nature photonics

ARTICLES

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Temporal solitons in optical microresonators

T. Herr[1], V. Brasch[1], J. D. Jost[1], C. Y. Wang[1], N. M. Kondratiev[2], M. L. Gorodetsky[2,3]* and T. J. Kippenberg[1]*

Temporal dissipative solitons in a continuous-wave laser-driven nonlinear optical microresonator were observed. The solitons were generated spontaneously when the laser frequency was tuned through the effective zero detuning point of a high-Q resonance, which led to an effective red-detuned pumping. Transition to soliton states were characterized by discontinuous steps in the resonator transmission. The solitons were stable in the long term and their number could be controlled via pump-laser detuning. These observations are in agreement with numerical simulations and soliton theory. Operating in the single-soliton regime allows the continuous output coupling of a femtosecond pulse train directly from the microresonator. This approach enables ultrashort pulse syntheses in spectral regimes in which broadband laser-gain media and saturable absorbers are not available. In the frequency domain the single-soliton states correspond to low-noise optical frequency combs with smooth spectral envelopes, critical to applications in broadband spectroscopy, telecommunications, astronomy and low noise microwave generation.

Jinuk Kim

Journal Club 2018-04-16

Tobias Kippenberg

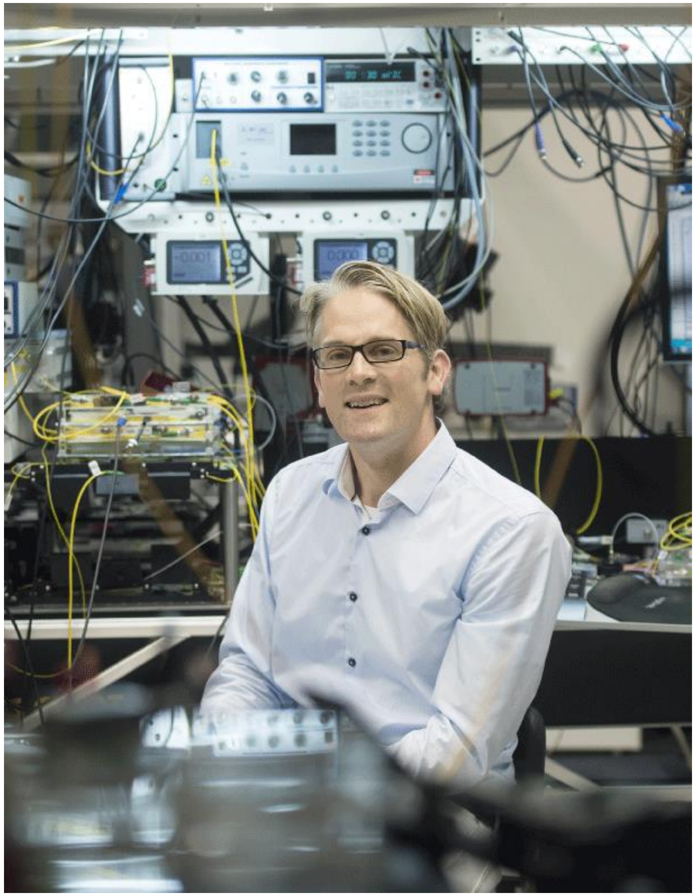
Biography

2004: PhD, California Institute of Technology (Advisor Professor **Kerry Vahala**)
2005-2006: Postdoctoral Scholar, Center for the Physics of Information, California Institute of Technology

2008 - 2010: Tenure Track Assistant Professor, **Ecole Polytechnique Federale de Lausanne**

2010 - 2012: Associate Professor EPFL

2013 - present: Full Professor EPFL

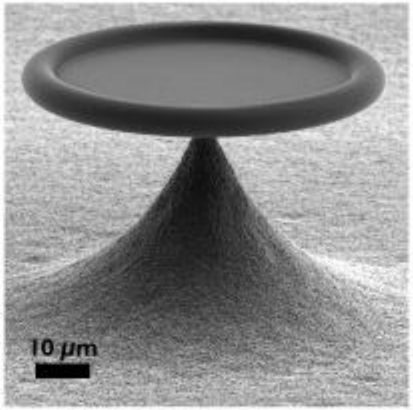


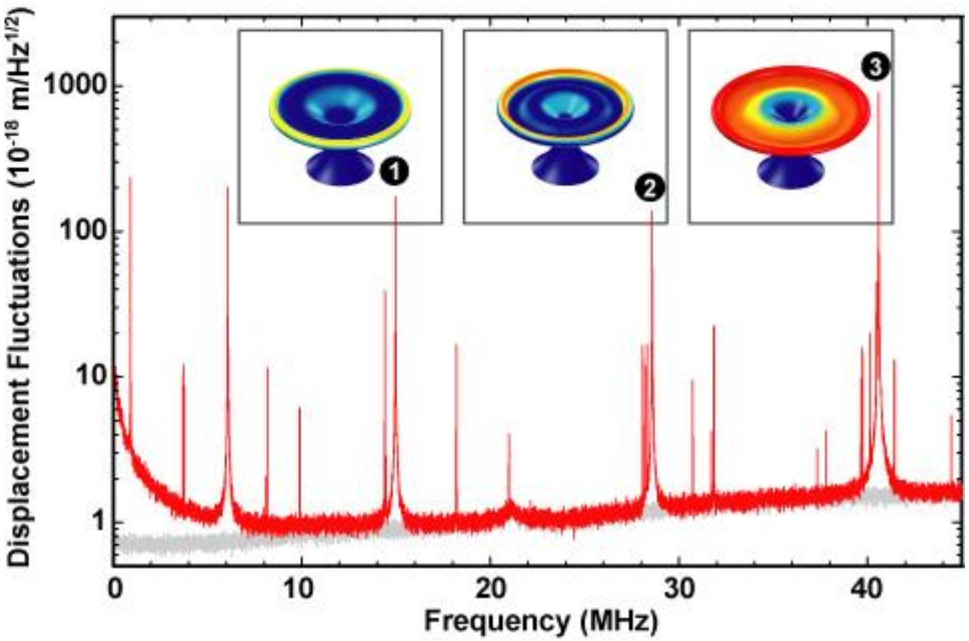
Laboratory of Photonics and Quantum Measurements

https://people.epfl.ch/cgi-in/people?id=182444&op=bio&lang=en&cvlang=en

Research area

Cavity Optomechanics

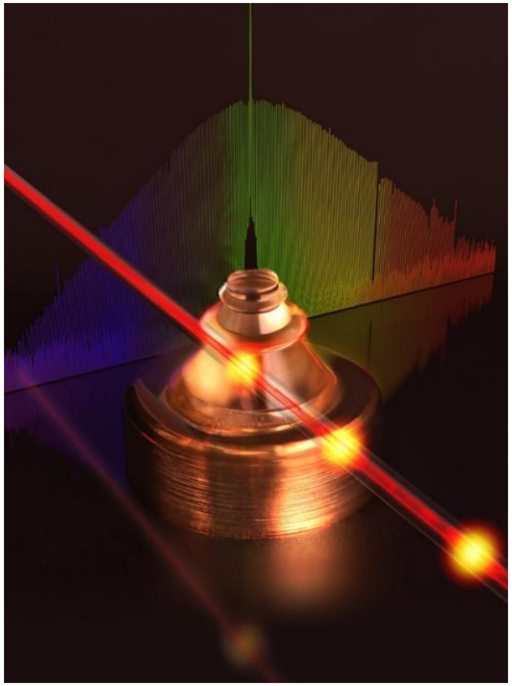


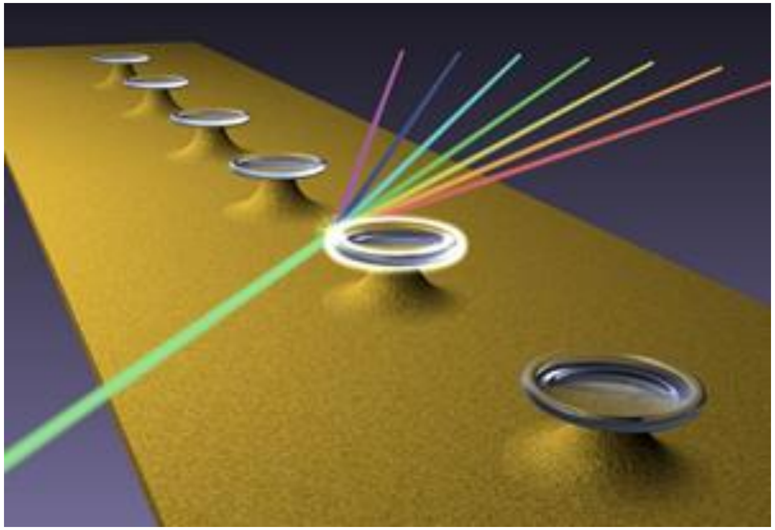


https://k-lab.epfl.ch/cavity_optomechanics_1

Research area

Monolithic Frequency Comb Generators





https://k-lab.epfl.ch/latest_scientific_results_2

nature Vol 450|20/27 December 2007|doi:10.1038/nature06401

LETTERS

Optical frequency comb generation from a monolithic microresonator

P. Del'Haye[1], A. Schliesser[1], O. Arcizet[1], T. Wilken[1], R. Holzwarth[1] & T. J. Kippenberg[1]

LETTERS
PUBLISHED ONLINE: 7 AUGUST 2017 | DOI: 10.1038/NPHOTON.2017.117
nature photonics

Counter-propagating solitons in microresonators

Qi-Fan Yang†, Xu Yi†, Ki Youl Yang and Kerry Vahala*

Science REPORTS

Cite as: V. Brasch *et al.*, *Science* 10.1126/science.aad4811 (2015).

