LATVIJAS UNIVERSITĀTE

FOTONIKA-LV

LATVIJAS UNIVERSITĀTES NACIONĀLĀ ZINĀTNES PLATFORMA

From ultra-stable laser resonators for atomic spectroscopy and fiber-based femtosecond optical frequency combs to whispering-gallery-mode microresonator sensors and microsphere optical frequency combs for telecommunication data transfer

Jānis Alnis, Aigars Atvars, Roberts Berķis, Dina Bērziņa, Uldis Bērziņš, Inga Brice, Artūrs Ciniņš, Kristians Draguns, Kārlis Grundšteins, Viesturs Ignatāns, Pauls Kristaps Reinis, Lāse Mīlgrāve, Arvīds Sedulis, Alma Ūbele

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NATIONAL DEVELOPMENT PLAN 2020

EUROPEAN UNION
European Regional Development Fund

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ERDF No 1.1.1.1/18/A/155

lzp-2018/1-0510

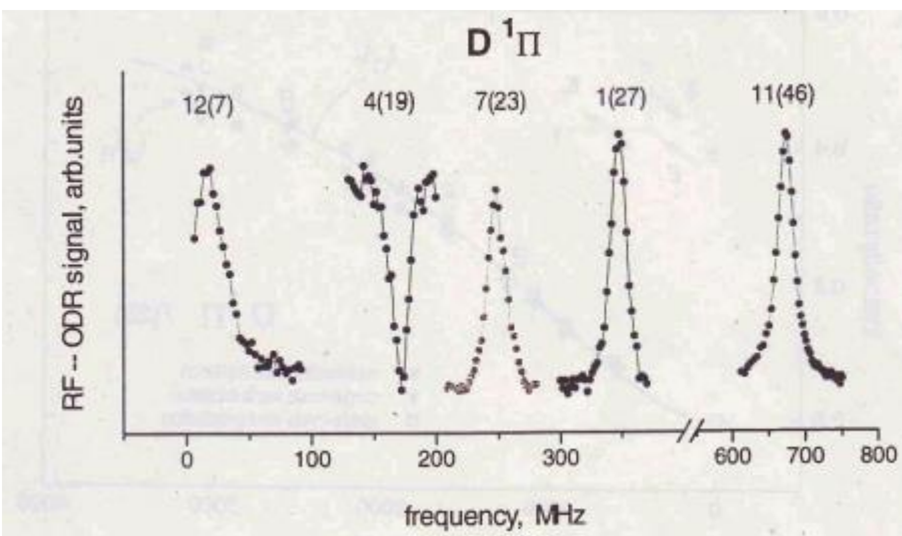
How it started:
Master studies at Institute of Atomic Physics and Spectroscopy
Prof. M. Auzins group, M. Tamanis lab

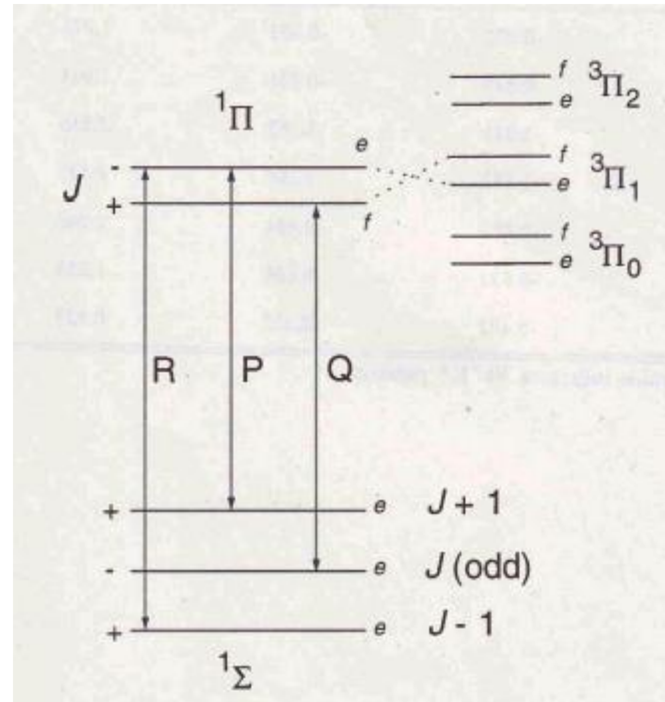
NaK PERMANENT ELECTRIC DIPOLES AND

Λ-DOUBLING IN LOW LYING STATES

M. Tamanis, J. Alnis, M. Auzinsh,
I. Klincare, O. Nikolayeva, R. Ferber
E.A. Pazyuk, A.V. Stolyarov, A. Zaitsevskii

Nr. 26/97

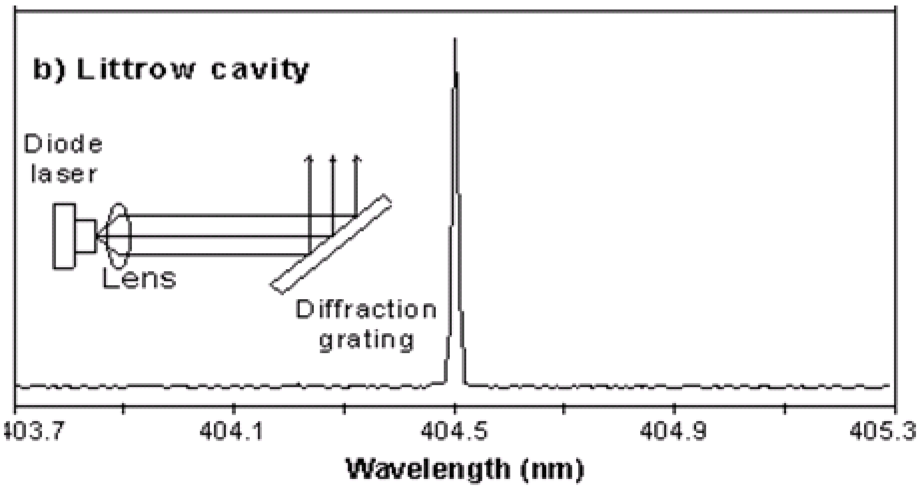




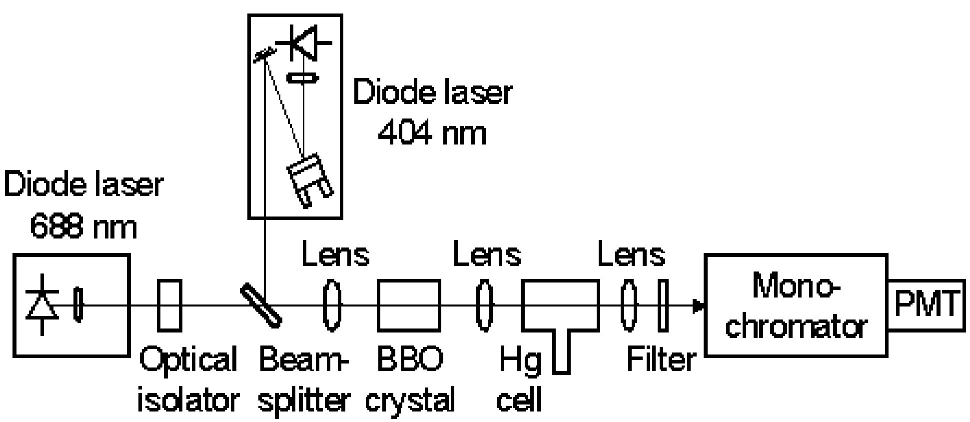
PhD part time in Lund University in Prof. Sune Svanberg group

Violet diode lasers were new at that time.

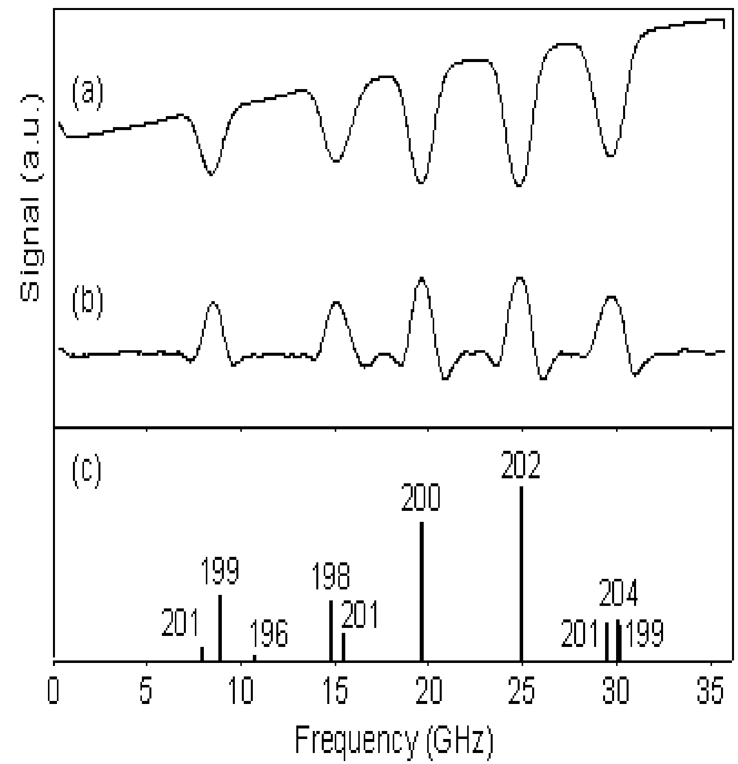
Tested violet laser use for spectroscopy.



