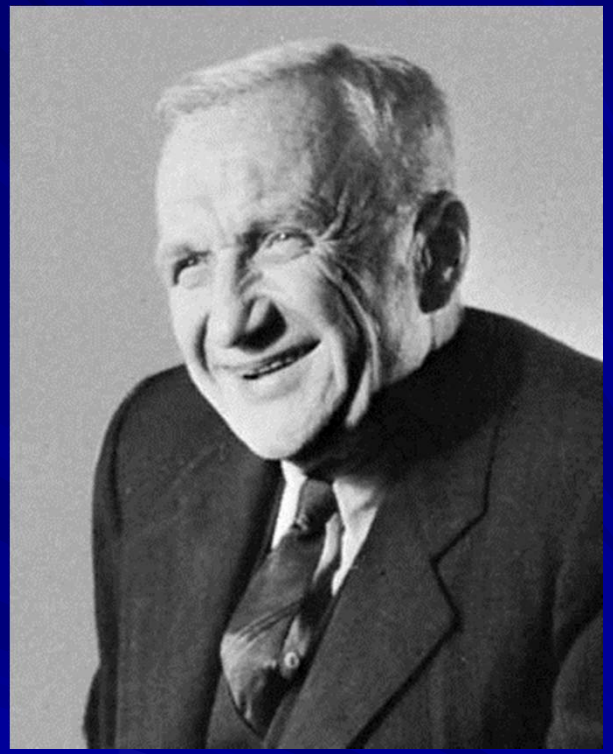


➢ **OPTICAL TAMM STATES**

www.rsphysse.anu.edu.au/nonlinear

Electronic Tamm States





Periodic boundary conditions → real values of k

Finite boundary condition → complex values of k

VOLUME 64, NUMBER 21 PHYSICAL REVIEW LETTERS 21 MAY 1990

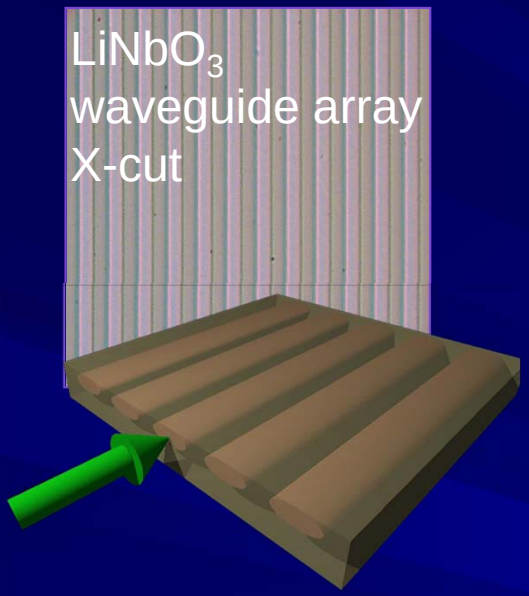
Observation of "Tamm States" in Superlattices

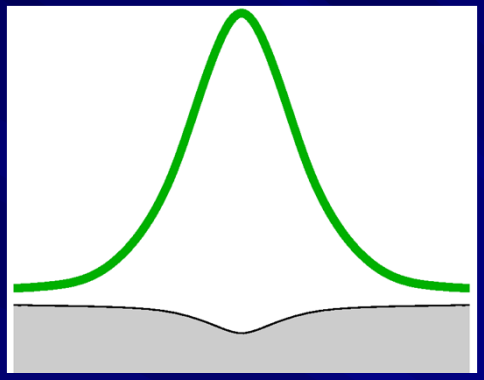
H. Ohno,[a] E. E. Mendez, J. A. Brum,[b] J. M. Hong, F. Agulló-Rueda,[c] L. L. Chang, and L. Esaki
IBM Research Division, T. J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598