Photonic chip-based optical frequency comb using soliton Cherenkov radiation

V. Brasch,[1] M. Geiselmann,[1] T. Herr,[1]* G. Lihachev,[2,3] M. H. P. Pfeiffer,[1] M. L. Gorodetsky,[2,3] T. J. Kippenberg[1]†
[1]École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland. [2]Russian Quantum Center, Skolkovo 143025, Russia. [3]Faculty of Physics, M. V. Lomonosov Moscow State University, Moscow 119991, Russia.
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ARTICLES
PUBLISHED ONLINE: 26 SEPTEMBER 2016 | DOI: 10.1038/NPHYS3893
nature physics

Universal dynamics and deterministic switching of dissipative Kerr solitons in optical microresonators

H. Guo[1†], M. Karpov[1†], E. Lucas[1†], A. Kordts[1], M. H. P. Pfeiffer[1], V. Brasch[1], G. Lihachev[2,3], V. E. Lobanov[3], M. L. Gorodetsky[2,3]* and T. J. Kippenberg[1]*

ARTICLES
PUBLISHED ONLINE: 21 AUGUST 2017 | DOI: 10.1038/NPHOTON.2017.140
nature photonics

Temporal solitons in microresonators driven by optical pulses

Ewelina Obrzud[1,2], Steve Lecomte[1] and Tobias Herr[1]*

news & views

FREQUENCY COMBS

Cavity solitons come of age

The generation and manipulation of cavity solitons in microresonators is creating new opportunities for Kerr combs to aid applications such as optical communications and spectroscopy.

Andrew M. Weiner

LETTER
doi:10.1038/nature22387

Microresonator-based solitons for massively parallel coherent optical communications

Pablo Marin-Palomo[1]*, Juned N. Kemal[1]*, Maxim Karpov[2]*, Arne Kordts[2], Joerg Pfeifle[1], Martin H. P. Pfeiffer[2], Philipp Trocha[1], Stefan Wolf[1], Victor Brasch[2], Miles H. Anderson[2], Ralf Rosenberger[1], Kovendhan Vijayan[1], Wolfgang Freude[1,3], Tobias J. Kippenberg[2] & Christian Koos[1,3]

RESEARCH

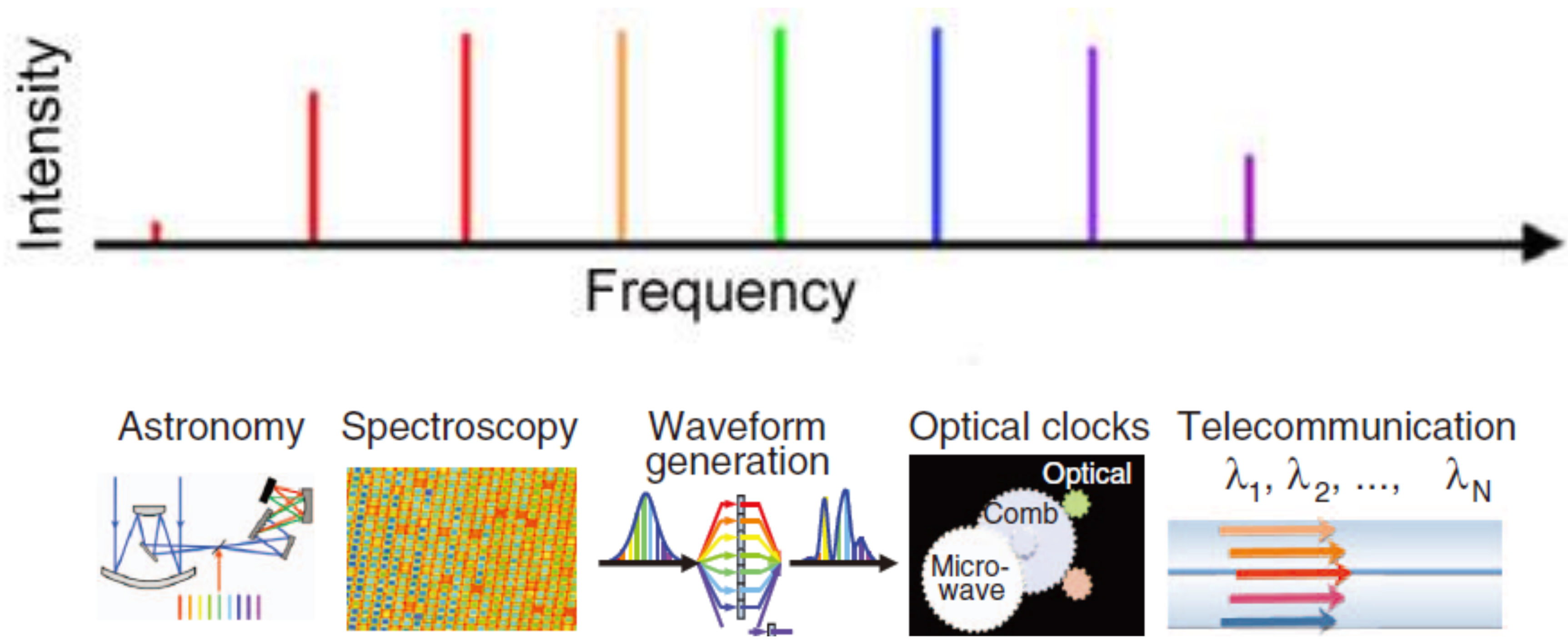
REPORT

OPTICS

Soliton microcomb range measurement

Myoung-Gyun Suh and Kerry J. Vahala*

Frequency comb

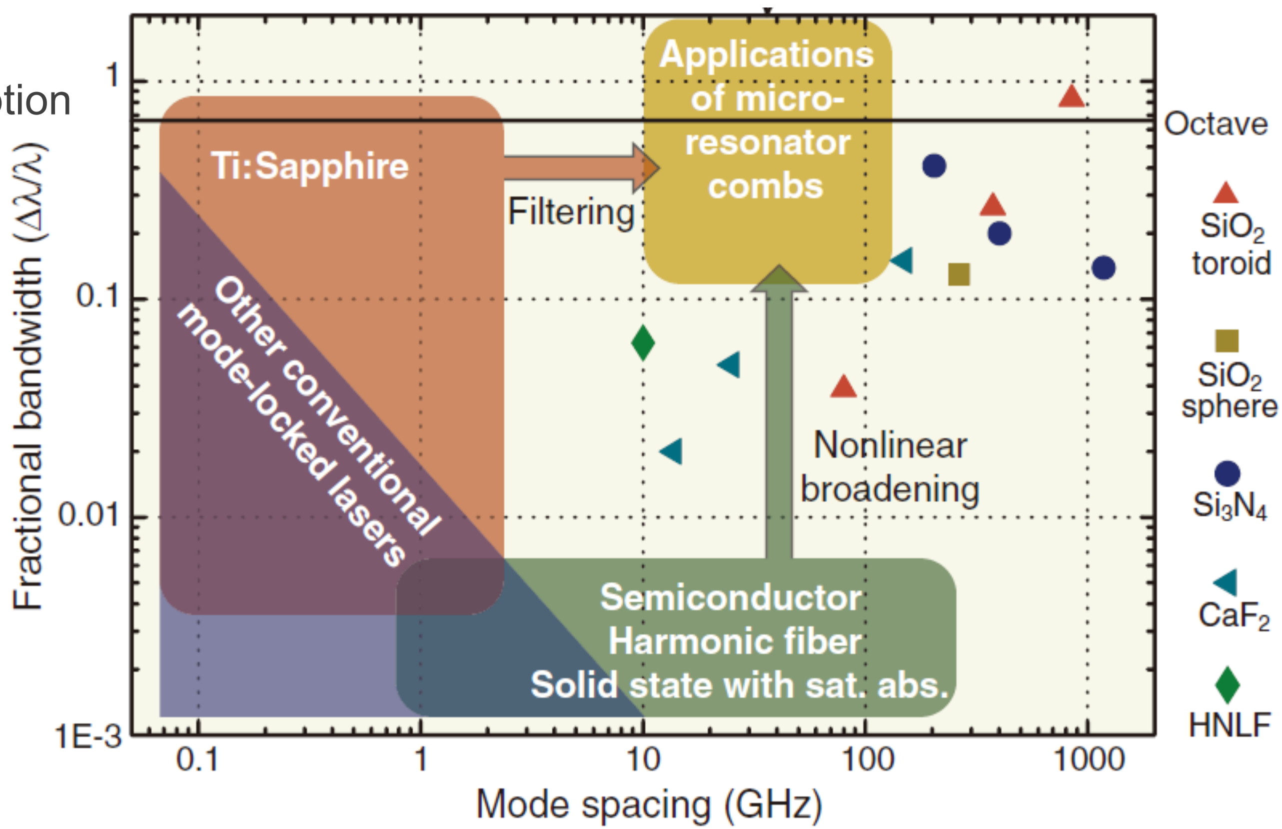


Science **322**, 555 (2011).
https://www.nist.gov/topics/physics/optical-frequency-combs

