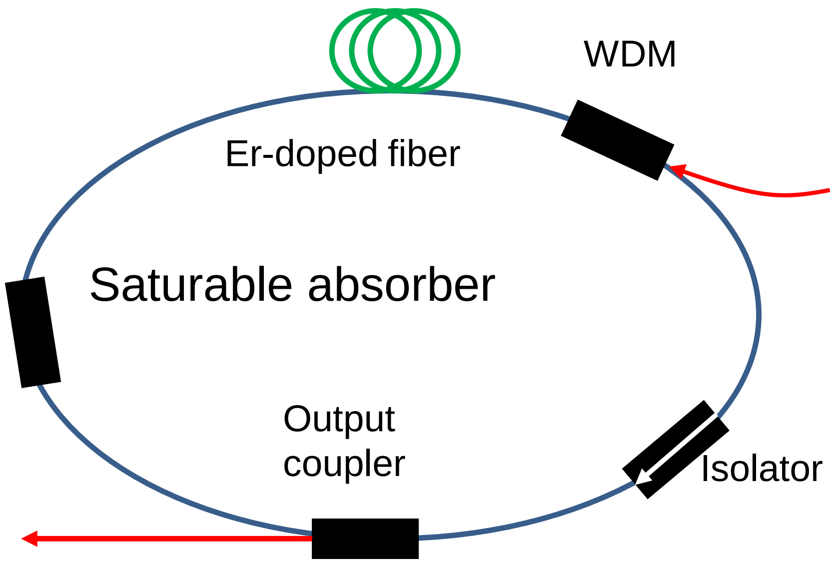
Mode-locked fiber lasers

by: Khanh Kieu

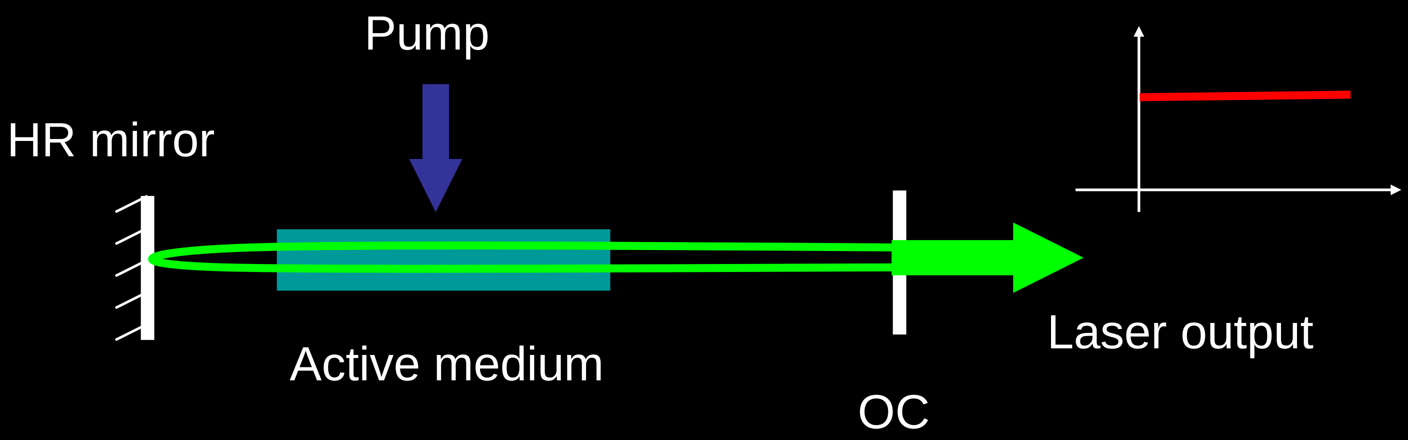
Project #8: Mode-locked fiber laser

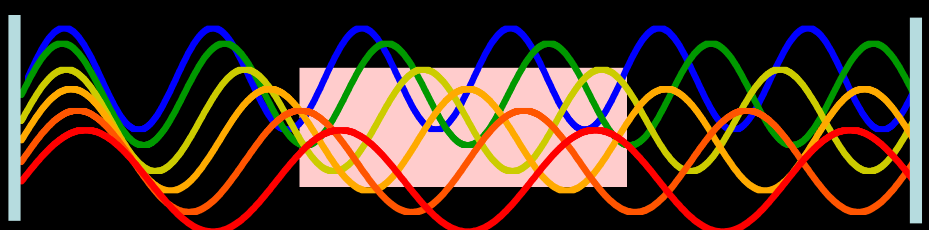
- Measure laser pulse train
- Measure output spectrum
- Measure laser pulse duration
- Observe phase-locked of laser modes