Experimental setup for
254 nm sum-frequency generation



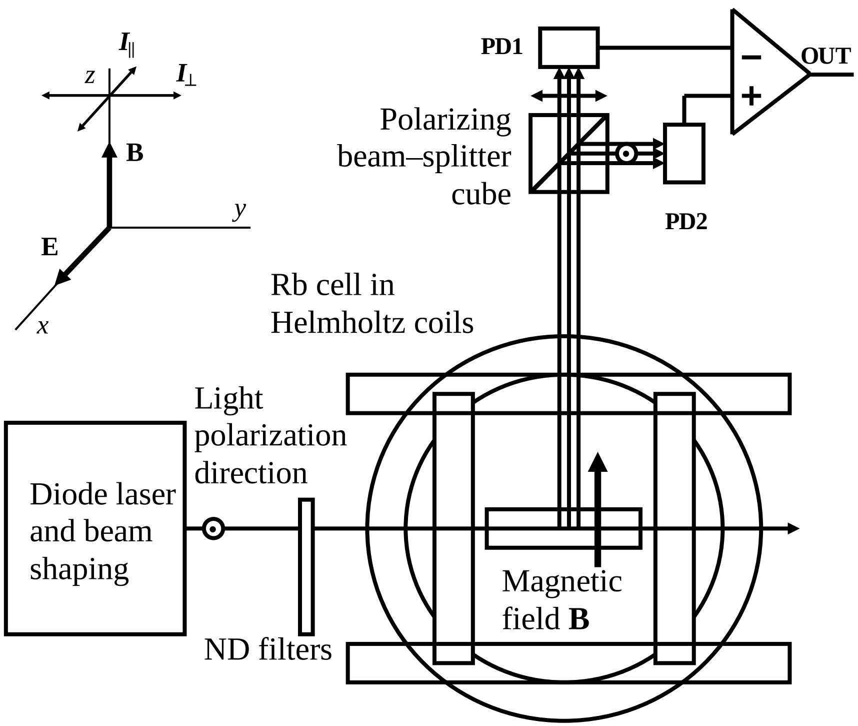
Absorption signal of natural Hg at 254 nm

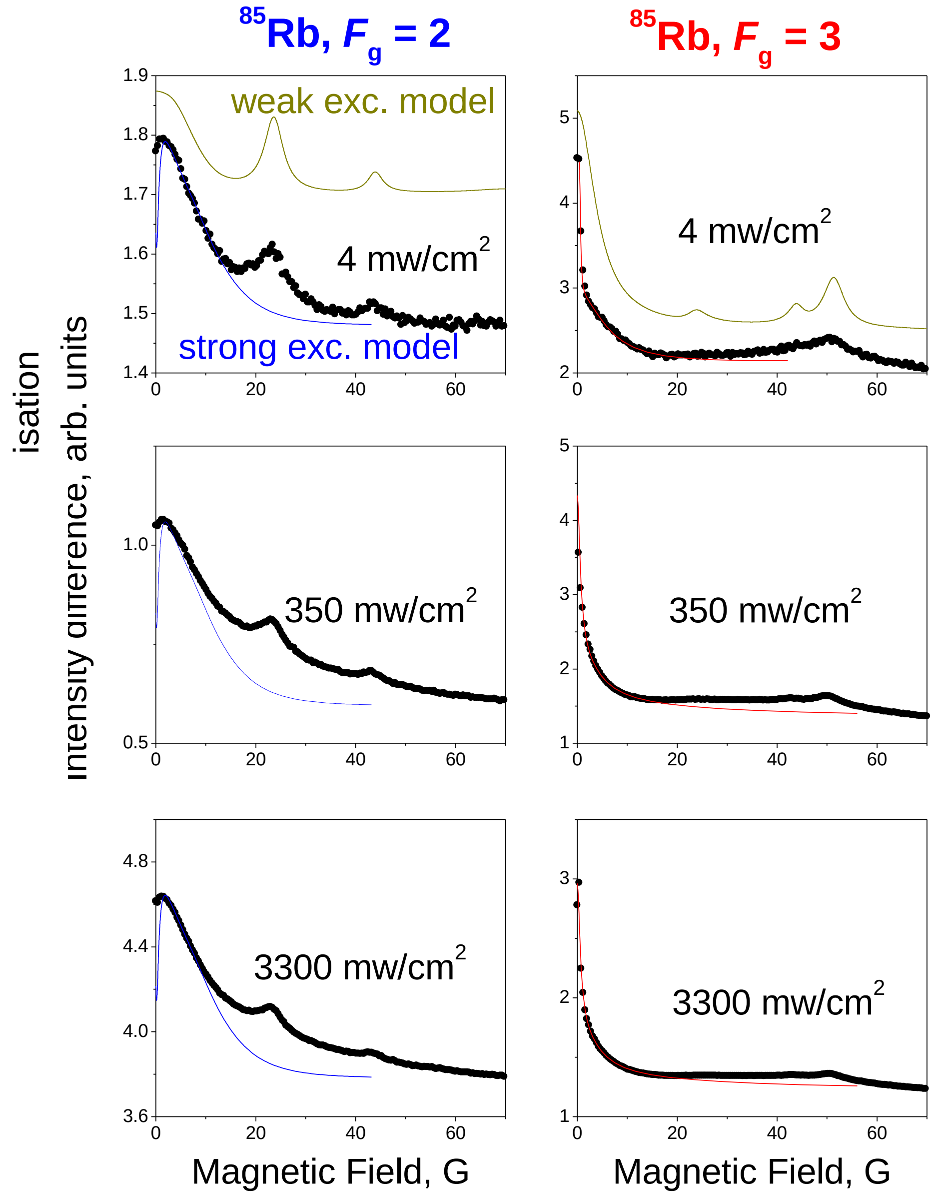


During PhD time introduced diode laser spectroscopy from Lund to University of Latvia in Riga

The Hanle effect and level crossing spectroscopy in Rb under strong laser excitation

J. Alnis, K. Blushs, M. Auzinsh





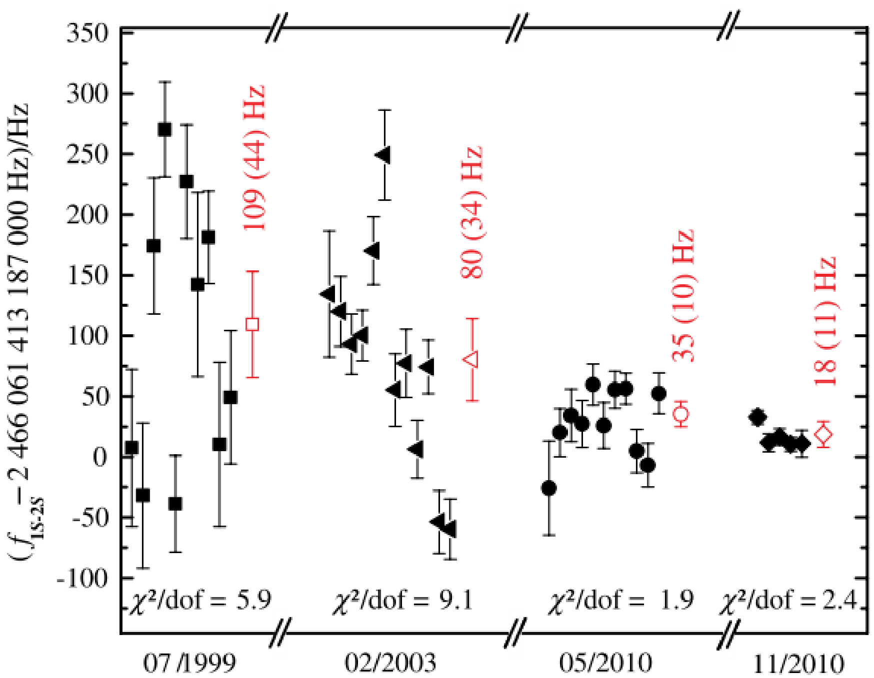
9 years (long-term) postdoc at MPQ Garching

Hydrogen spectroscopy, Prof. T. Hansch group

PRL 110, 230801 (2013) PHYSICAL REVIEW LETTERS

Precision Measurement of the Hydrogen 1S-2S Frequency via a 920-km Fiber Link

Arthur Matveev,[1] Christian G. Parthey,[1] Katharina Predehl,[1] Janis Alnis,[1] Axel Beyer,[1] Ronald Holzwarth,[1,*] Thomas Udem,[1] Tobias Wilken,[1] Nikolai Kolachevsky,[1,†] Michel Abgrall,[2] Daniele Rovera,[2] Christophe Salomon,[3] Philippe Laurent,[2] Gesine Grosche,[4] Osama Terra,[4] Thomas Legero,[4] Harald Schnatz,[4] Stefan Weyers,[4] Brett Altschul,[5] and Theodor W. Hänsch[1,‡]



www.sciencemag.org SCIENCE VOL 336 27 APRIL 2012 441

A 920-Kilometer Optical Fiber Link for Frequency Metrology at the 19th Decimal Place

K. Predehl,[1*] G. Grosche,[2,3]† S. M. F. Raupach,[2]† S. Droste,[1] O. Terra,[2] J. Alnis,[1] Th. Legero,[2] T. W. Hänsch,[1,4] Th. Udem,[1] R. Holzwarth,[1,5] H. Schnatz[2,3]