Microresonator-Based Optical Frequency Combs

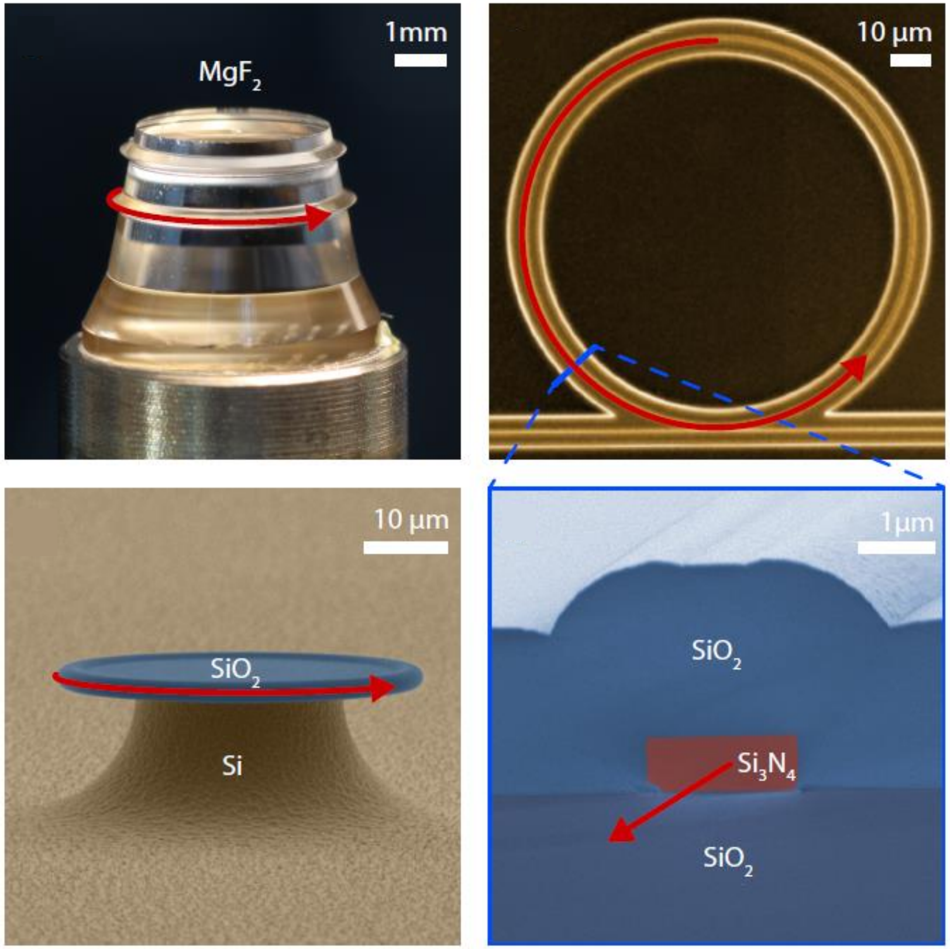
Advantages

- Compact design
- Low power consumption
- Operating range



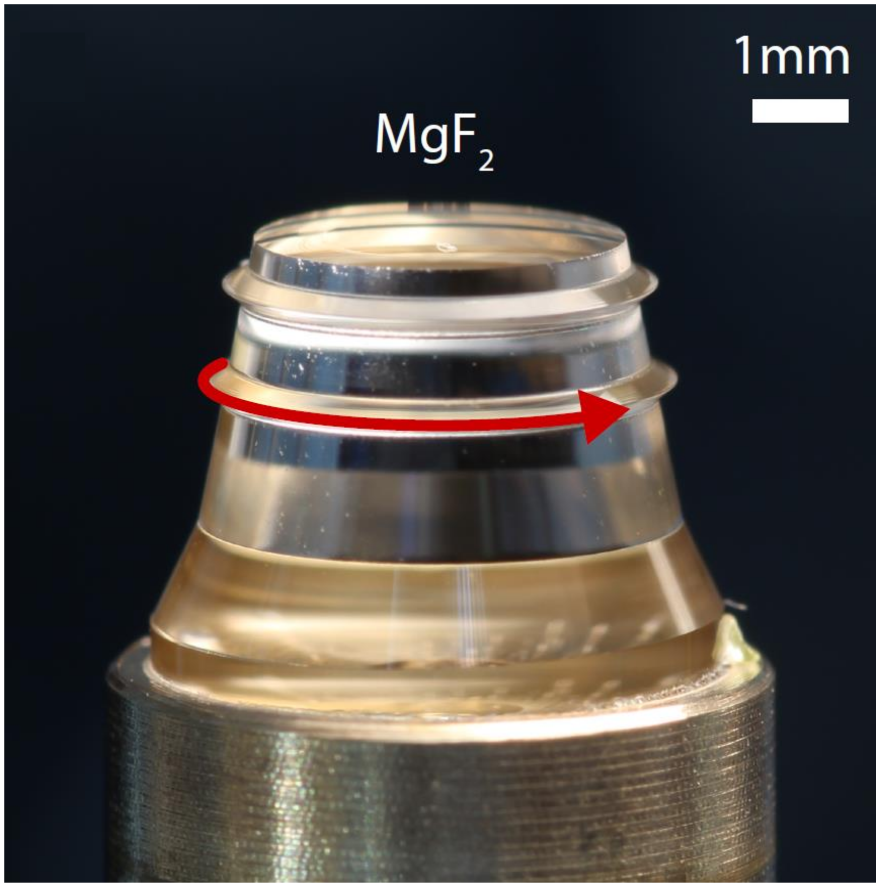
Science **322**, 555 (2011).

Microresonators for frequency combs



T. Herr, Ph.D. thesis, EPFL (2013).

MgF_2 resonator



Resonator Type:	Crystalline MgF_2
Q	10^8-10^9
FSR (GHz)	10-200
n_0	1.37(o), 1.38(e)
n_2 ($10^{-20}\mathrm{m}^2\mathrm{W}^{-1}$)	0.9
A_{eff} ($\mu\mathrm{m}^2$)	30-100
Transparency (μm)	0.13-7.7
$1/L\cdot \mathrm{d}L/\mathrm{d}T$ ($10^{-6}K^{-1}$)	~10
$1/n\cdot \mathrm{d}n/\mathrm{d}T$ ($10^{-6}K^{-1}$)	0.09(o),0.03(e)
Coupling method	tapered fiber

$$n = n_0 + n_2 I$$

T. Herr, Ph.D. thesis, EPFL (2013).

Kerr nonlinearity

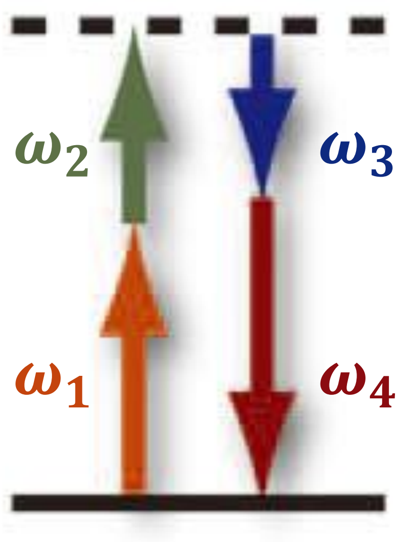
Four wave mixing

$$\boldsymbol{P} = \boldsymbol{\epsilon_0}\left(\boldsymbol{\chi^{(1)} E} + \cancel{\boldsymbol{\chi^{(2)} E^2}} + \boxed{\boldsymbol{\chi^{(3)} E^3}} + \cdots\right)$$

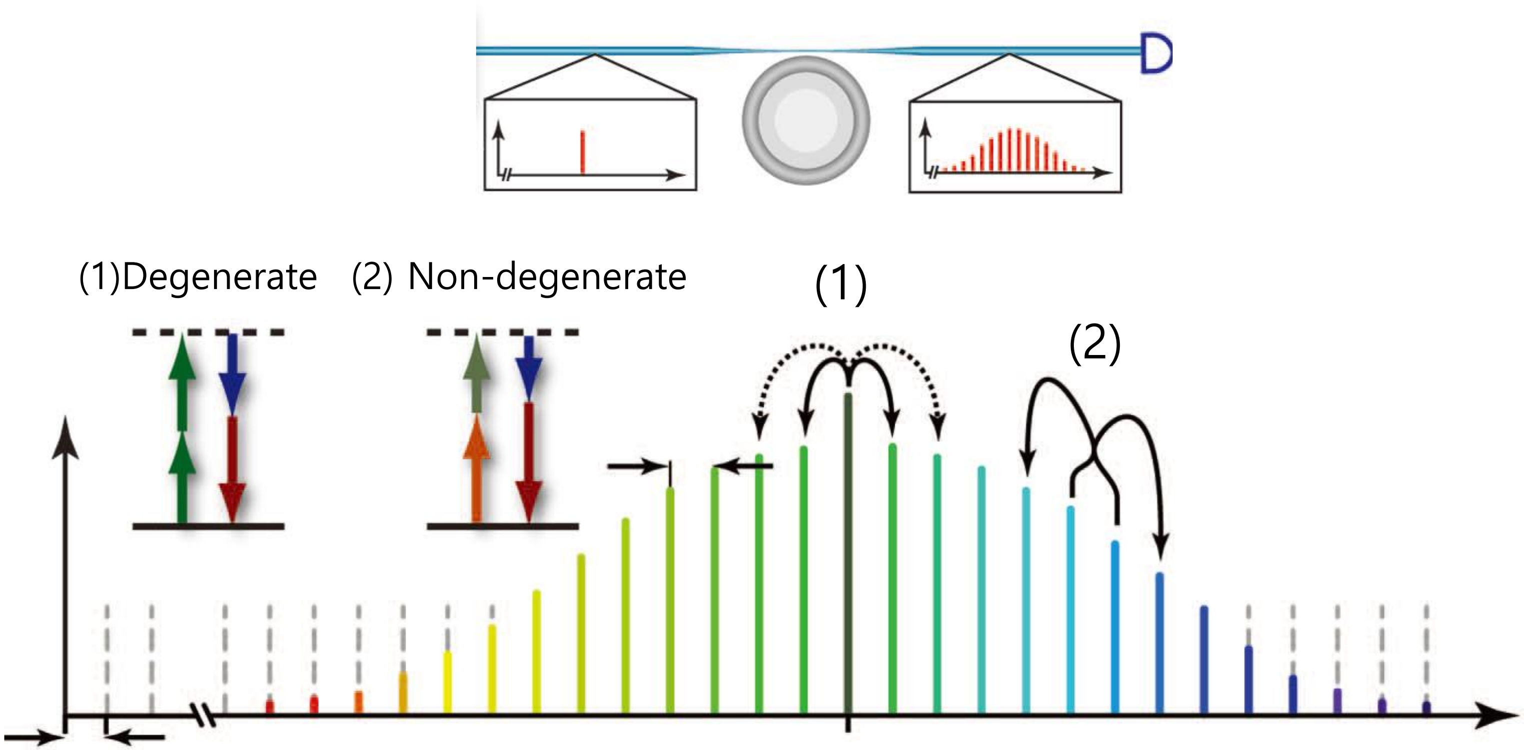
$$E = E_1 e^{i\omega_1 t} + E_2 e^{i\omega_2 t} + E_3 e^{-i\omega_3 t} + \cdots$$