nonlinear physics group

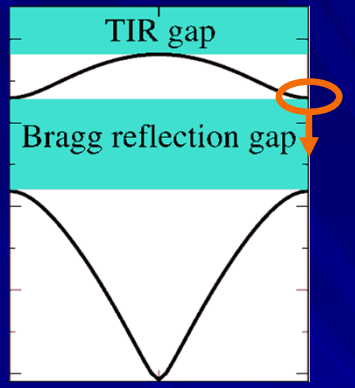
ANU THE AUSTRALIAN NATIONAL UNIVERSITY

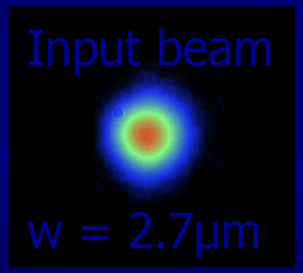
$LiNbO_3$ waveguide array



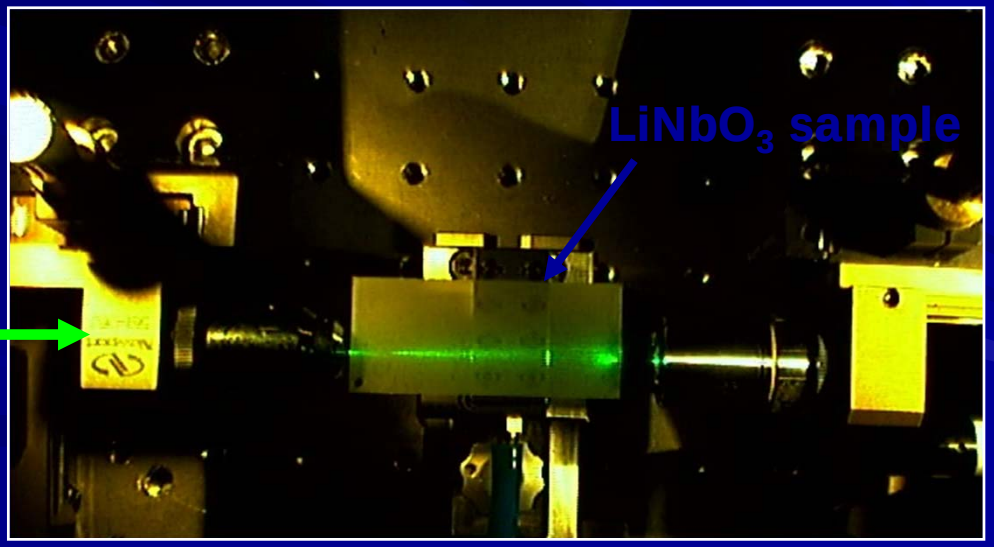


defocusing nonlinearity



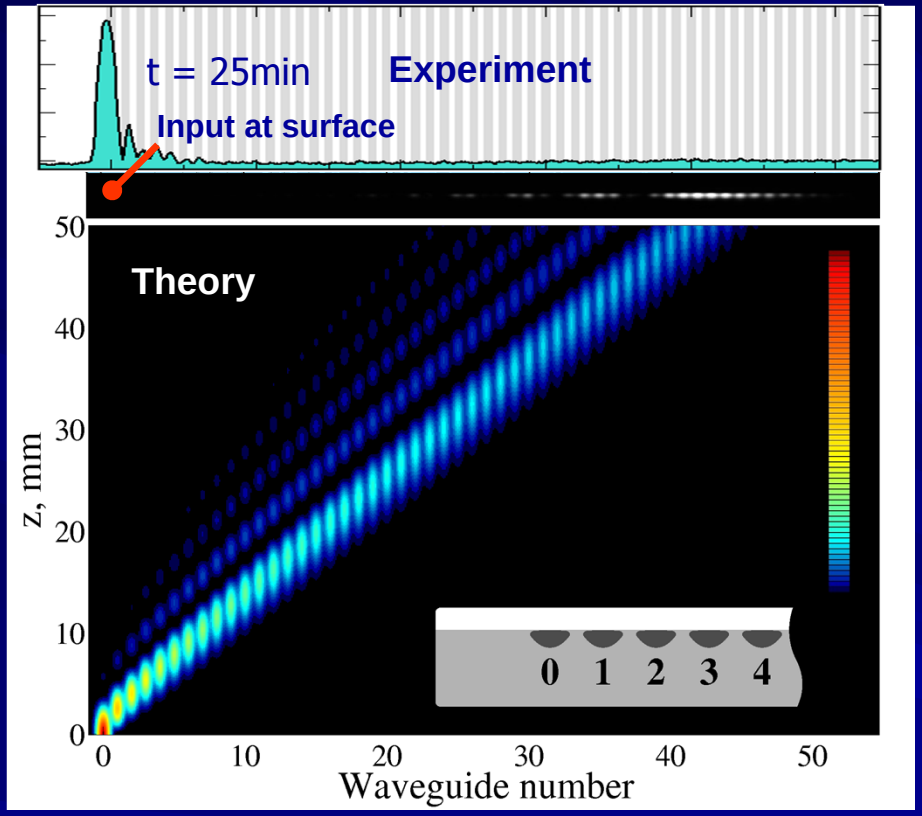


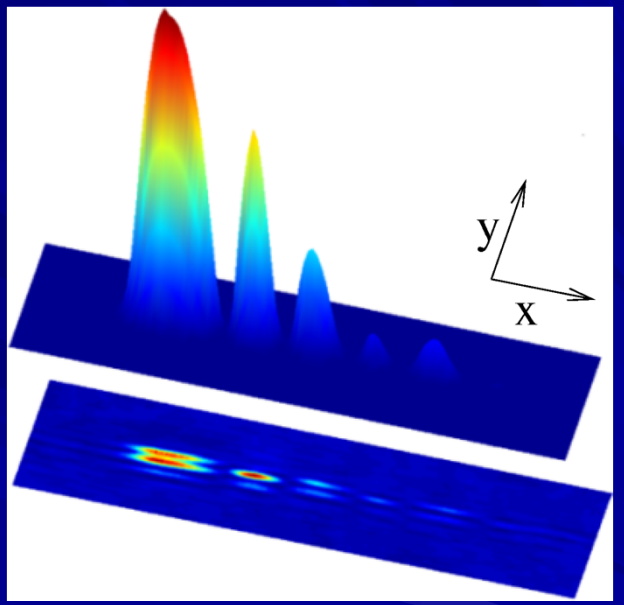
Single-site excitation

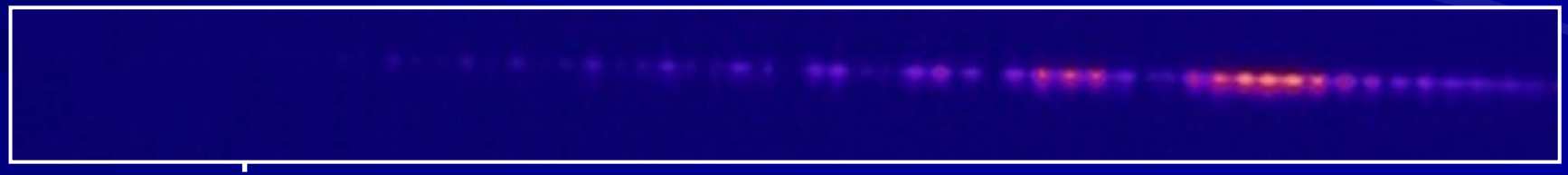


Optics Express **14,** 254 (2006)

Nonlinear optical Tamm states







PRL **97**, 083901 (2006)