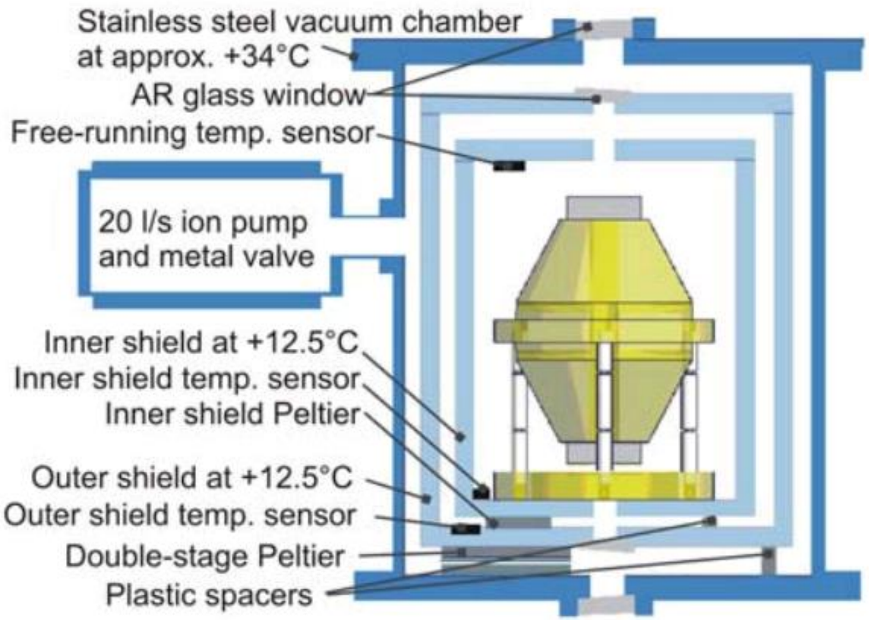
INNOVATION - transportable optical reference resonators

PHYSICAL REVIEW A

Subhertz linewidth diode lasers by stabilization to vibrationally and thermally compensated ultralow-expansion glass Fabry-Pérot cavities

J. Alnis, A. Matveev, N. Kolachevsky, Th. Udem, and T. W. Hänsch

Phys. Rev. A **77**, 053809 – Published 12 May 2008



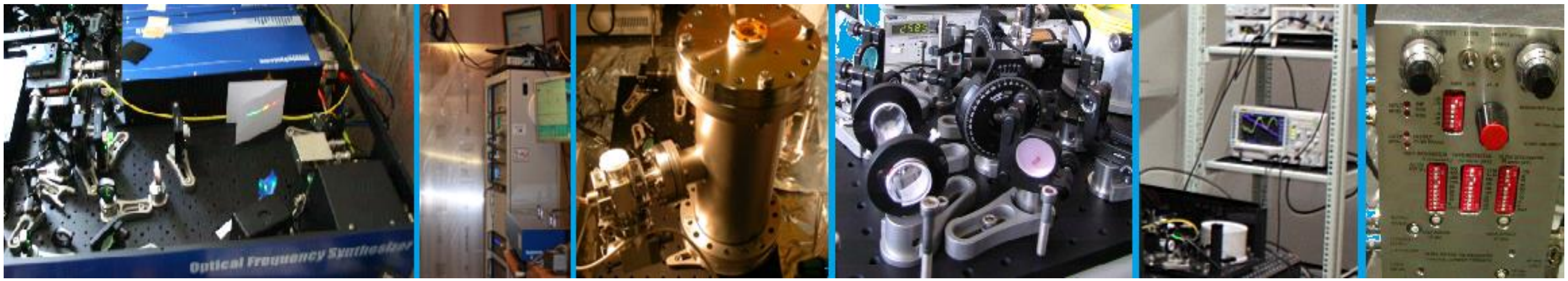
Repeated in: MPQ, PTB, ETH, Singapure, CERN, Lebedev inst.

Commercialized by : *Menlo Systems* DE and *Stable lasers USA.*

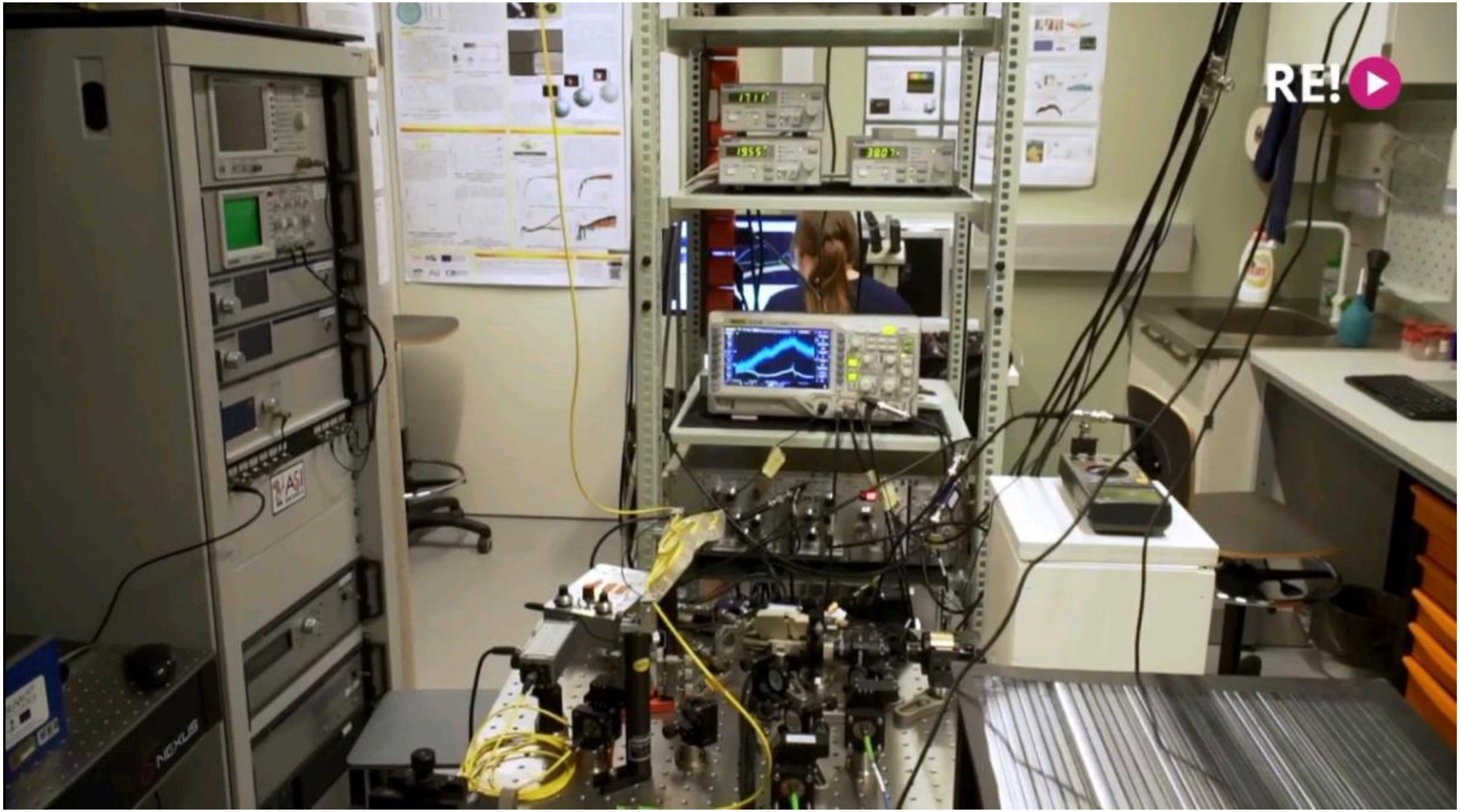
Quantum Optics lab at the Institute of Atomic Physics and Spectroscopy

started in 2013 during the Fotonika-LV project

fiber comb, FP resonators, Rb spectroscopy



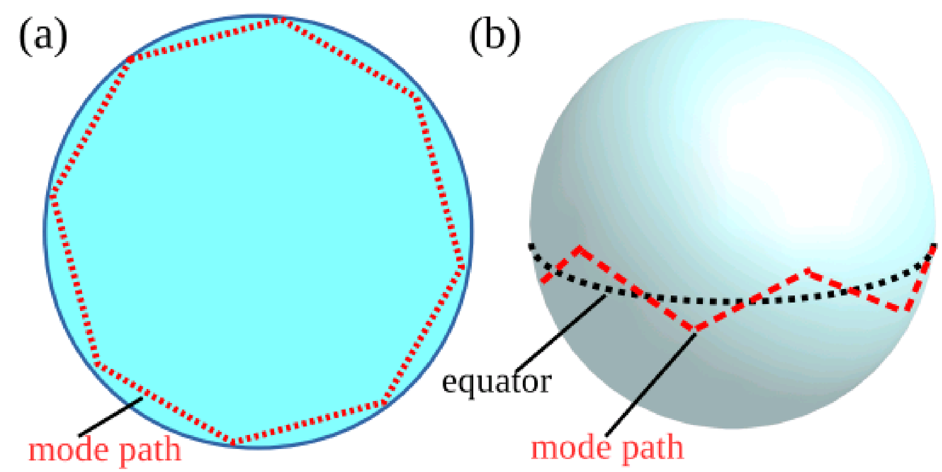
Quantum Optics Lab
in the new Science building since 2019
Fiber-laser frequency comb, repetition rate 250 MHz,
made by Menlo Systems (on the left)
and 780 nm WGM biosensor (on the right)



Whispering gallery microresonators

- Uses total internal reflection
- Do not need mirror coatings
- Work in broad wavelength range
- Can be made in house
- Simple enough for Latvia
- Sensors, nonlinear optics