$$\rightarrow P = \cdots + \chi^{(3)} E_1 E_2 E_3 e^{i(\omega_1+\omega_2-\omega_3)t} + \cdots$$

$$\omega_4 = \omega_1 + \omega_2 - \omega_3$$



Principle of Kerr comb



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Soliton

Dispersion

$$\frac{\partial u}{\partial t} + \frac{\partial^3 u}{\partial x^3} = 0$$

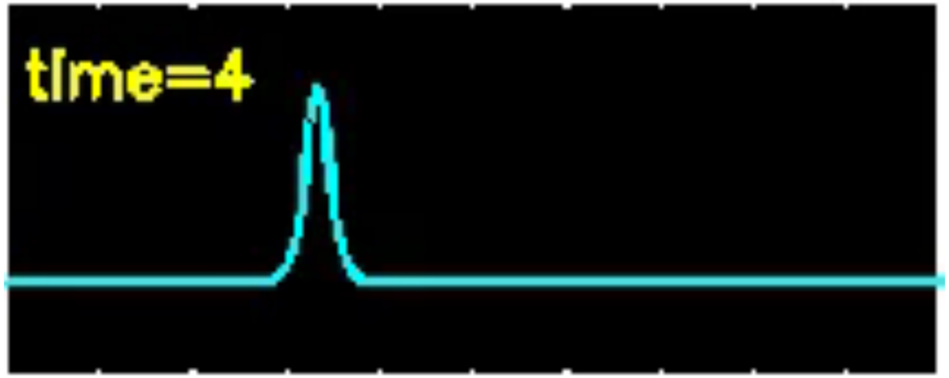
http://www.imm.dtu.dk/math_phys/Solitons.html

Soliton

Balance of dispersion and nonlinearity

$$\frac{\partial u}{\partial t} + \frac{\partial^3 u}{\partial x^3} + u\frac{\partial u}{\partial x} = 0$$

KdV(Korteveg - de Vries) equation

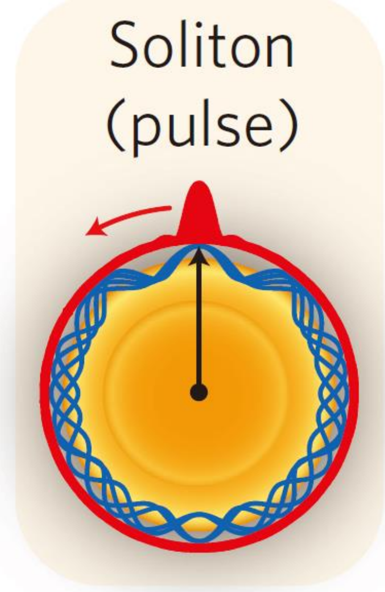


$$u(x,t) = a\,\mathrm{sech}^2[b(x - vt)]$$

where $b = \sqrt{a/12}$, $v = 3a$

http://www.imm.dtu.dk/math_phys/Solitons.html

Dissipative Kerr soliton



Lugiato-Lefever equation

A : Slowly varying envelope

$$\frac{\partial A}{\partial t} \underbrace{- i\frac{1}{2}D_2\frac{\partial^2 A}{\partial \phi^2}}_{\text{Anomalous dispersion}} \underbrace{- ig|A|^2 A}_{\text{Kerr effect}} = \underbrace{-\left(\frac{\kappa}{2} + i\left(\omega_0 - \omega_p\right)\right)A}_{\text{Decay}} + \underbrace{\sqrt{\frac{\kappa\eta P_{in}}{\hbar\omega_0}}}_{\text{Pumping}}$$

$$A \sim \mathrm{sech}(B\phi - \omega t)$$

Dissipative Kerr soliton

August 1, 2011 / Vol. 36, No. 15 / OPTICS LETTE

Mode-locked Kerr frequency combs

A. B. Matsko,* A. A. Savchenkov, W. Liang, V. S. Ilchenko, D. Seidel, and L. Maleki

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**Corresponding author: andrey.matsko@oewaves.com*

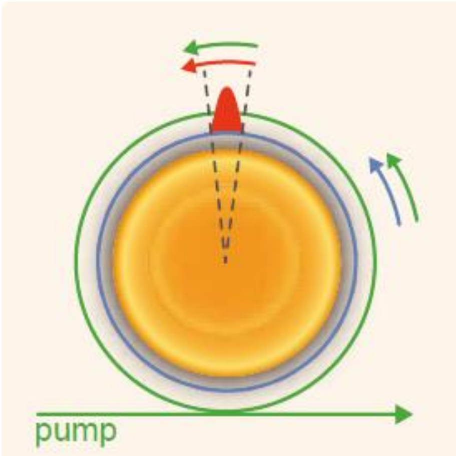
Received May 17, 2011; accepted June 24, 2011;
posted July 1, 2011 (Doc. ID 147700); published July 22, 2011

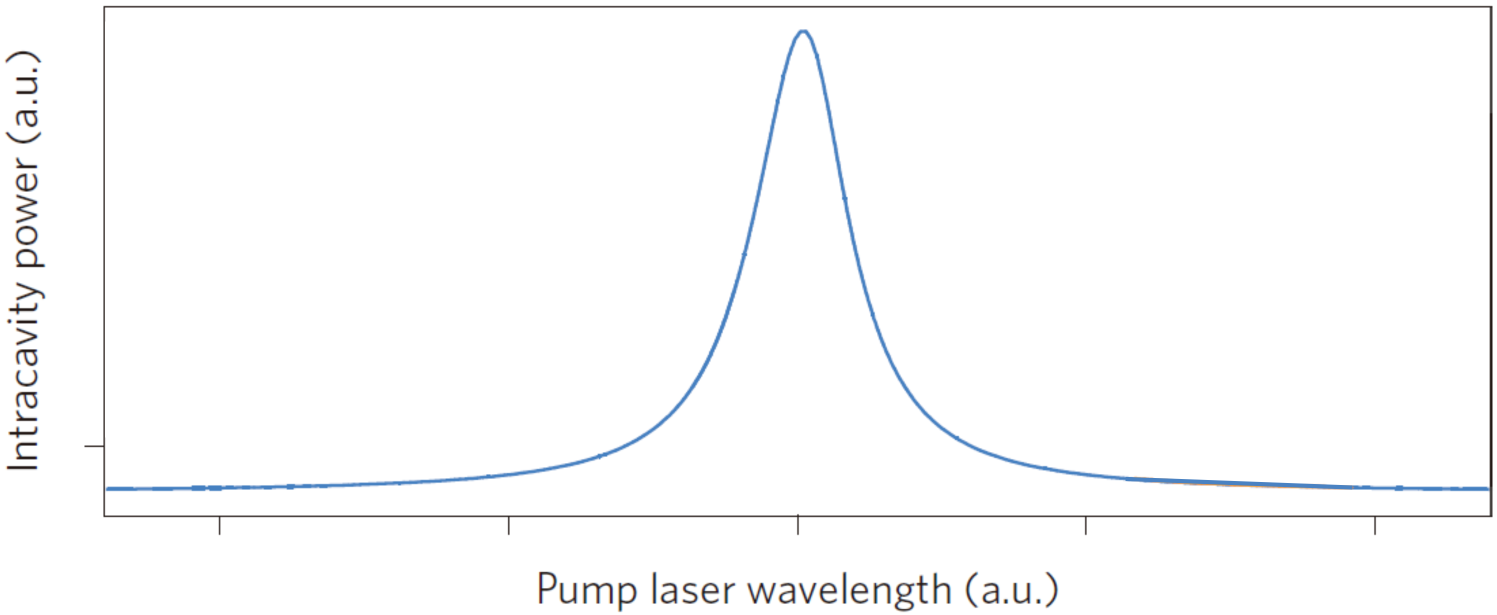
We analyze a mode-locked regime in Kerr frequency combs generated in nonlinear microresonators. Using damped driven nonlinear Schrödinger equations we show that the combs can produce subpicosecond optical pulses when the resonators are characterized with a small enough anomalous group velocity dispersion. We provide an analytical solution of the problem for the case of small damping.

OCIS codes: 190.5530, 190.2620, 190.4223.

Method for creating solitons

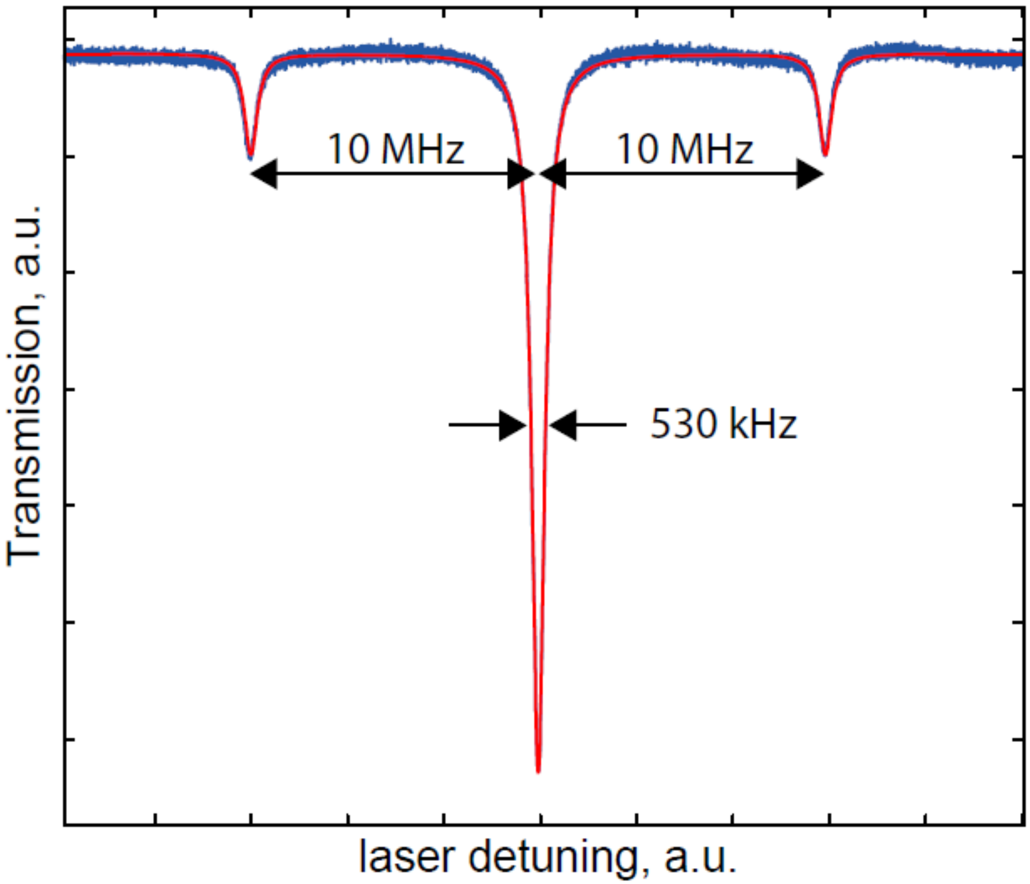
1. Sweep the frequency of the pump laser