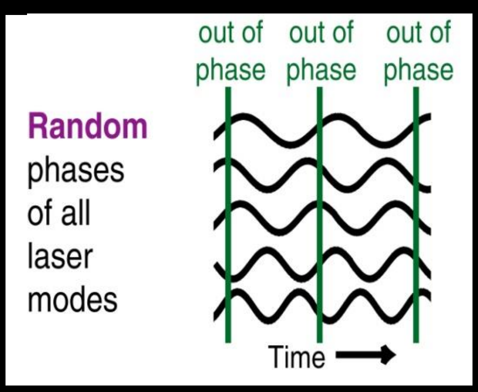
Mode-locked ring fiber laser

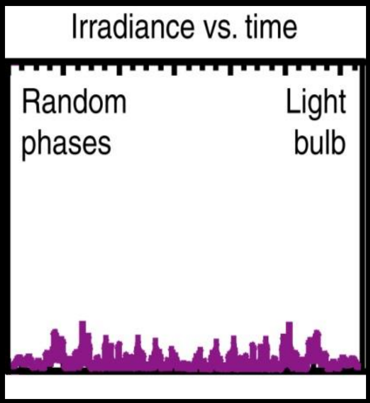
How does the laser work?



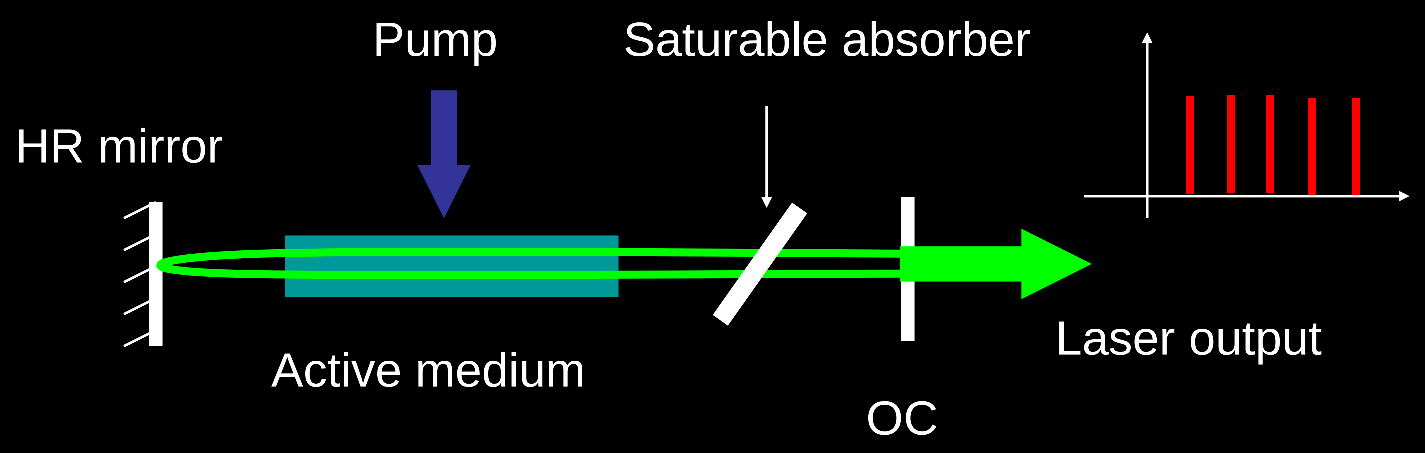


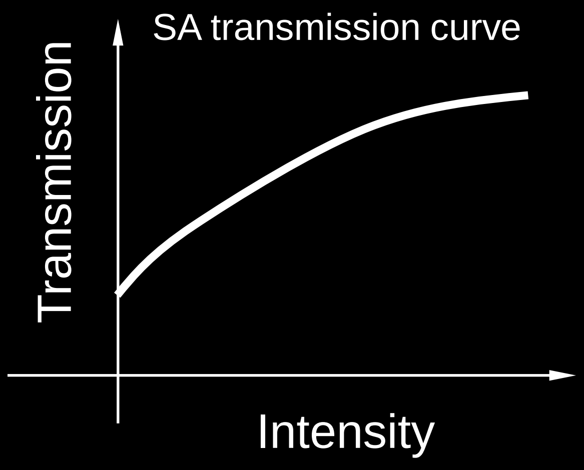
$L = q*\lambda/2$