Classical optics



Optical quality factor Q

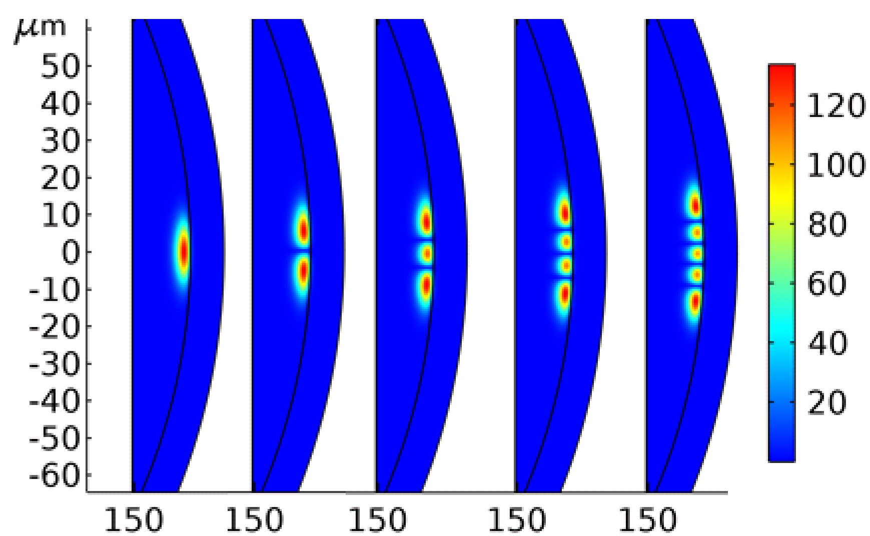
Q = $\omega\,\tau$,
where □ is the phton lifetime

Q = $\upsilon/\Delta\,\upsilon$, where υ is optical frequency $\Delta\,\upsilon$ linewidth

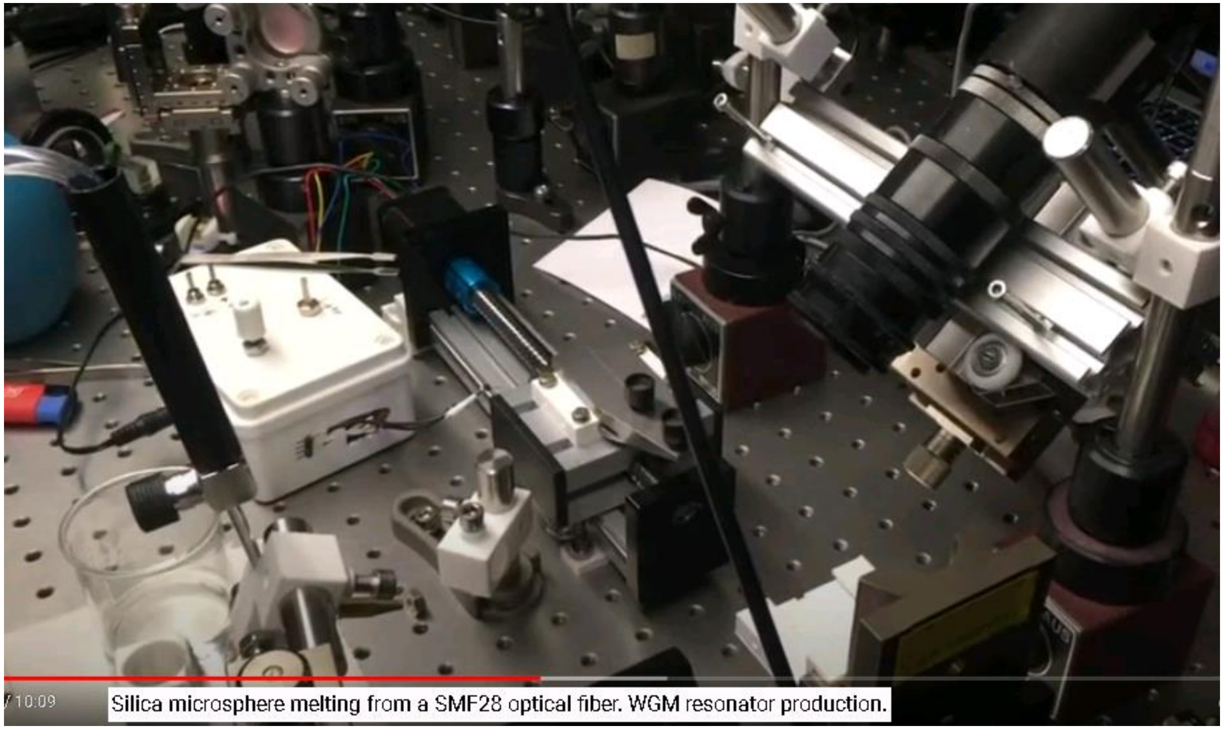
Q = 2π L / λ where L is the photon path length.

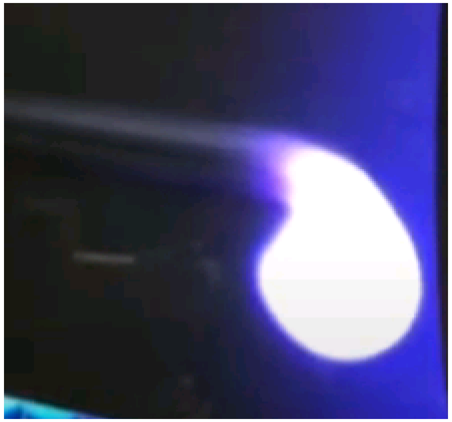
- <u>Example.</u> Resonator Q factor 10^8. Light runs 25 m in 1 mm sphere.

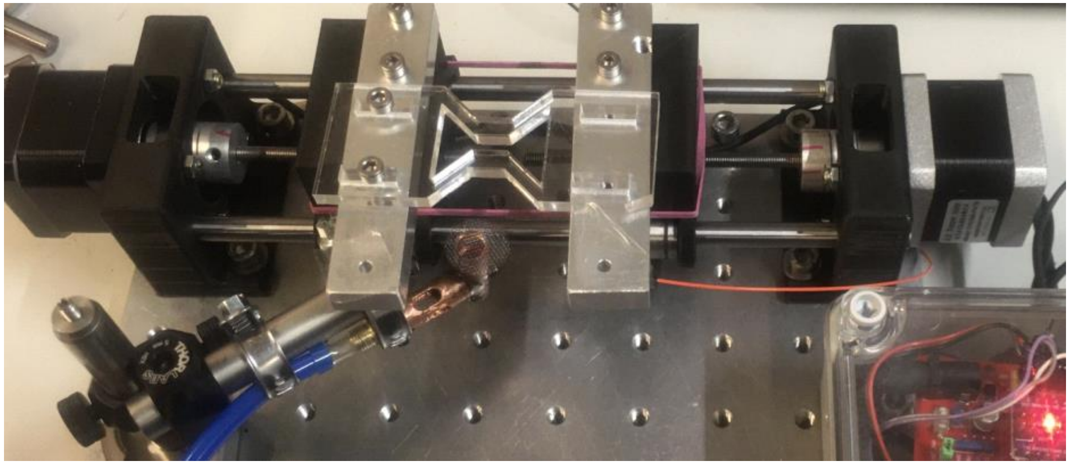
Wave optics



Microsphere fabrication in ohy-hydrogen flame
tapered fiber pulling in pure hydrogen or propane flame

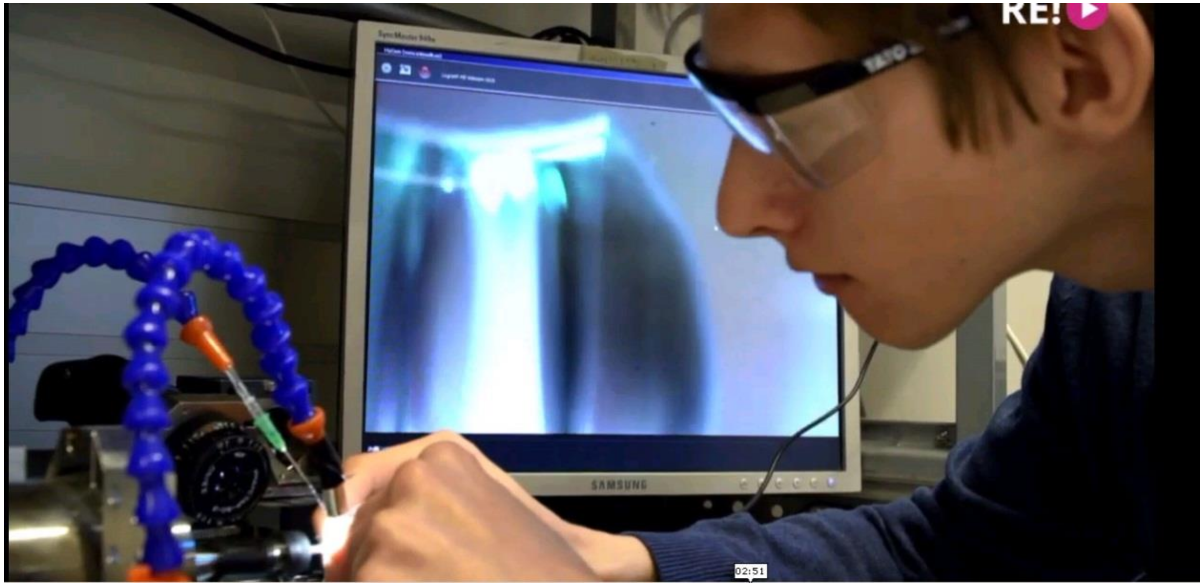






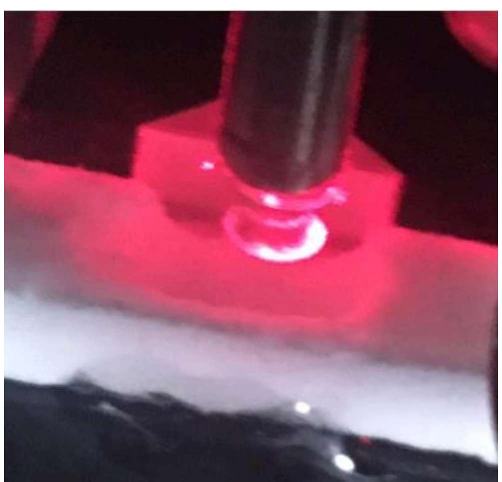
Grinding and polishing of resonators with abrasives on air-bearing spindle