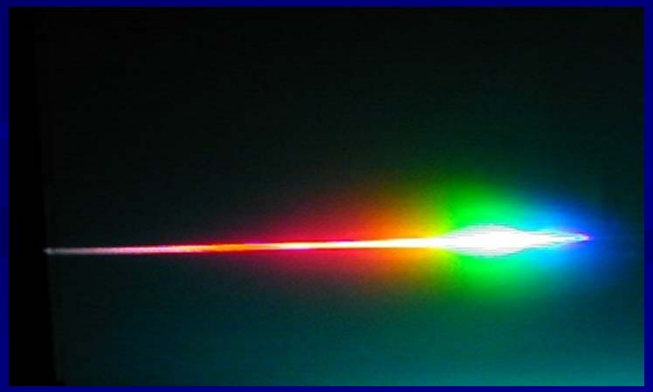
Polychromatic solitons

Motivation

Light bulb
+ all colors
- all directions

Lasers
- one colour
+ one direction
+ very bright

Nonlinear optics: light-matter interactions

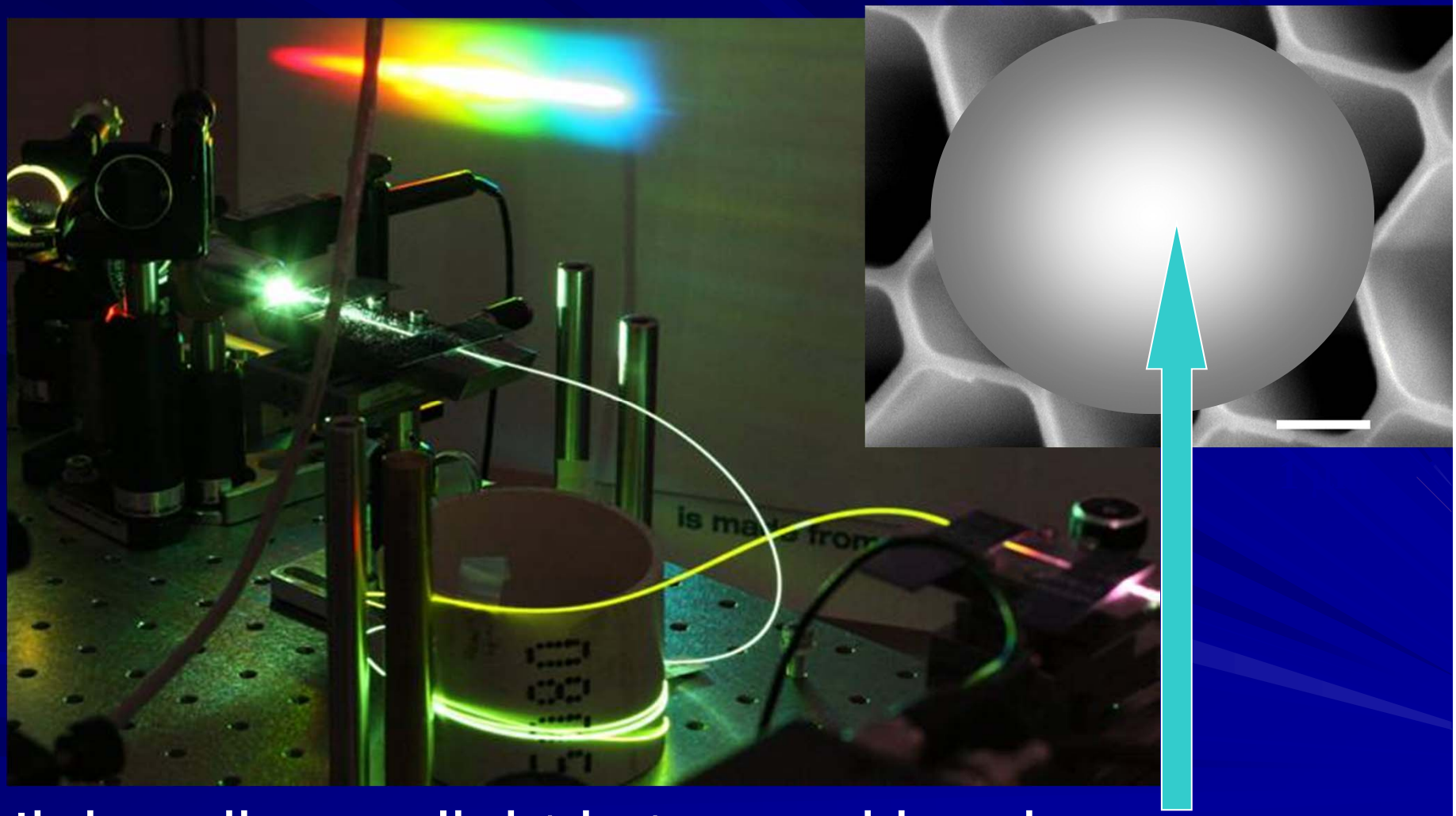


White-light laser
+ all colors
+ one direction
+ high brightness

nonlinear physics group

ANU THE AUSTRALIAN NATIONAL UNIVERSITY

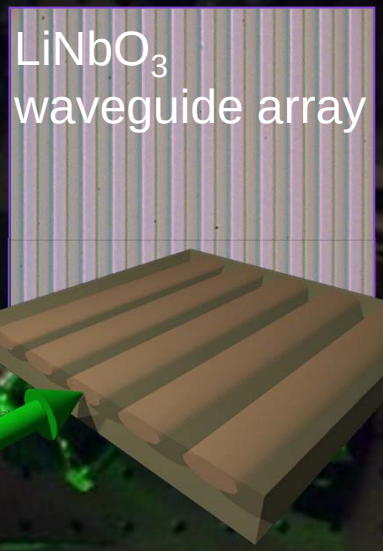
Brighter than 10,000 suns

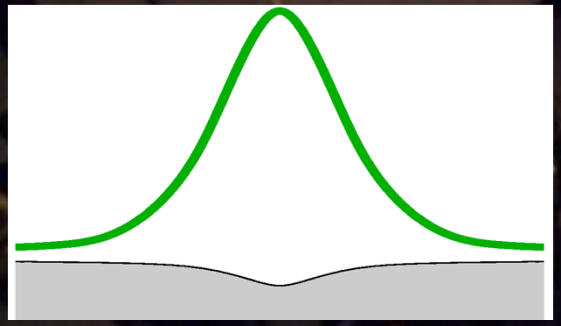


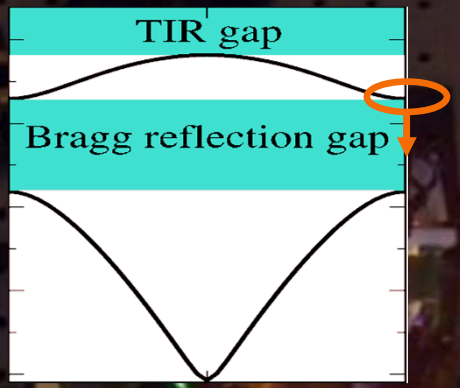
High radiance: light is trapped in micro-core

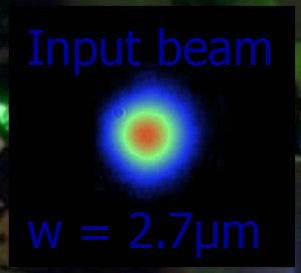
Fabricated structures

Kivshar, OL **18**, 1147 (1993)