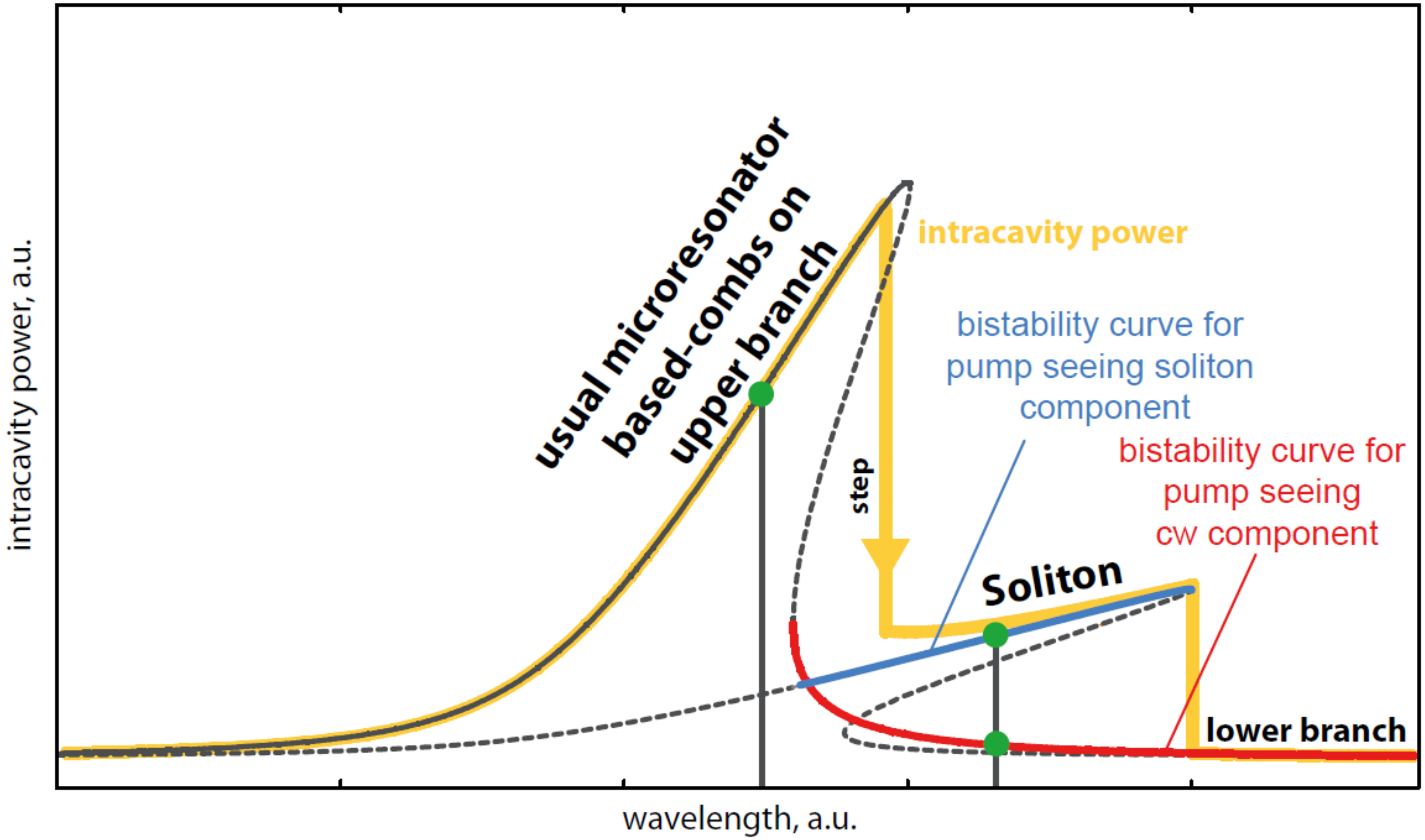
Transmission spectrum

Low power limit

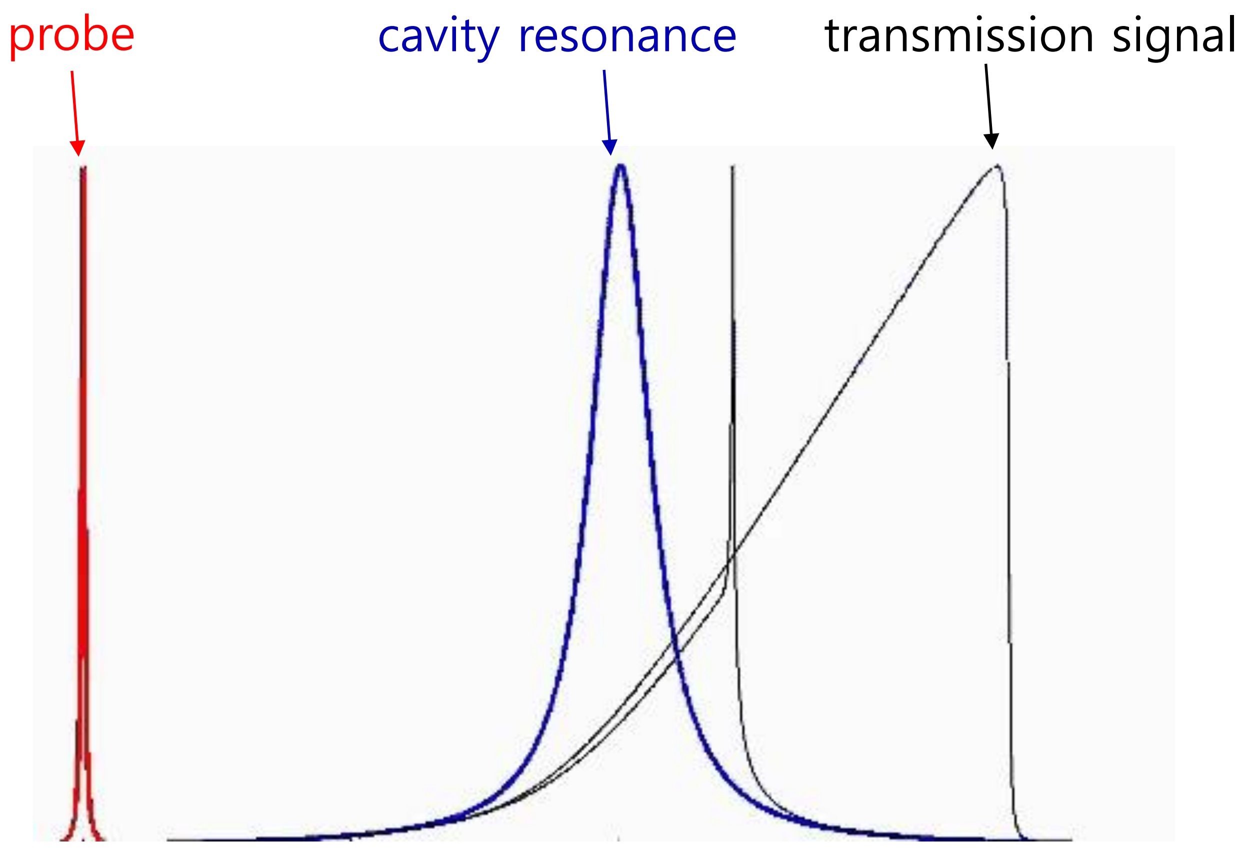


T. Herr, Ph.D. thesis, EPFL (2013).

Bistable resonance

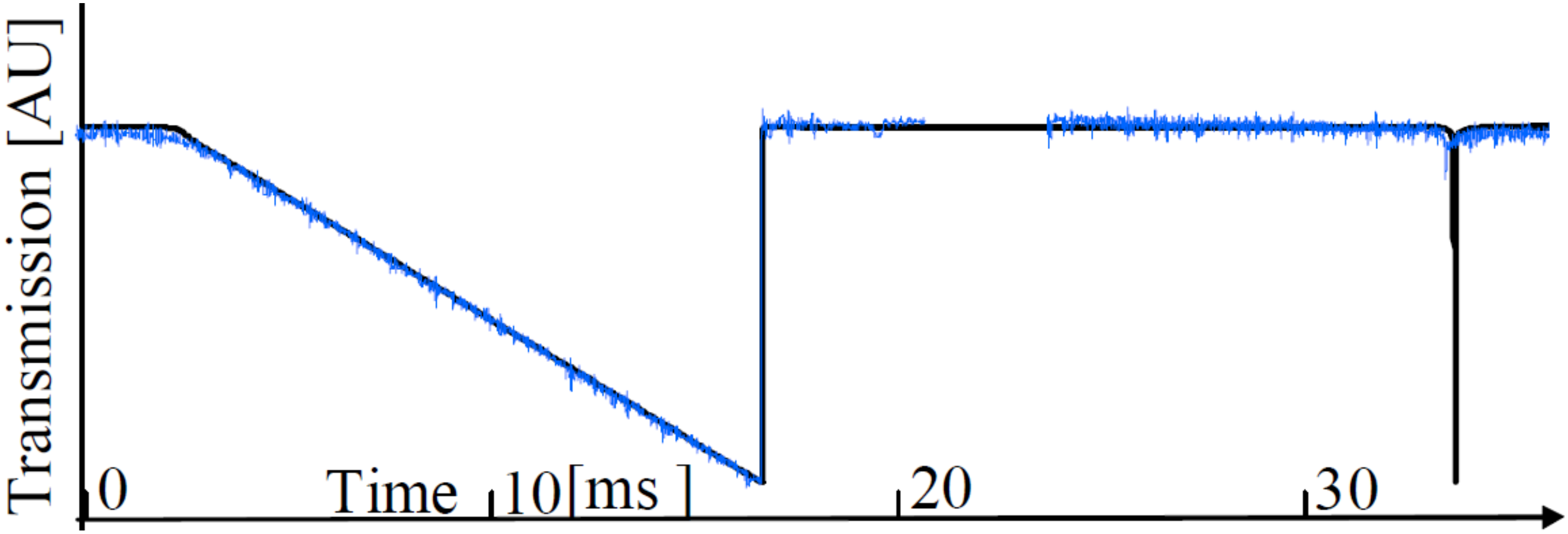


Triangular resonance



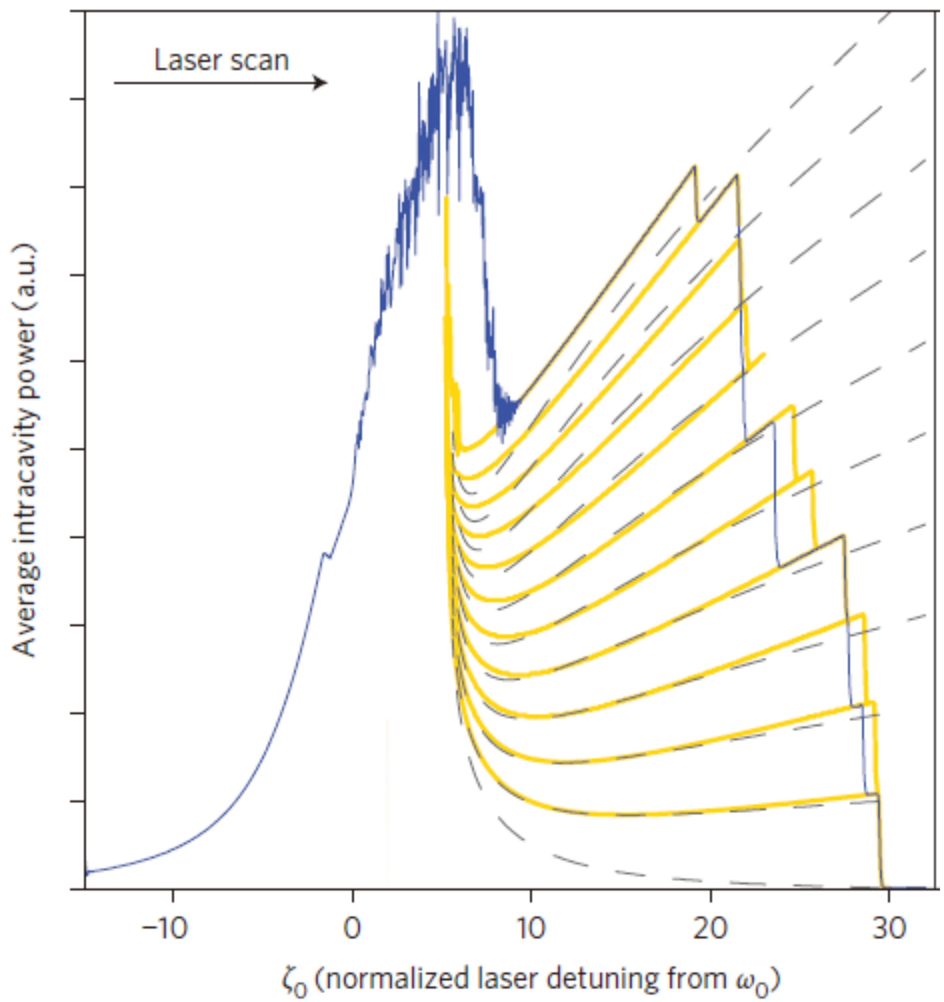
https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-12-20-4742&id=81300

Triangular resonance



Opt. Express **12**, 4742 (2004).