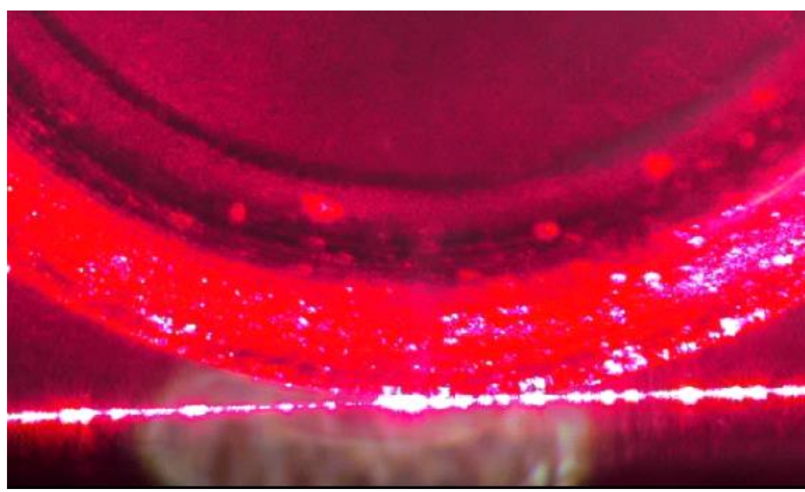
Materials CaF_2 , MgF_2 plexiglass, fused silica.



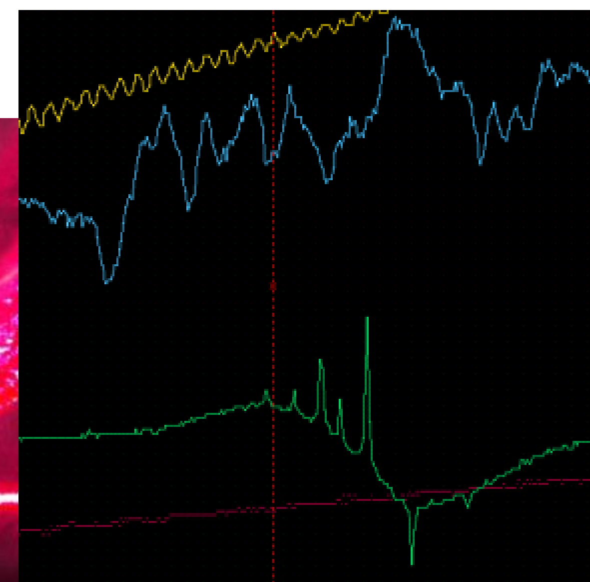
Diamond abrasives

Prism and tapered fiber coupling

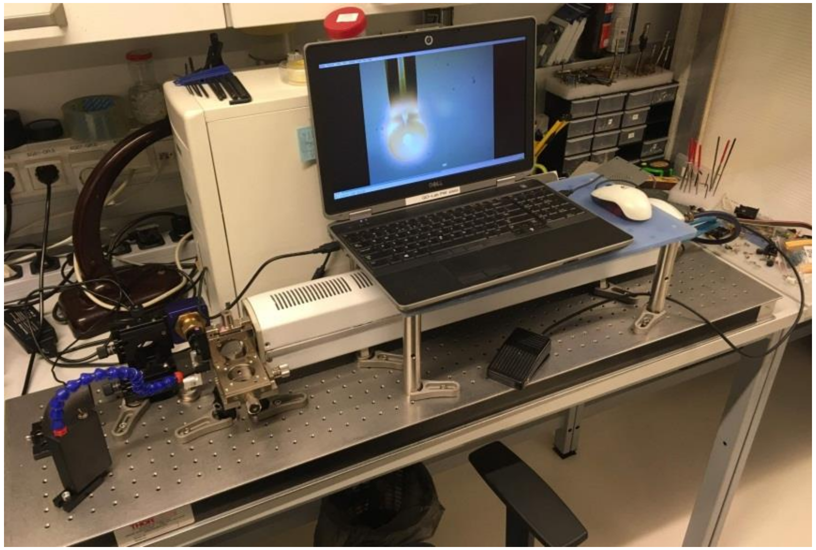


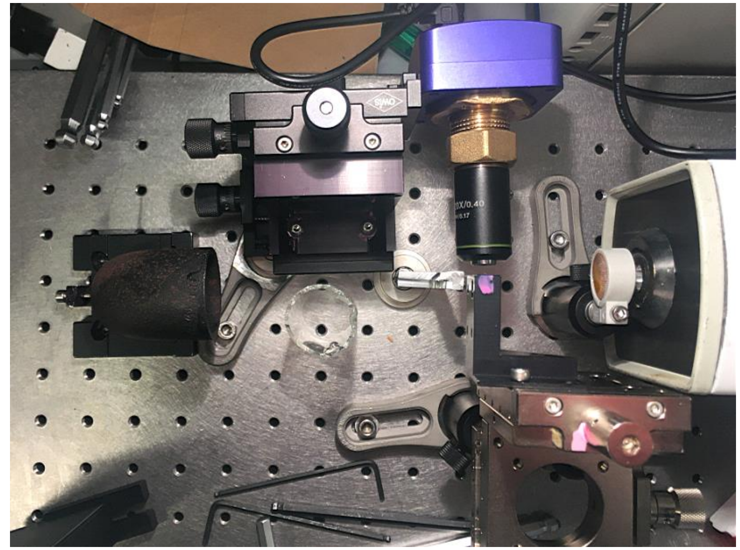


resonances →



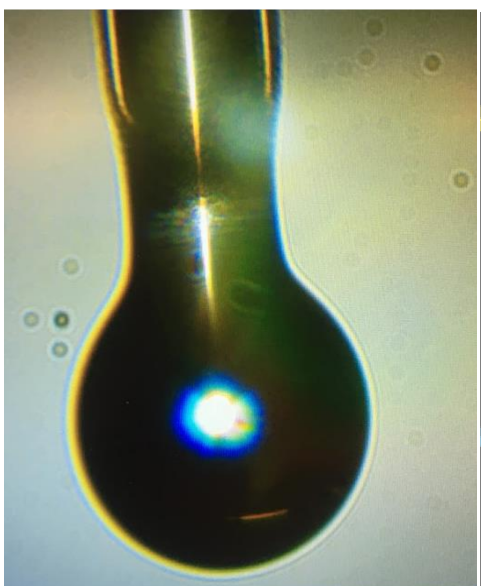
Microspheres and microrods fabricated with a 40W CO_2 laser lathe

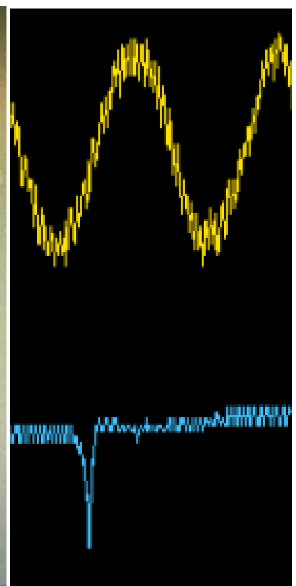




Home-made microscope: 20x objective from Ebay (60 EUR) and Astronomy webcam (150 EUR)

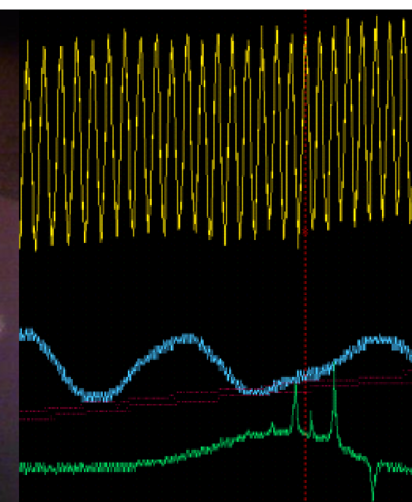
Sphere WGMR FWHM = 2 MHz **Q = 2E8 at 780 nm**





Yellow reference interference fringes from fiber etalon have 50 MHz period.