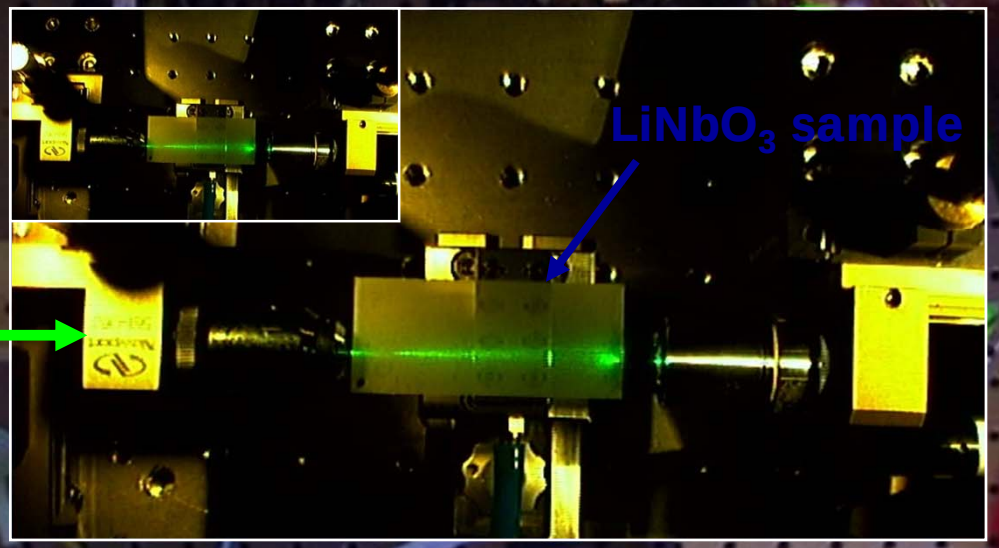






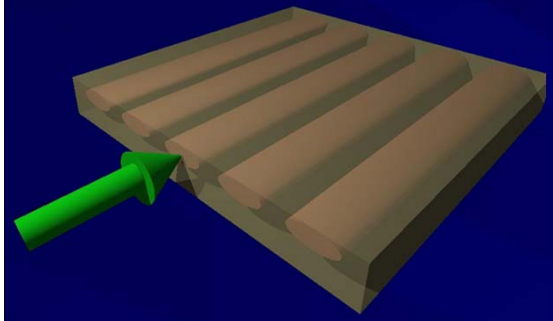


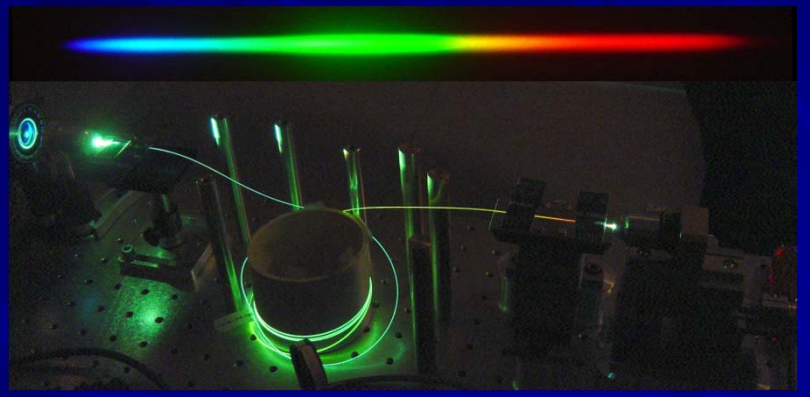
532nm

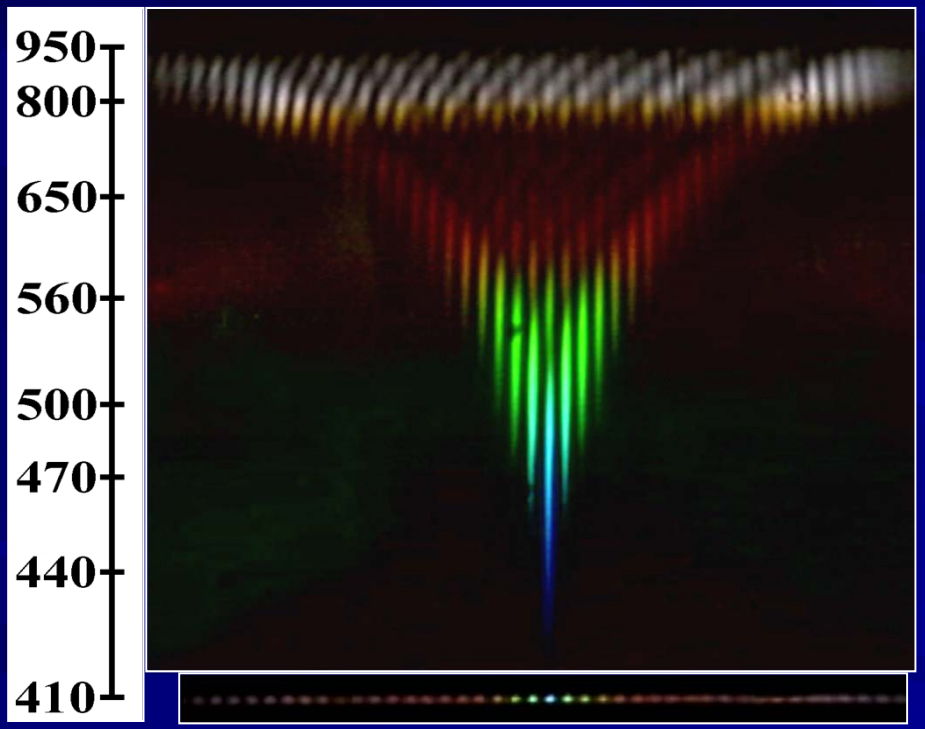


Single-site excitation

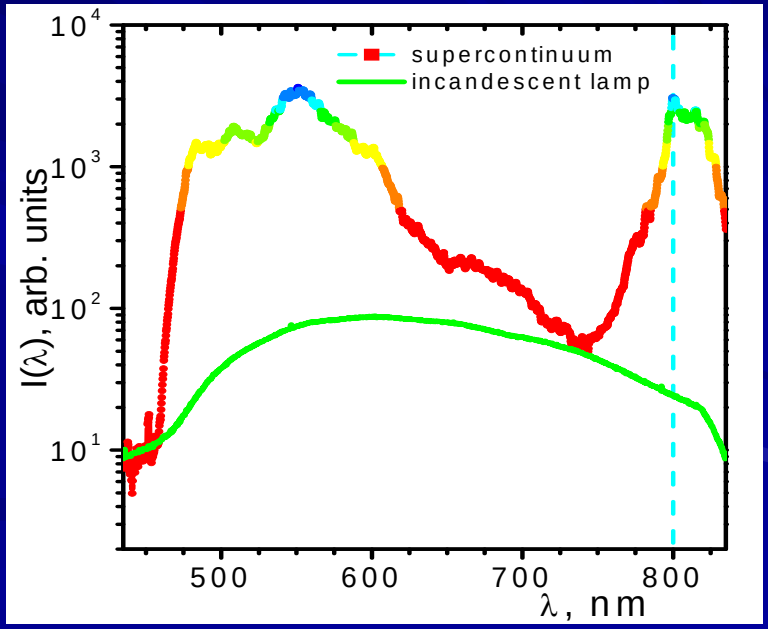
Spectrally-resolved discrete diffraction