Numerical simulation



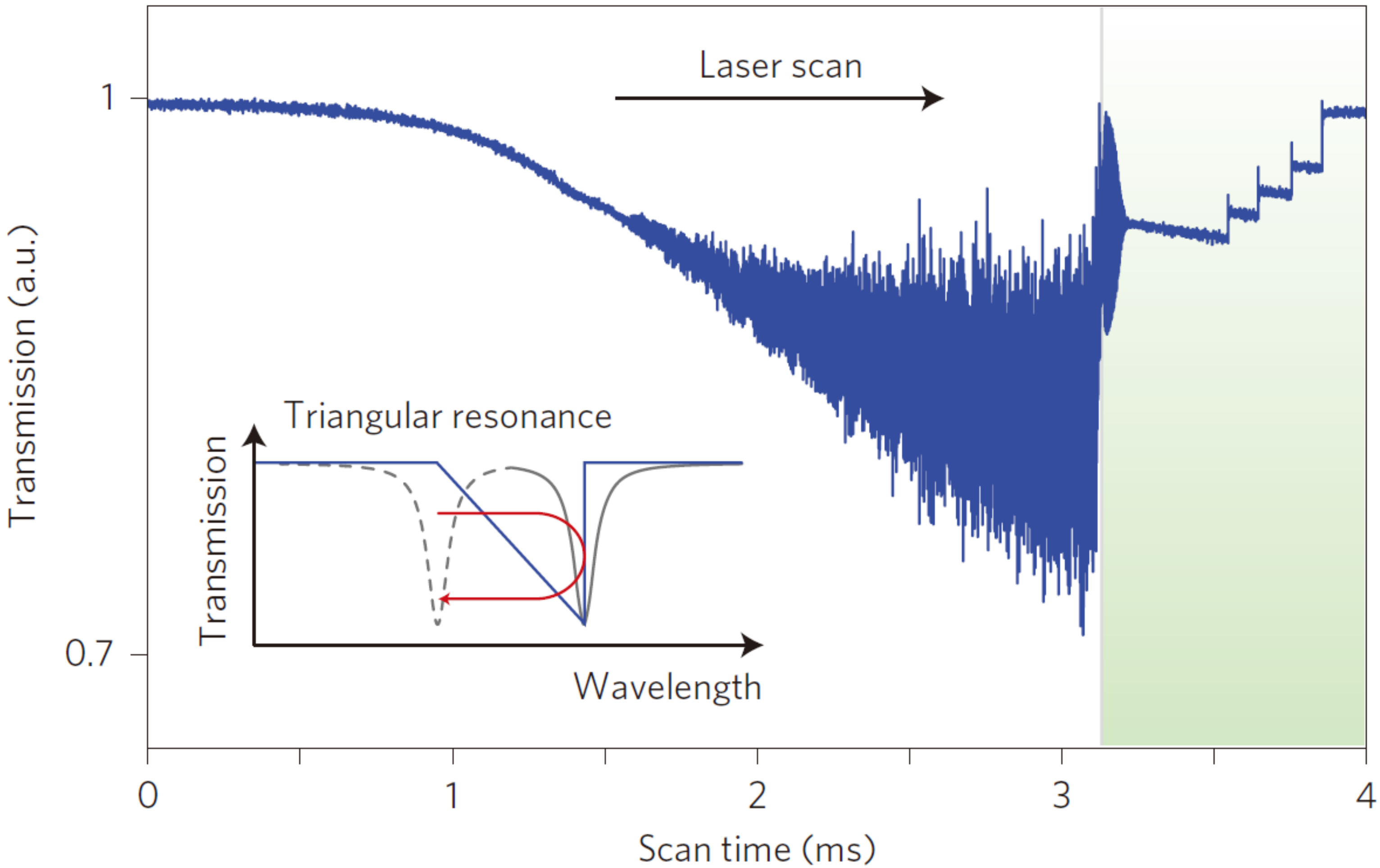
numerical simulation

all possible evolutions

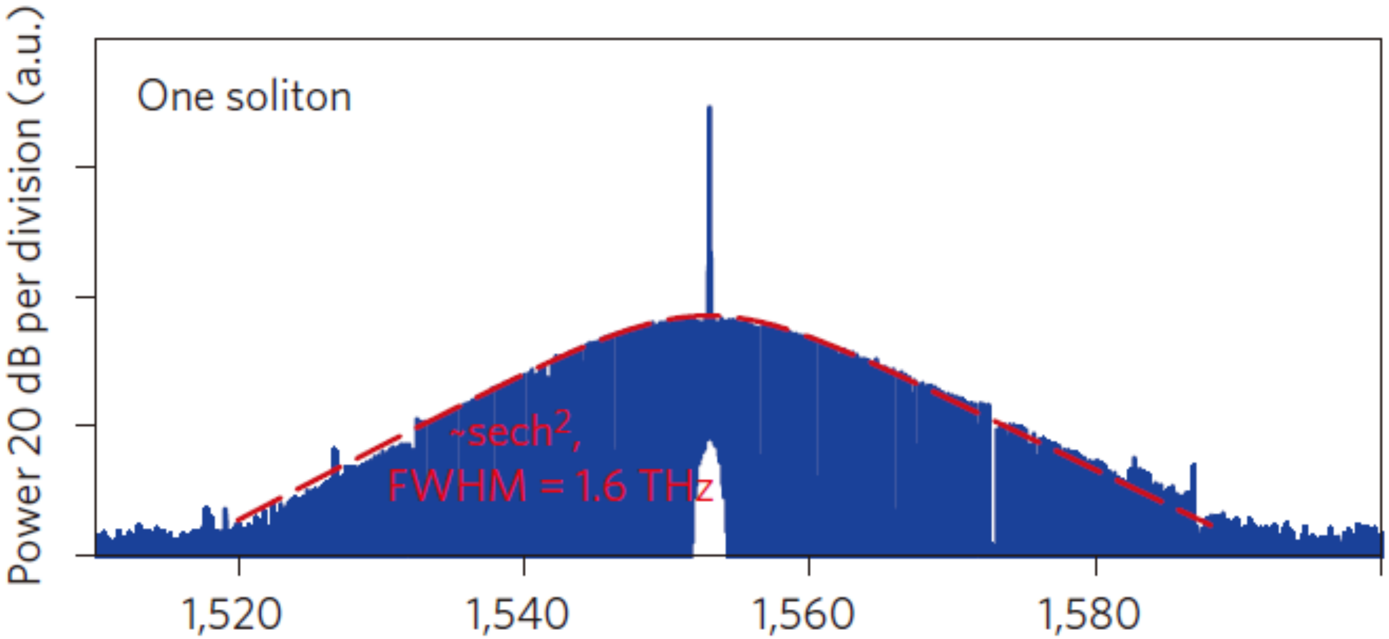
analytic solutions

Transmission spectrum

High power pump

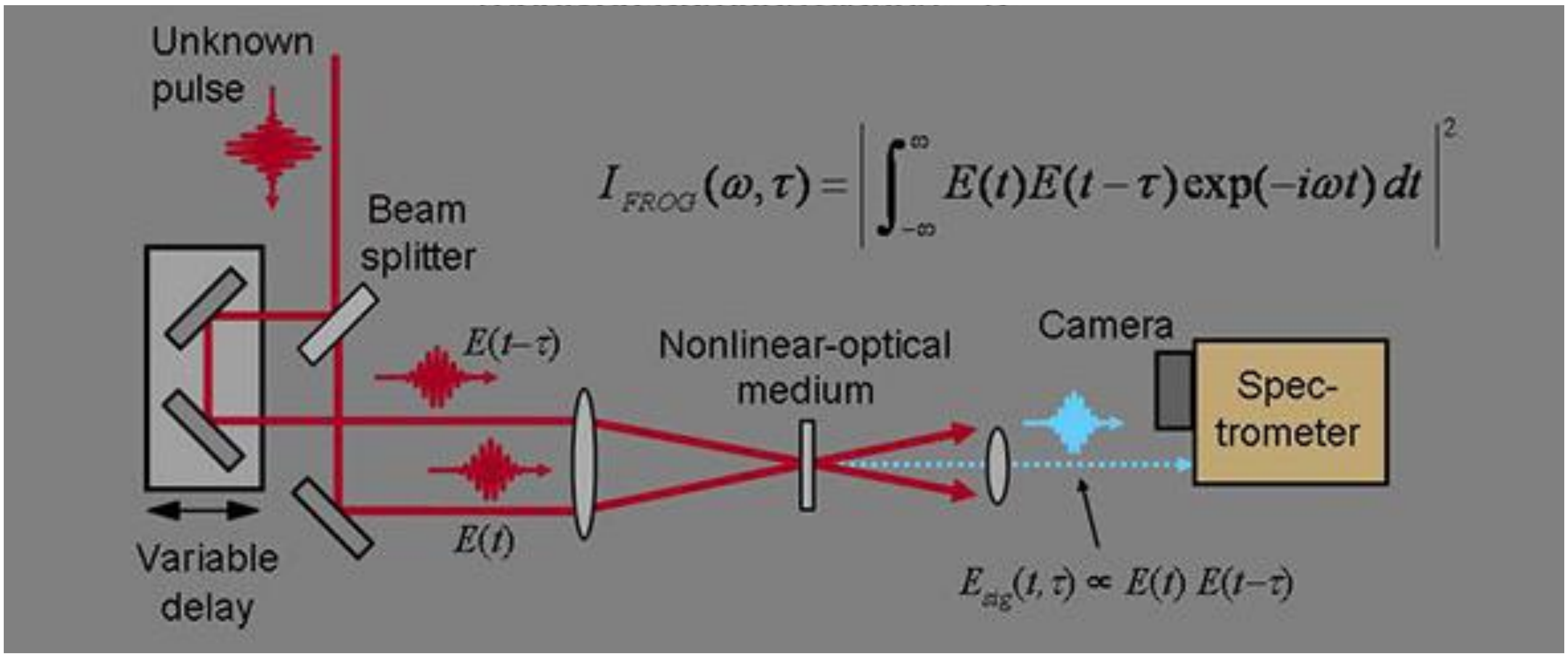


Spectrum measurement



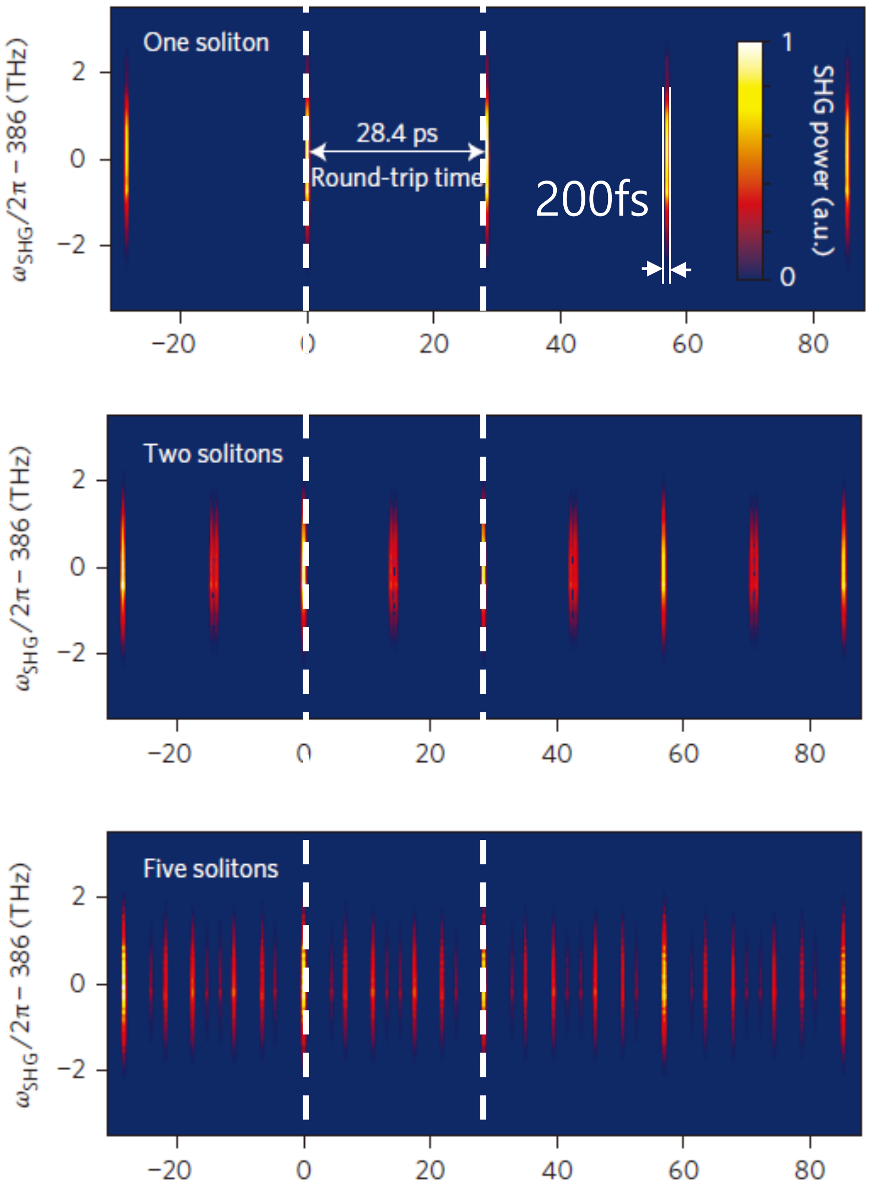
FROG measurement

Frequency resolved optical gating