Microrod CO_2 lathe
first resonances Q ~ 10^6.
Evaporated silica dust is a problem



Microsphere resonator combs

For Kerr effect (modifying the index of refraction) intensities ~ 1 GW/cm^2 are necessary
Kerr effect has been usually observed with pulsed lasers
In microspheres it is possible with a CW laser

Peak intensity and circulating power calculations

power circulating $$P_{circ} = P_{in} Q \frac{\lambda}{\pi^2 n R} \frac{K}{(1+K)^2}$$

λ is the resonance wavelength, R is the device radius,
Q is the quality factor of the device,
n is the effective refractive index
K is the coupling coefficient

transmission : $$T = \frac{(1-K)^2}{(1+K)^2}$$

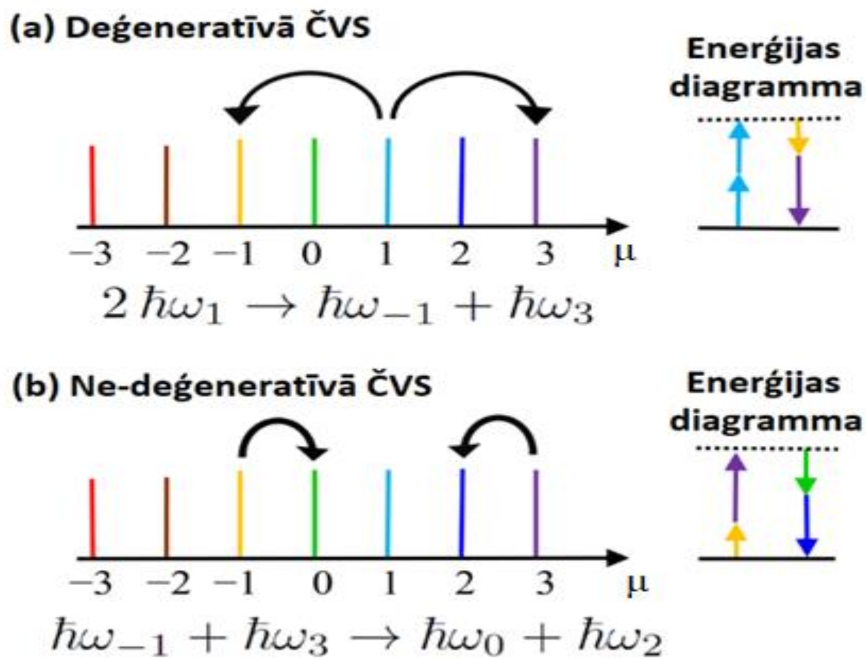
intensity circulating P_{circ}/A_m,

mode area $$A_m = \frac{\int \varepsilon(r)|E|^2 dA}{\max(\varepsilon(r)|E|^2)}$$

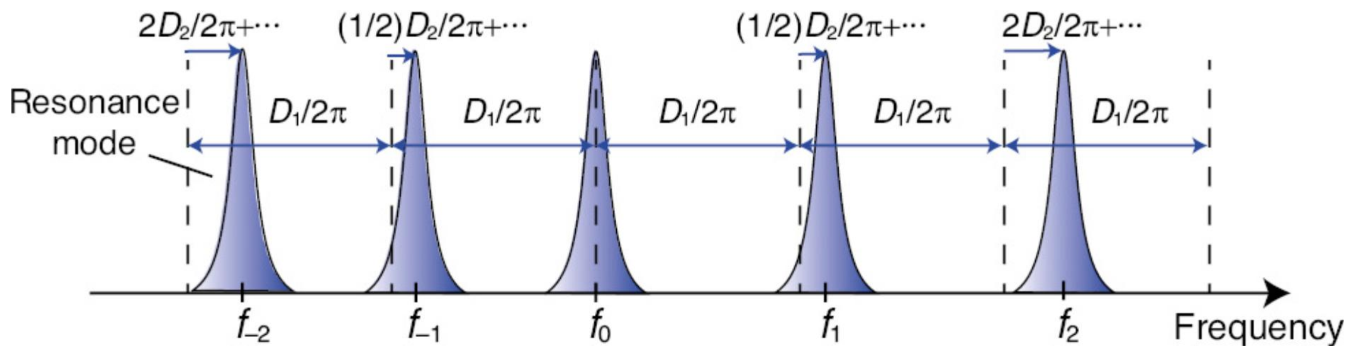
Power and optical intensity circling inside the WGMR from 0.1 W input laser power.

R, μm	Q ·10^7	T	K	Q_{intr} ·10^7	P_{circ} W	A_{eff}, μm^2	I_{circ}, GW/cm^2
135	2.0	0.17	1.69	5.4	1016	36.15	2.8
60	1.2	0.26	2.05	3.7	1468	18.45	8.0
85	4.6	0.54	3.89	22.0	4671	24.62	19.0
83	5.2	0.14	1.61	13.6	4217	24.14	17.5

Four Wave mixing (FWM) nonlinear process

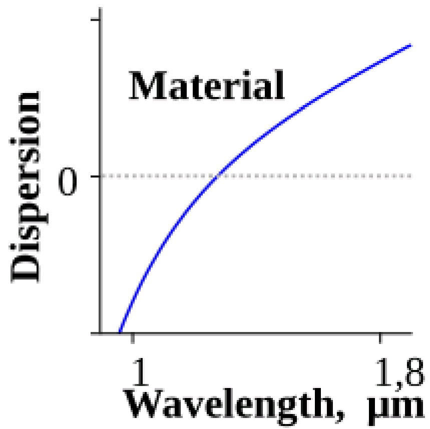


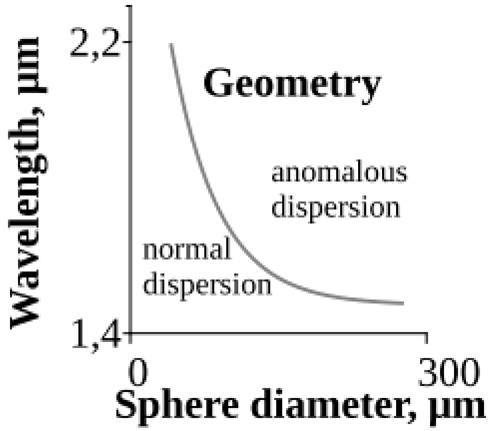
Dispersion caused detuning between comb and WGM lines

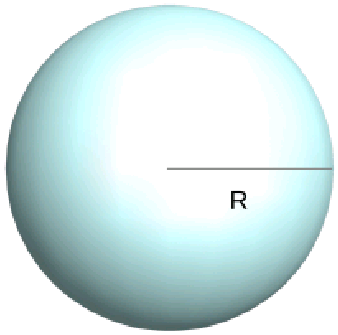


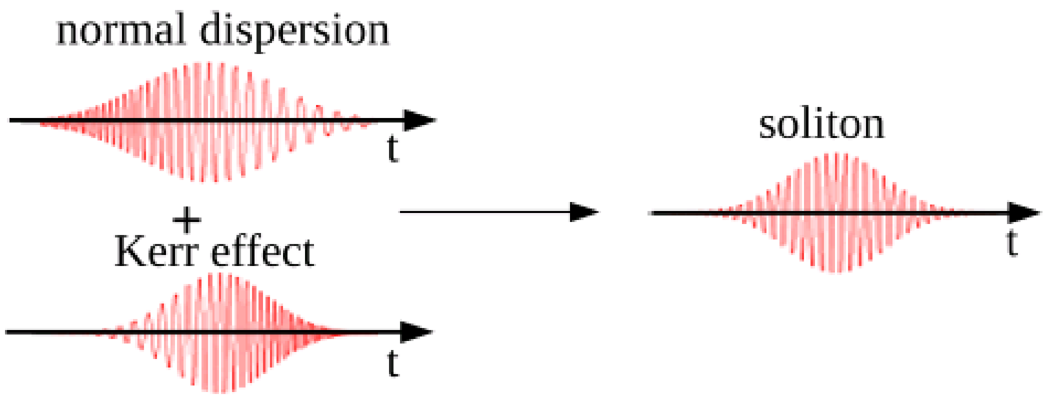
[S. Fujii, T. Tanabe, (2020) Dispersion engineering and measurement of whispering gallery mode microresonator for Kerr frequency comb generation, Nanophotonics 9, 1087–1104]

Material and geometrical dispersion depending on microsphere size







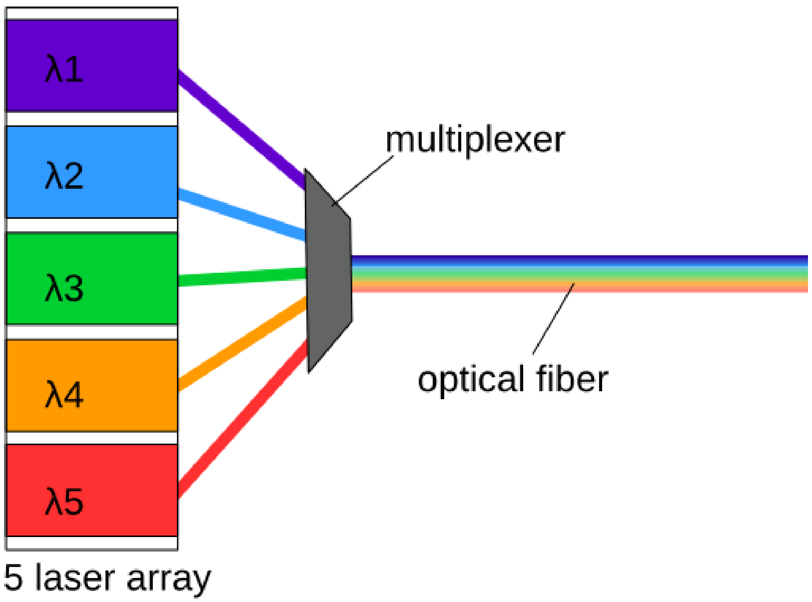


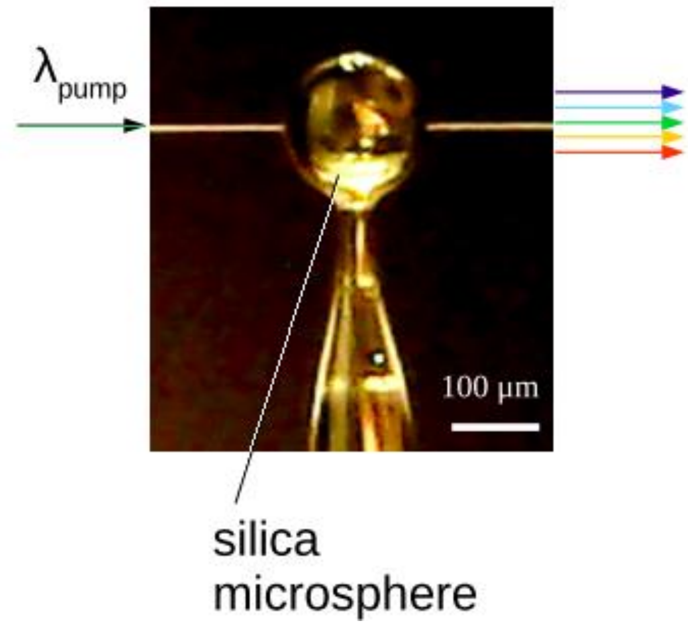
In soliton regime Kerr effect compensates dispersion.
In such case dispersion is 0 and pulse circulates without changing length.
Soliton regime is the mos stable regime, hard to get.