waveguide channel



nonlinear physics group

ANU THE AUSTRALIAN NATIONAL UNIVERSITY

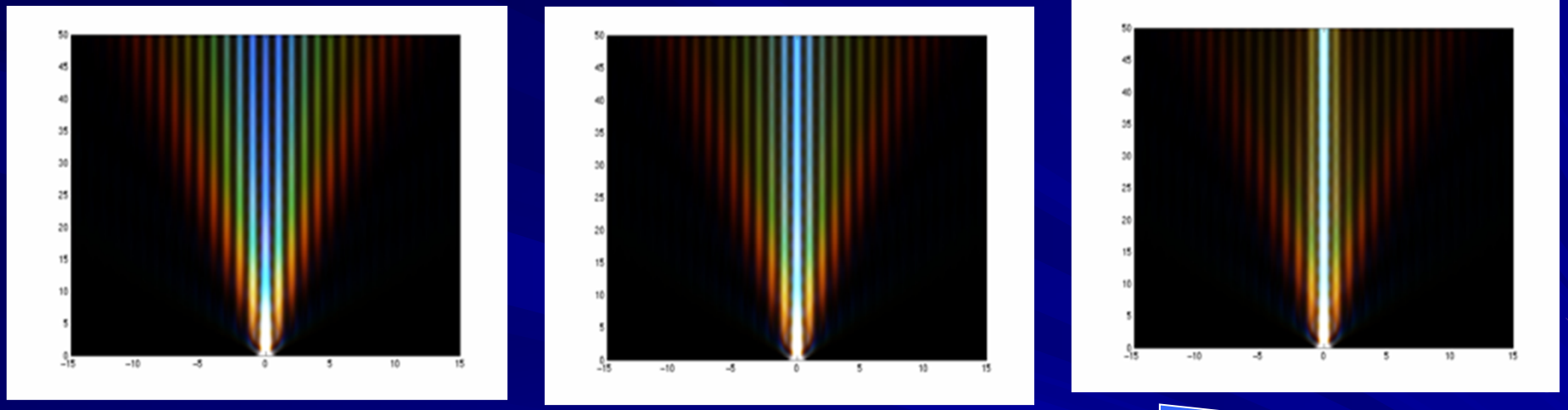
www.rsphysse.anu.edu.au/nonlinear

Light selects its colors

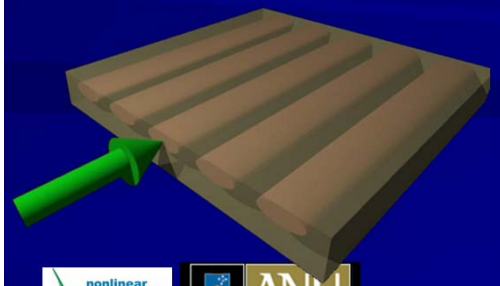
Micro-scale prism

Filtering of red

White-light input and output



Power



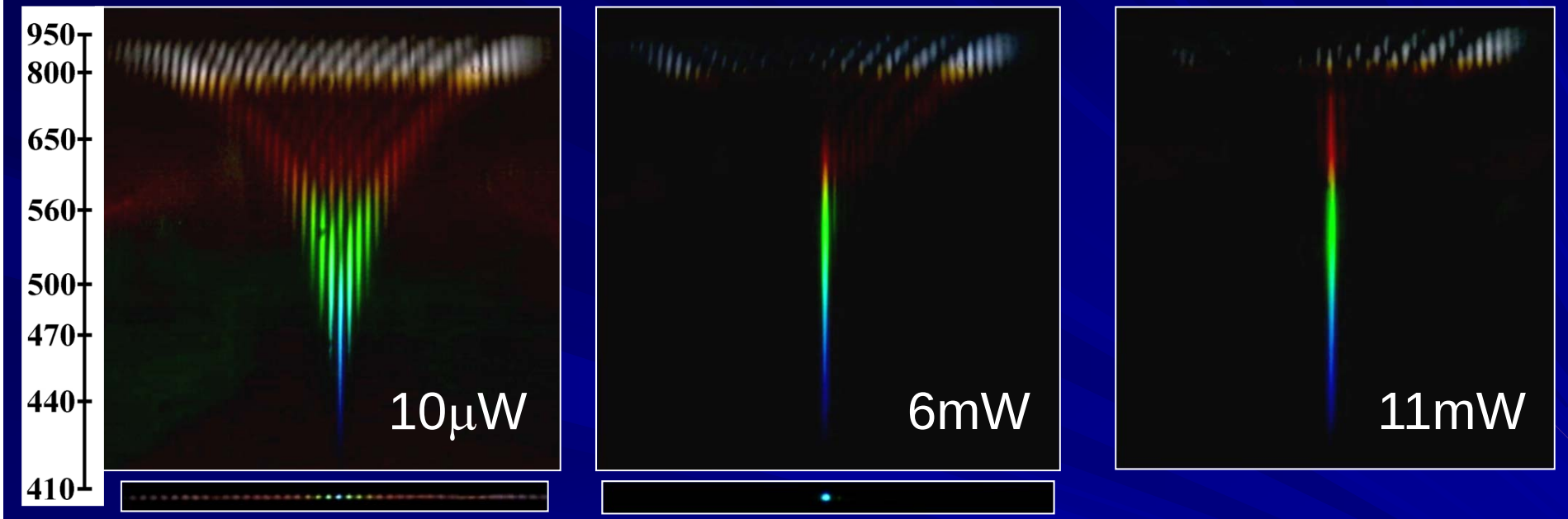
- Optically-controlled separation and mixing of colors