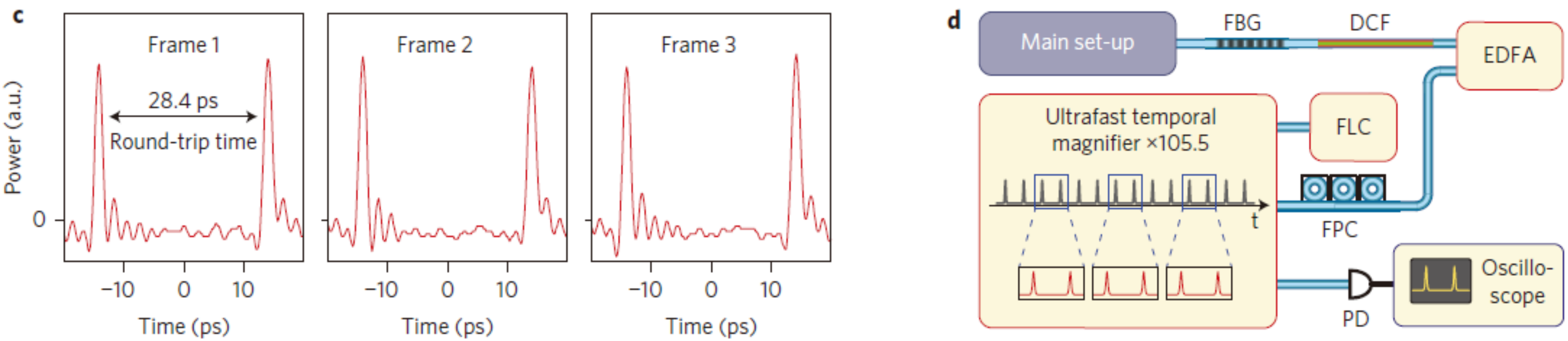
http://frog.gatech.edu/frog.html

FROG measurement

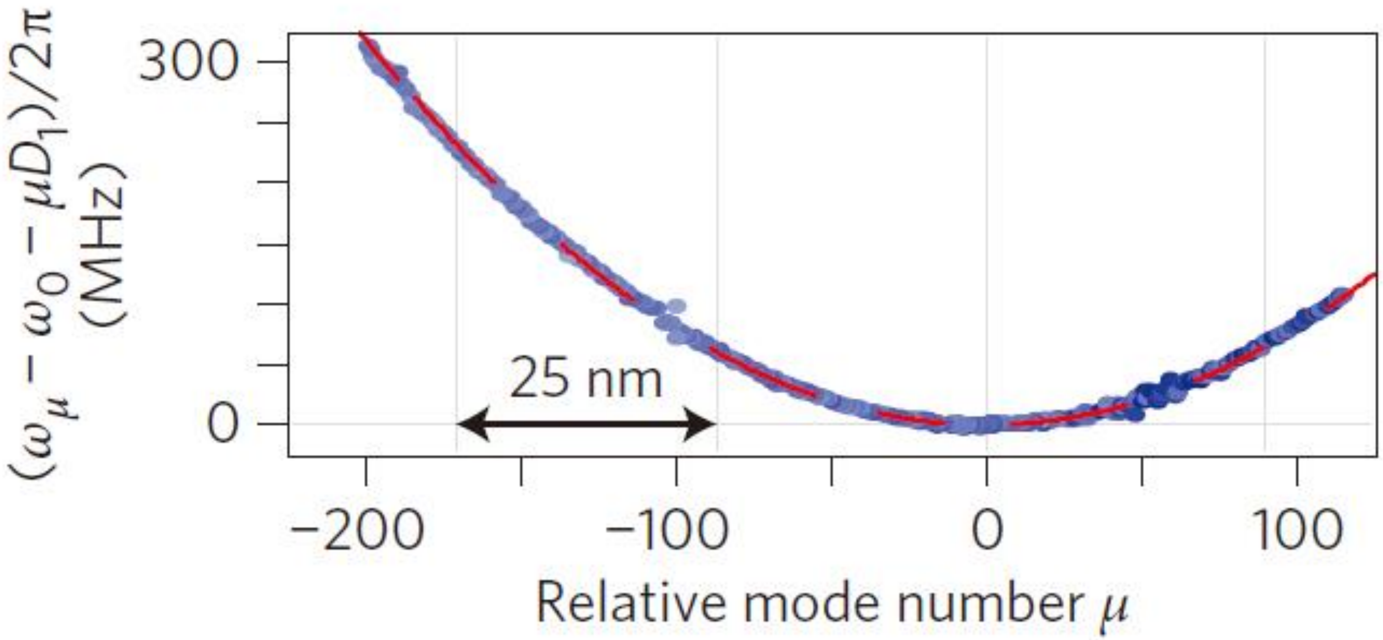


Supplementary Material

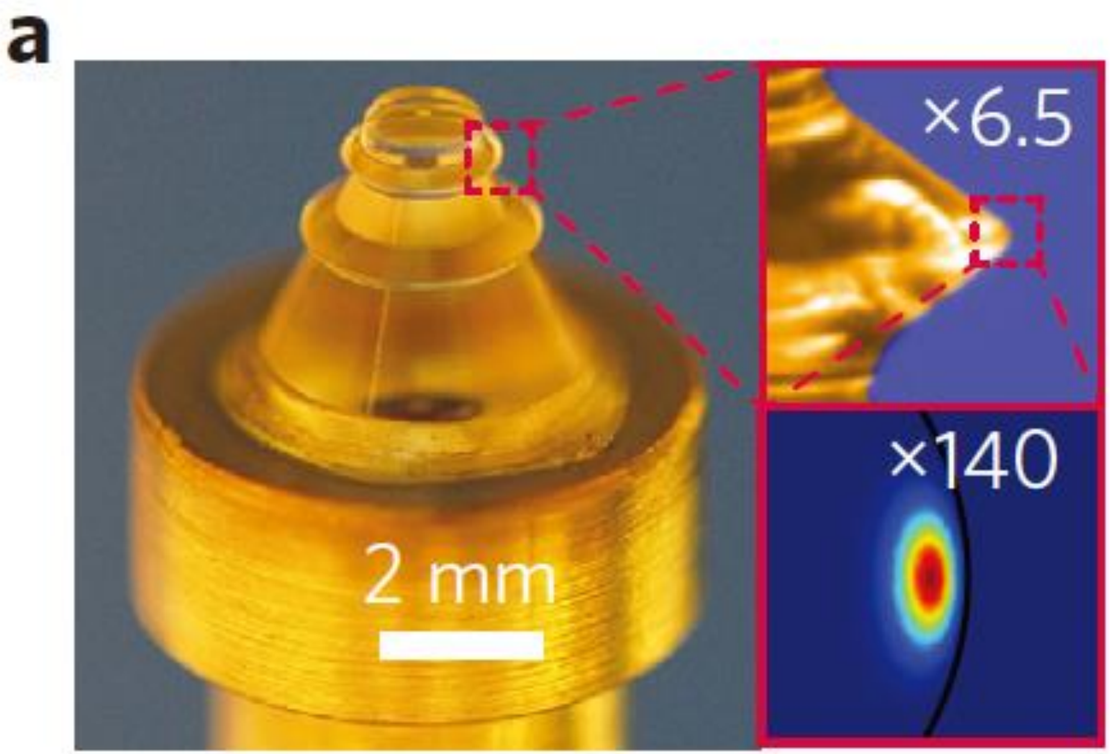
Temporal magnifier

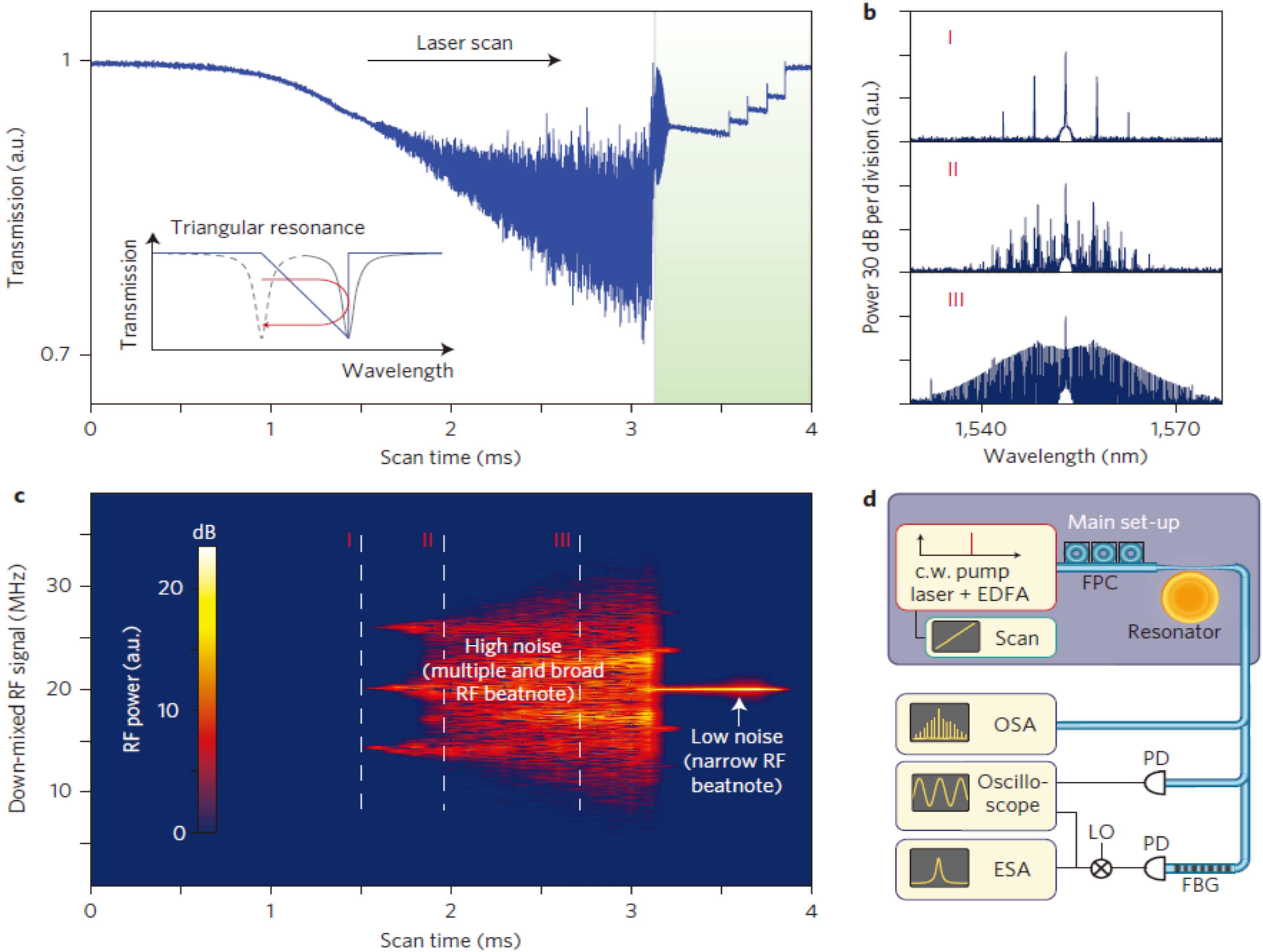


Anomalous dispersion



WGM mode




Laser scan
1
0.7
Transmission (a.u.)
Triangular resonance
Transmission
Wavelength
0
1
2
3
4
Scan time (ms)
b
I
II
III
Power 30 dB per division (a.u.)
1,540
1,570
Wavelength (nm)
c
dB
20
10
0
RF power (a.u.)
I
II
III
30
20
10
Down-mixed RF signal (MHz)
High noise
(multiple and broad
RF beatnote)
Low noise
(narrow RF
beatnote)
0
1
2
3
4
Scan time (ms)
d
Main set-up
c.w. pump
laser + EDFA
FPC
Resonator
Scan
OSA
PD
Oscillo-
scope
LO
PD
ESA
FBG