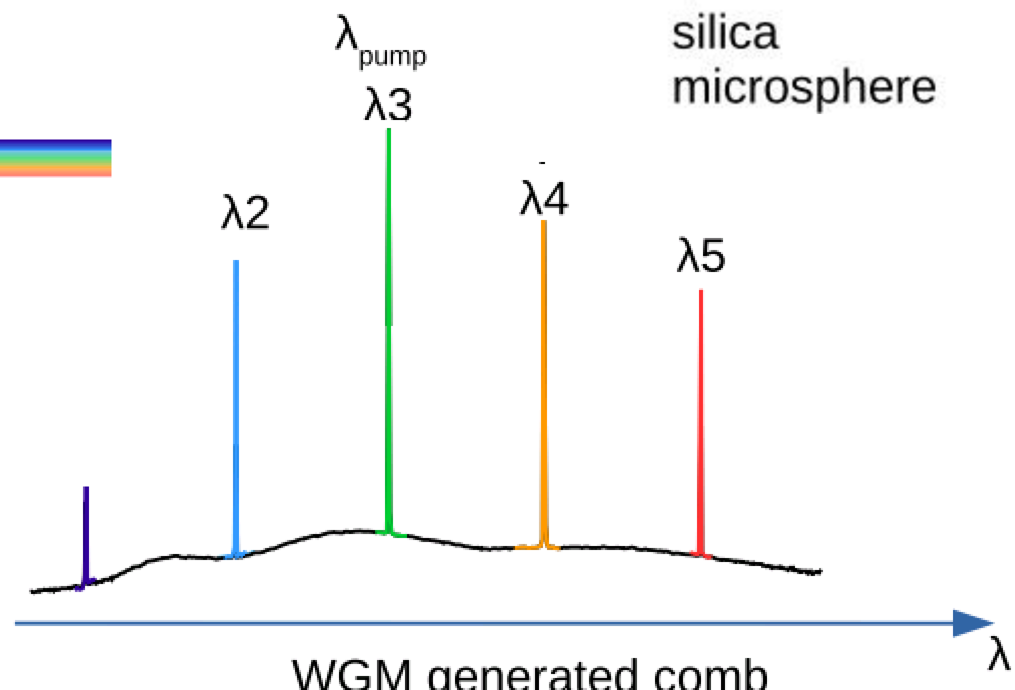
Future Vision

Wavelength Division Multiplexing

Replace laser array with frequency comb generated inside WGM resonator.

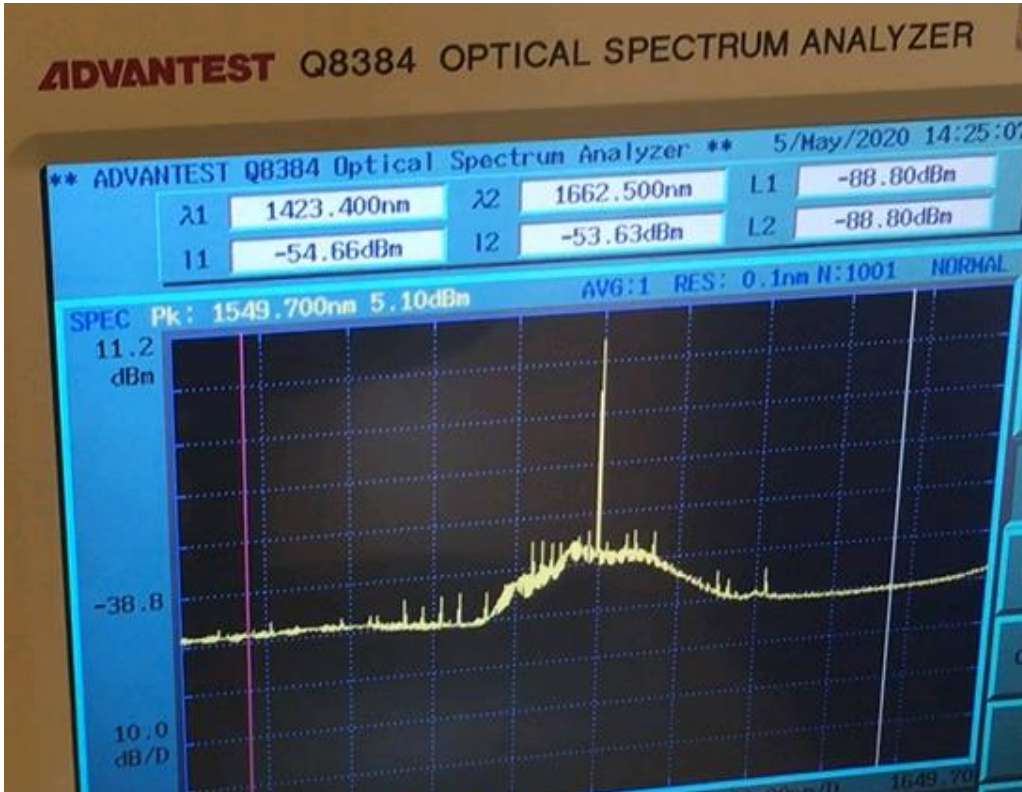


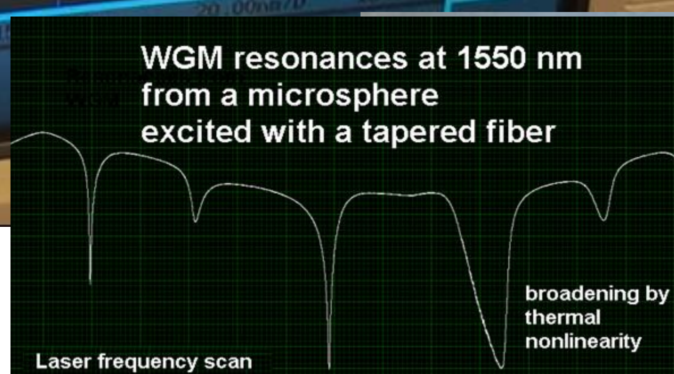




May 2020. Our first comb from SiO_2 microsphere.