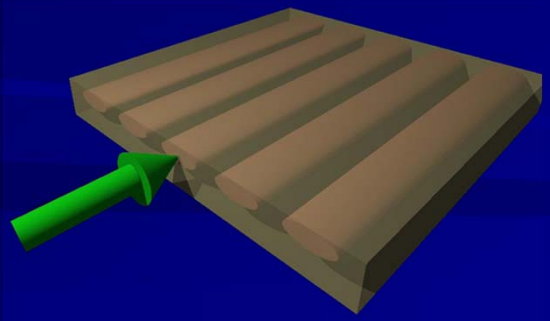
nonlinear physics group

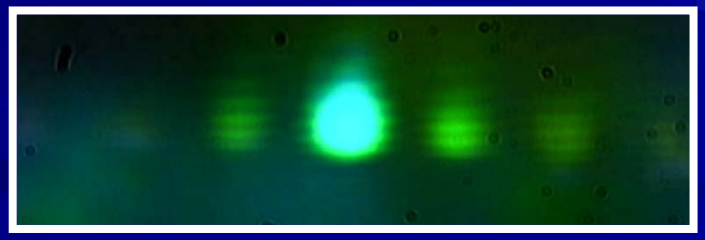
ANU THE AUSTRALIAN NATIONAL UNIVERSITY

www.rsphysse.anu.edu.au/nonlinear

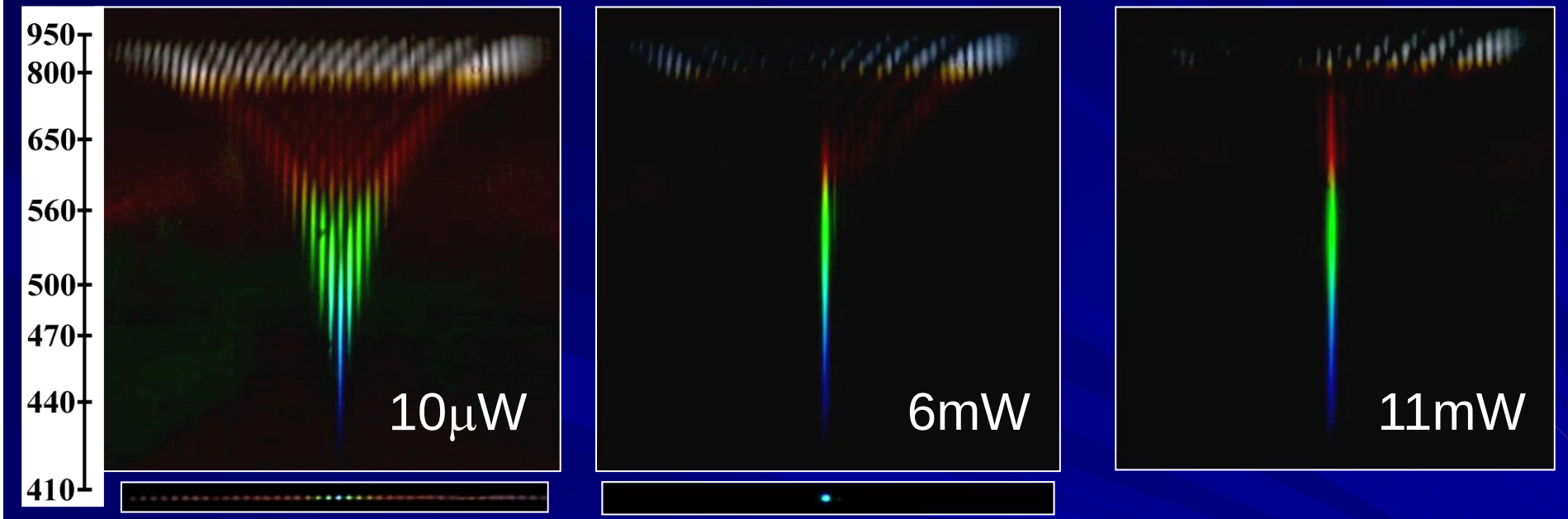
Trapped supercontinuum

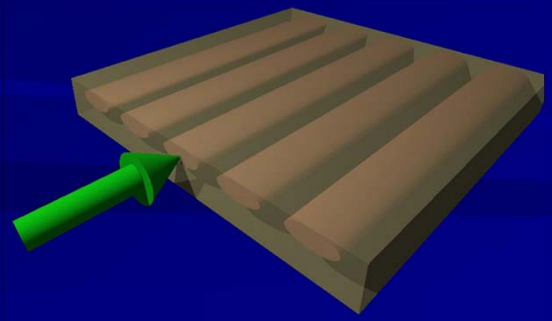


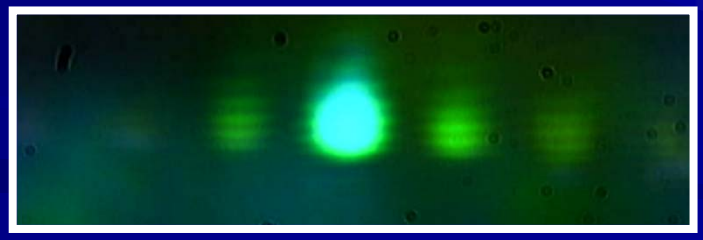




Experiment: polychromatic gap soliton

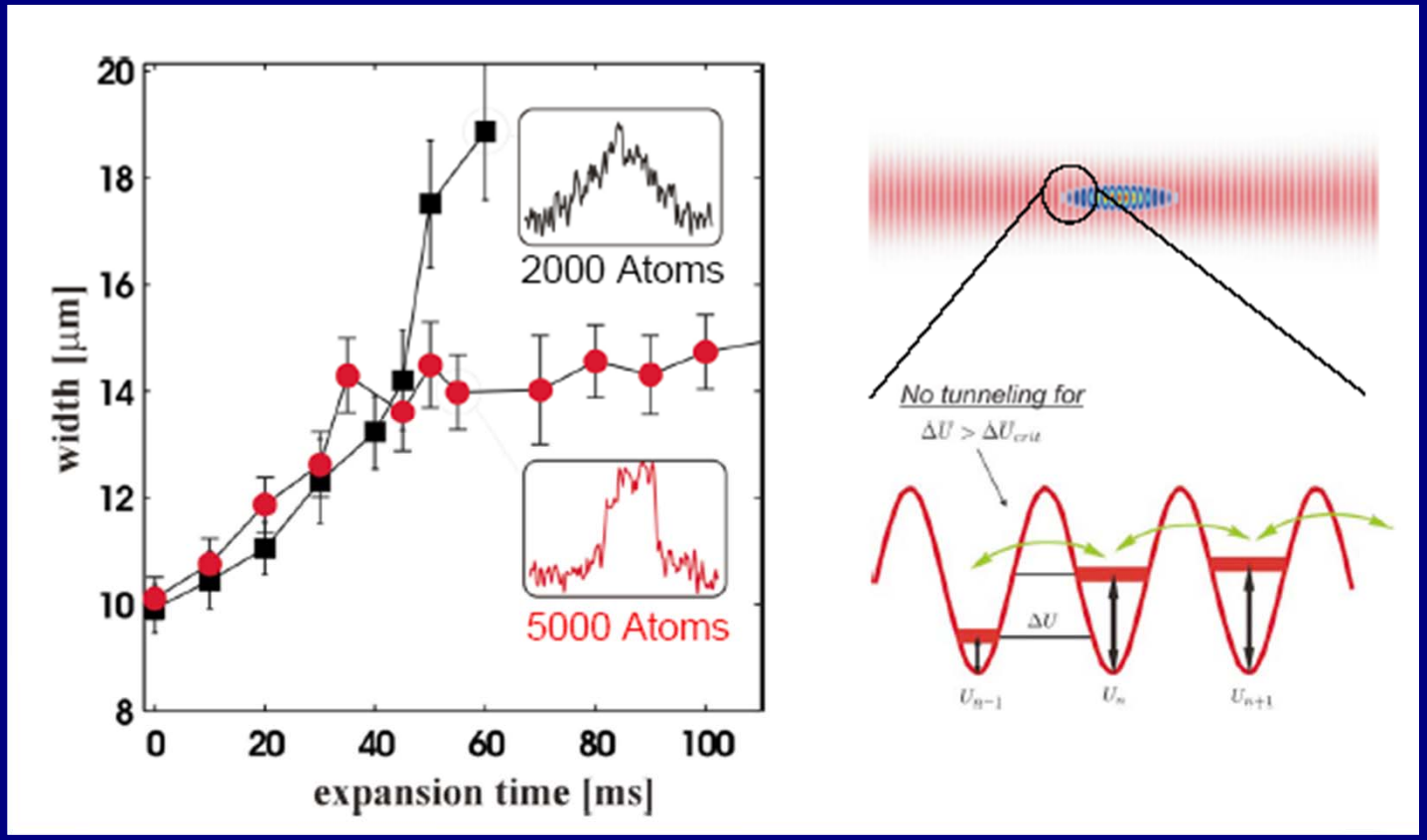






Nonlinear self-trapped states: multi-soliton complexes

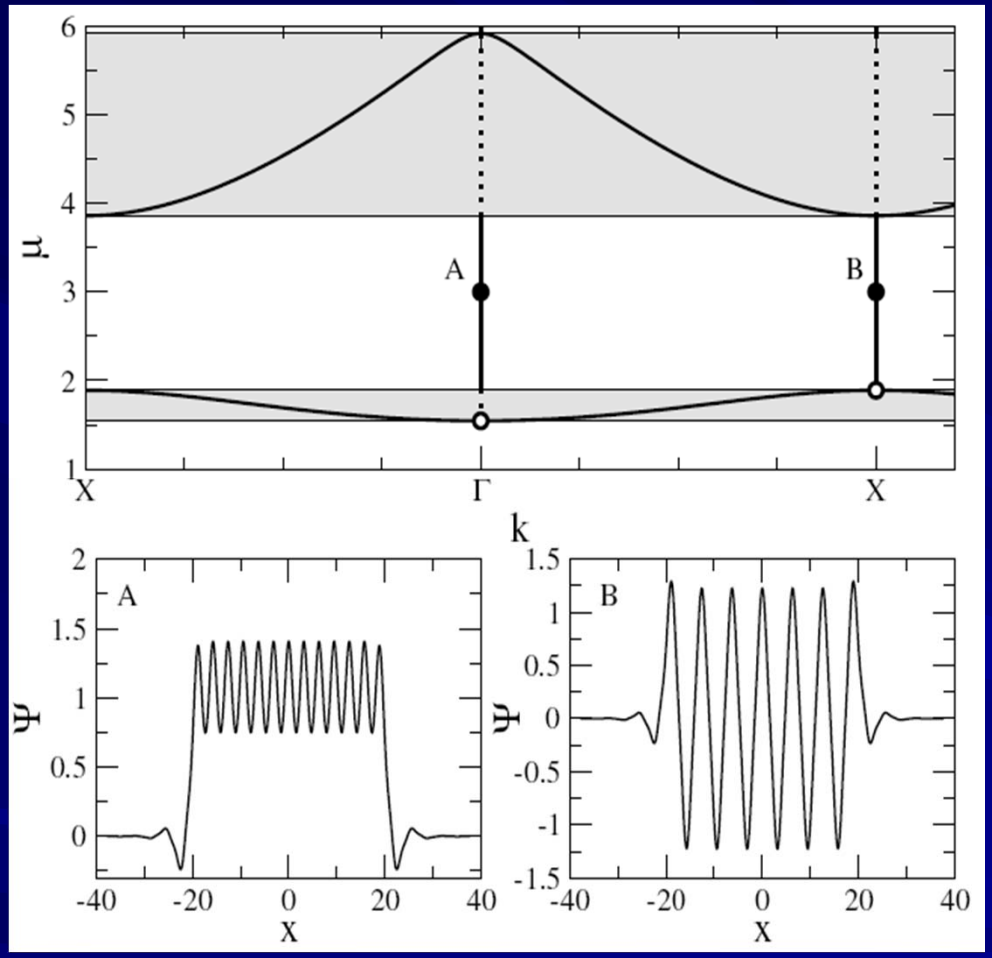
Self-trapping in BEC



Th. Anker et al, PRL **94**, 020403 (2005)

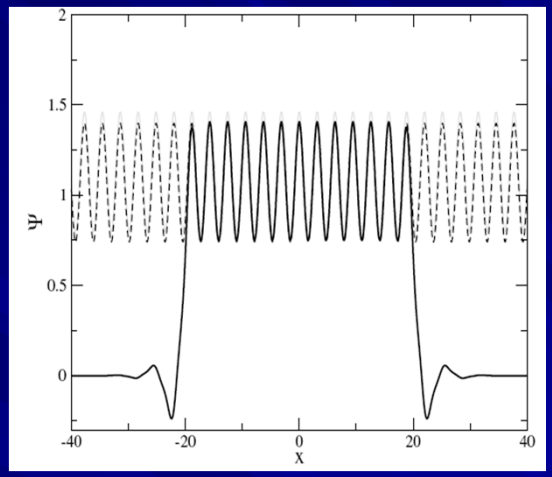
Novel ‘broad’ gap states

T.J. Alexander *et al*, Phys. Rev. Lett. **96**, 140401 (2006)