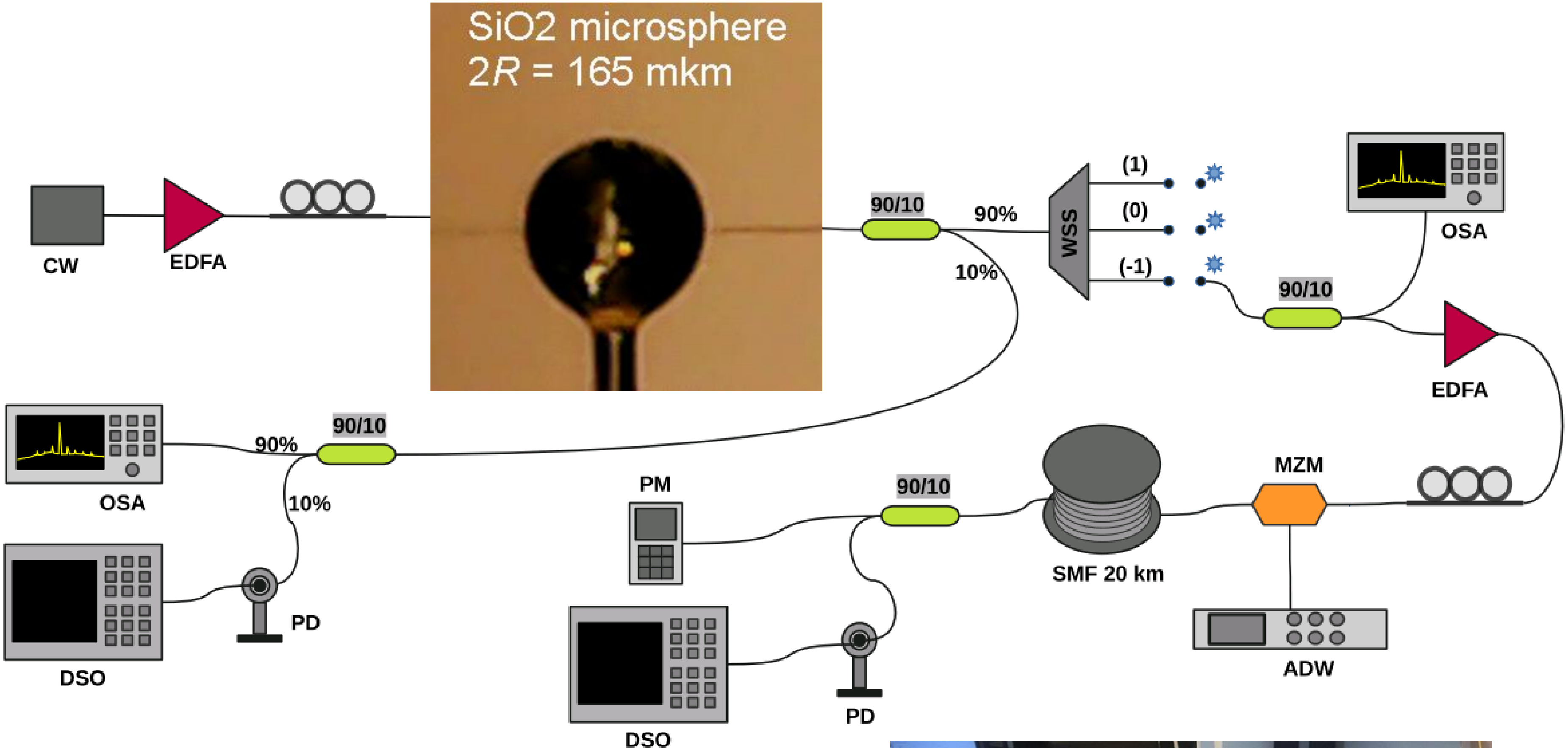
Weak and unstable in time. `

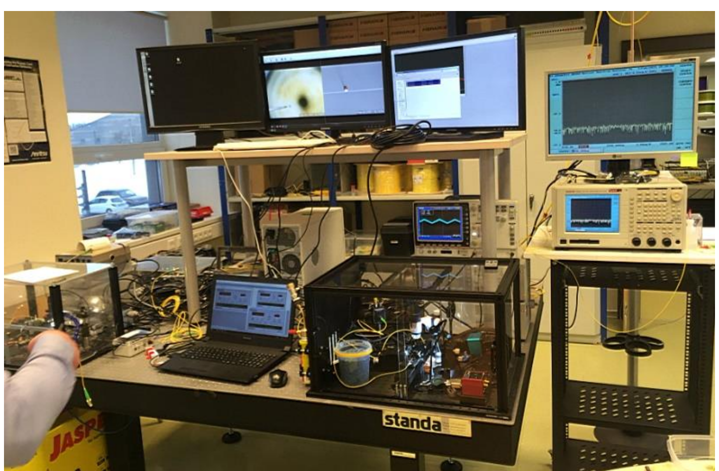


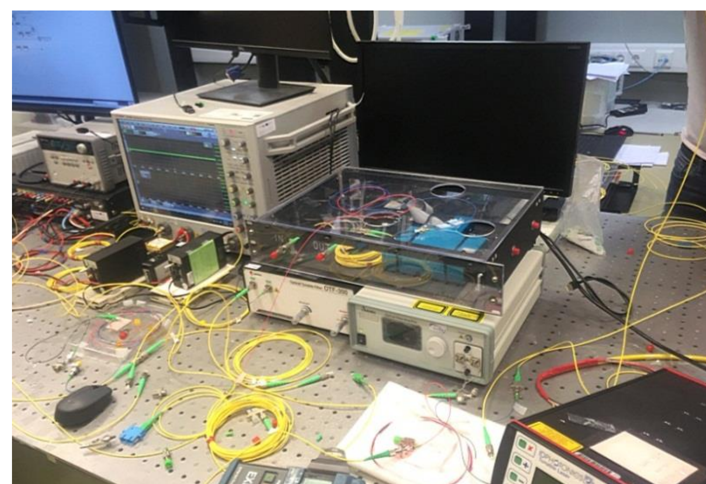


$Q \approx 3 \times 10^7$

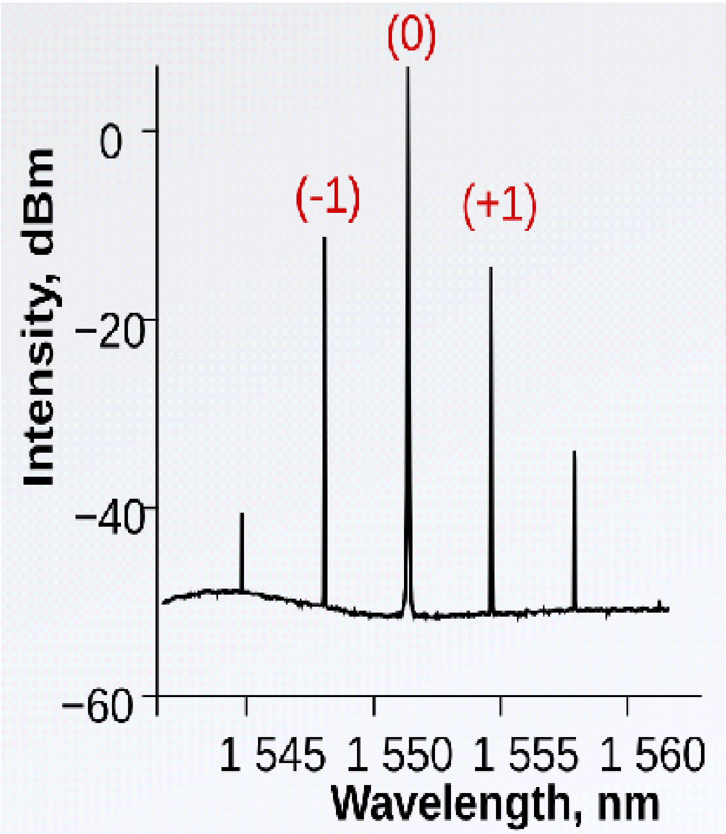
Microsphere comb experiment for telecom

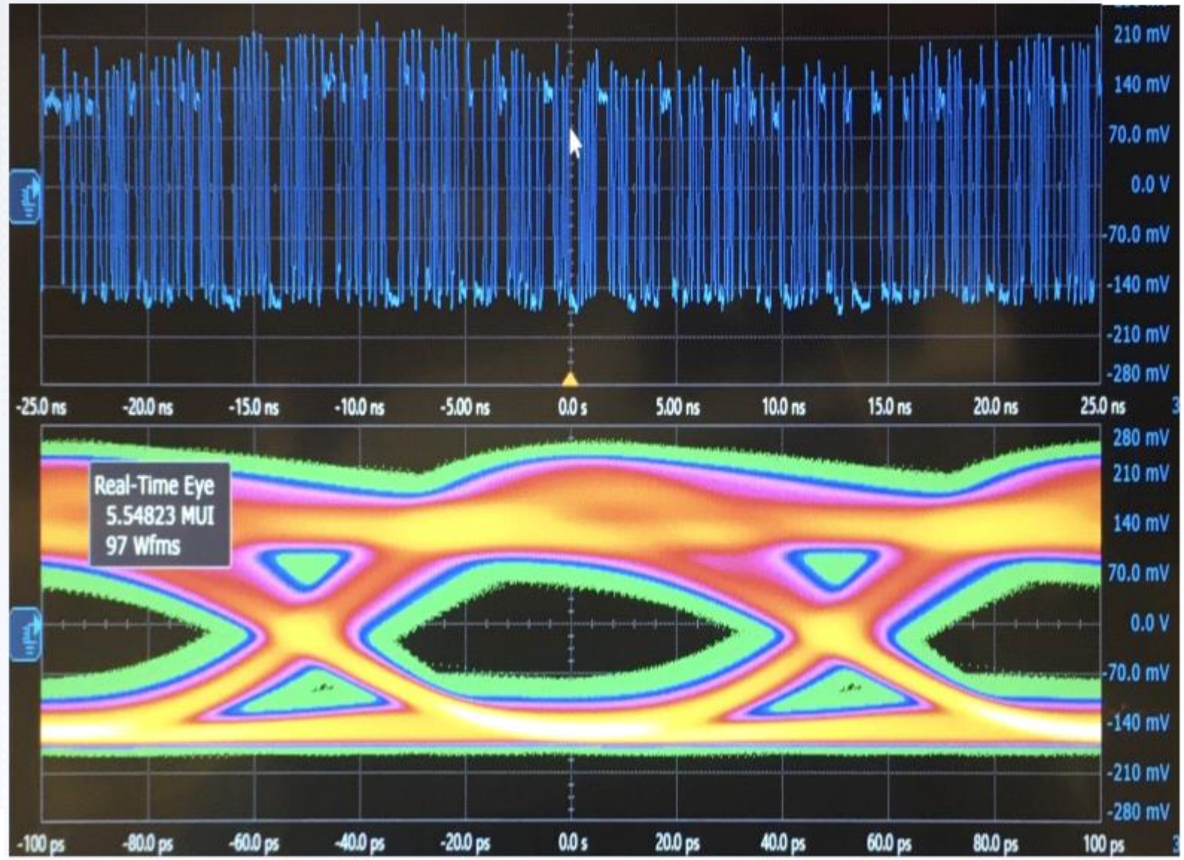






10 Gbit/s data and eye diagram on WDM selected OFC line (+1)





E.A. Anashkina, V. Bobrovs, T. Salgals, I. Brice, J. Alnis, A.V. Andrianov,
Kerr optical frequency combs with multi-FSR mode spacing in silica microspheres
IEEE Photonics Technology Letters 33, 453-456 (2021).

T. Salgals, J. Alnis, R. Murnieks, I. Brice, J. Porins, A. V. Andrianov, E. A. Anashkina, S. Spolitis, V. Bobrovs,
Demonstration of a fiber optical communication system employing a silica microsphere-based OFC source,Optics Express 29, 10903-10913 (2021).