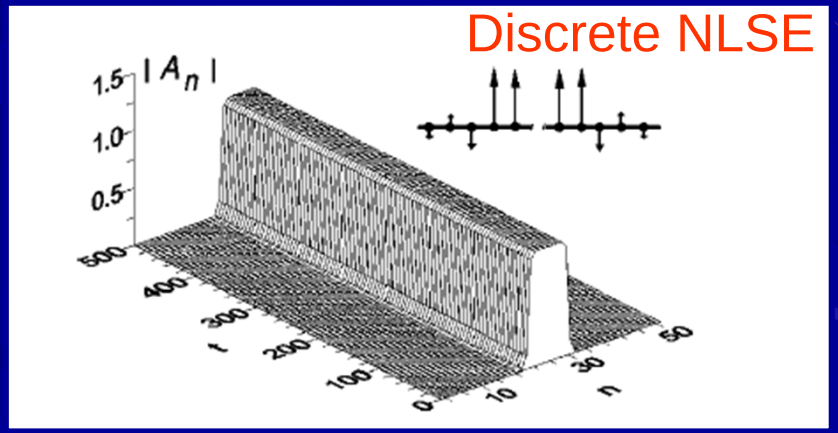


two types of modes

truncated nonlinear Bloch modes



Discrete NLSE

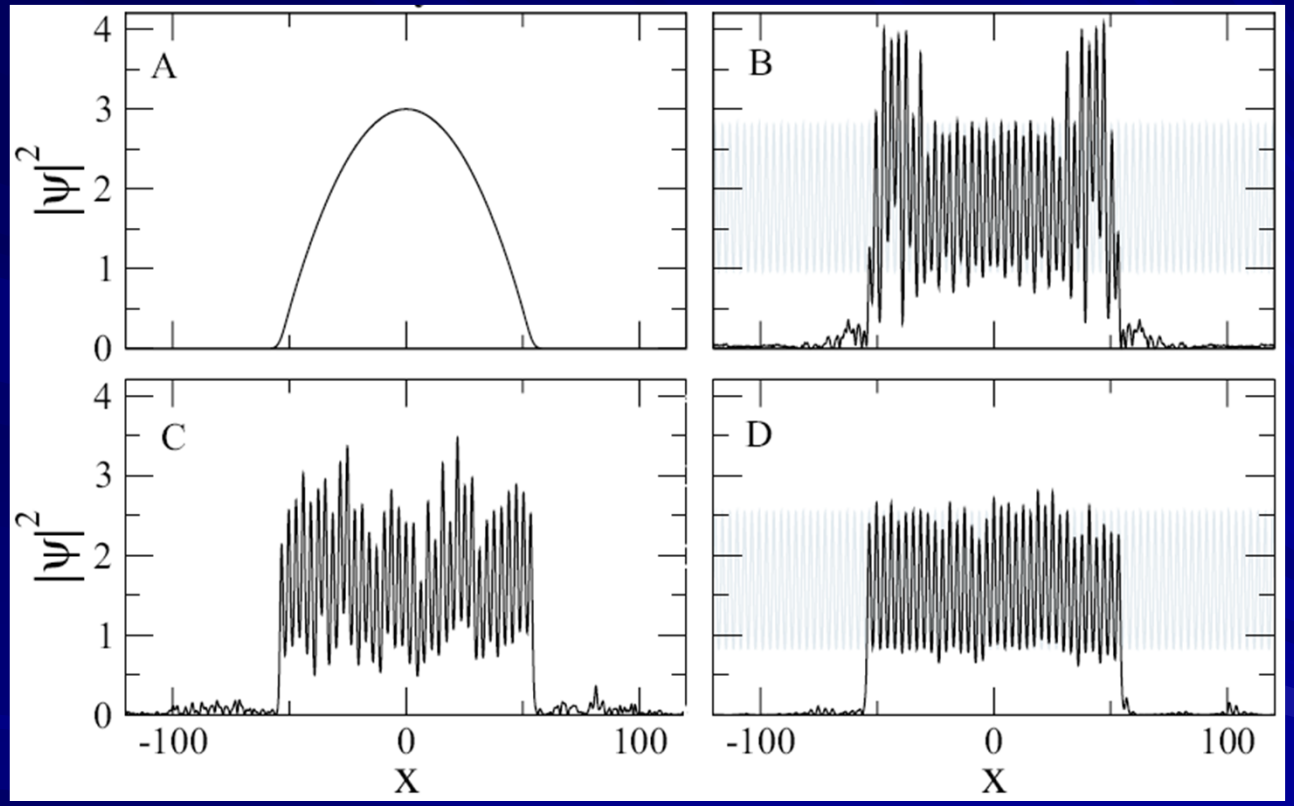


Darmanyan et al, 1999

Nonadiabatic generation

- Nonadiabatic loading into a 1D optical lattice produces broad states

t=0



t=25 ms

$$V_0 = 4E_R; \quad N \sim 10^3$$

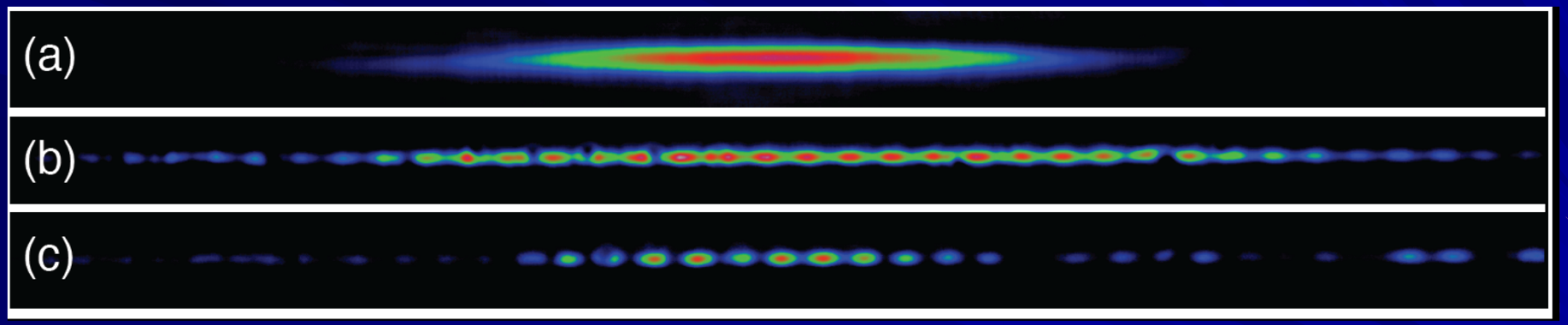
$$\mu < V_0$$

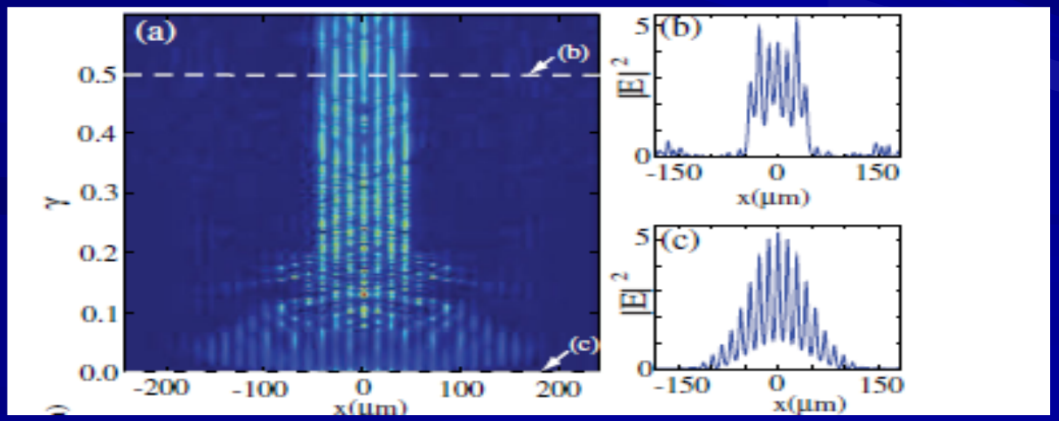
Experimental observation in optics

PRL 106, 093901 (2011) PHYSICAL REVIEW LETTERS week ending 4 MARCH 2011

Observation of Nonlinear Self-Trapping of Broad Beams in Defocusing Waveguide Arrays

Francis H. Bennet,[1] Tristram J. Alexander,[1,2] Franz Haslinger,[1] Arnan Mitchell,[3]
Dragomir N. Neshev,[1] and Yuri S. Kivshar[1]





Conclusions

- The study of solitons and spatial localization remains a very active field of nonlinear physics
- Physics research is linked more to experiments and nonintegrability of nonlinear equations
- Novel soliton physics discovered recently: gap solitons, soliton ratchets, compactons, azimuthons, etc
- Optical systems allows to observe and study many different types of nonlinear waves and solitons