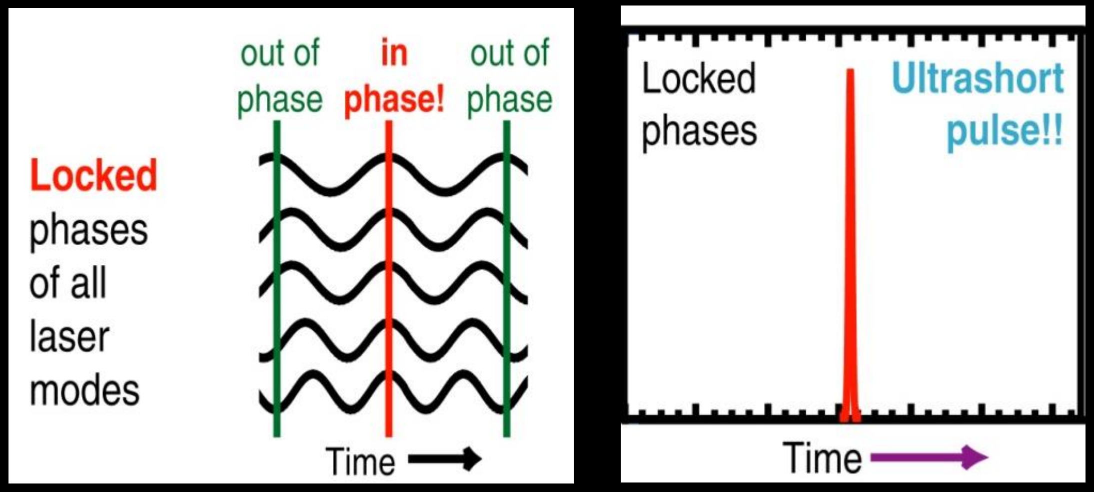




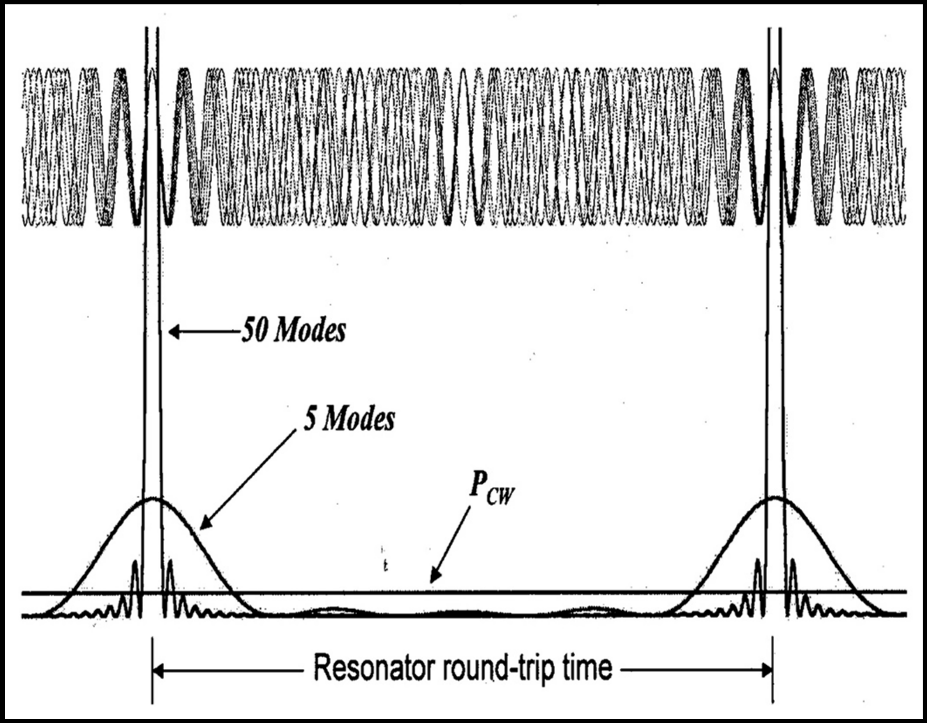
Mode-locking

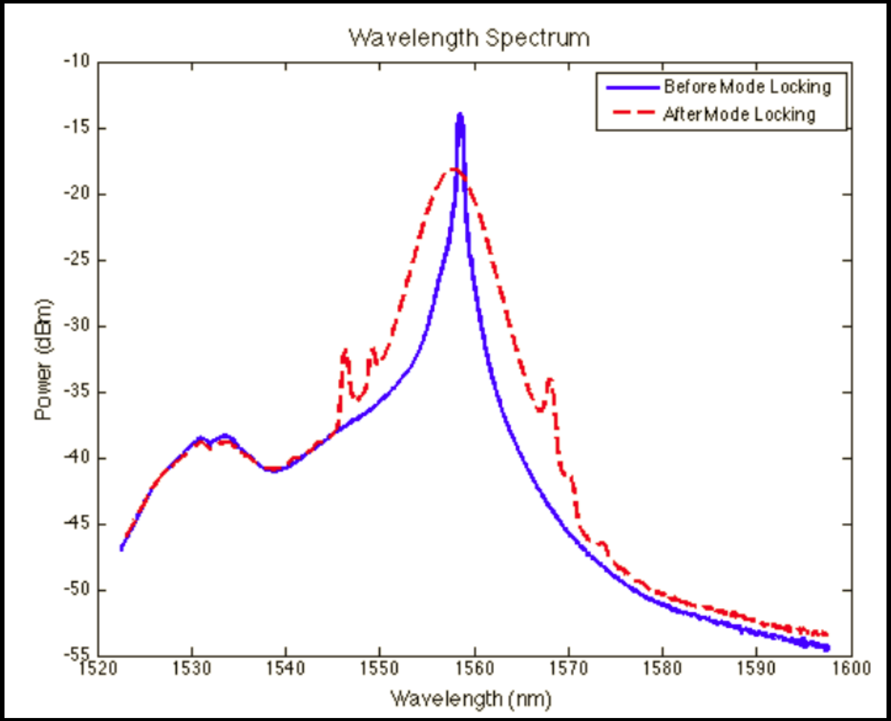






Mode-locking

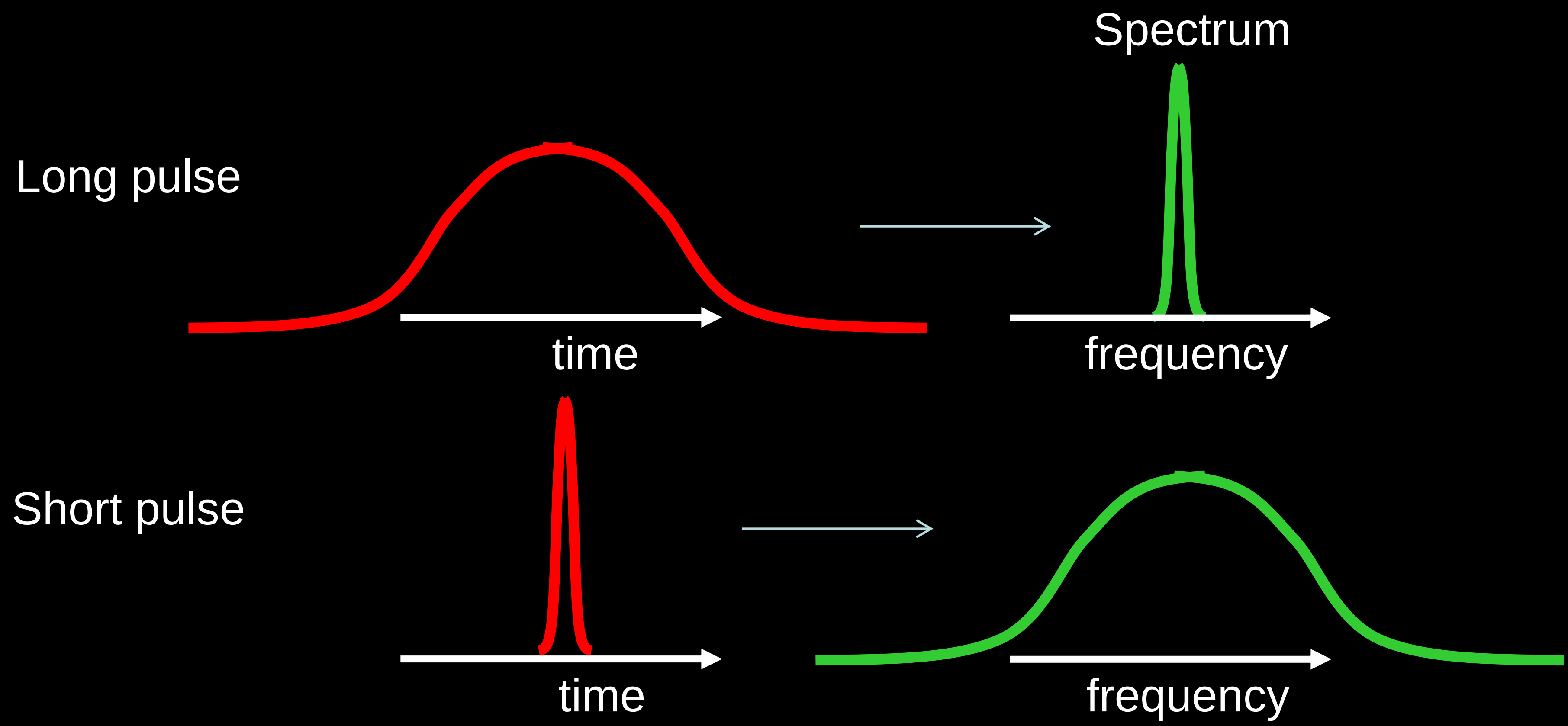




Credit: Oscar Herrera

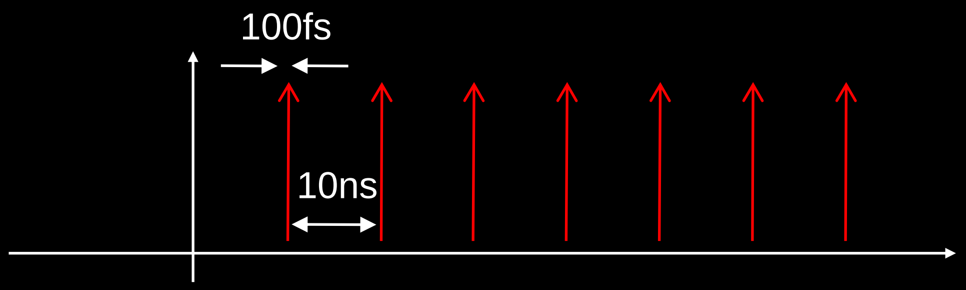
Time domain vs. frequency domain

Connected by the Fourier transform



Interesting facts about mode-locked lasers

Mode-locked lasers do not “work” 99.9999% of the time!



Mode-locked lasers generate the highest peak power among lasers

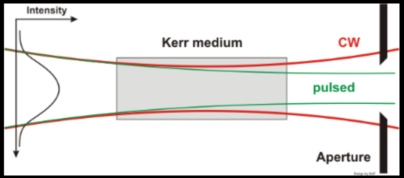
Mode-locked lasers provide one of the shortest events in nature

Mode-locked lasers are one of the best frequency rulers

Mode-locked lasers have the lowest timing jitter compared with most elec. devices

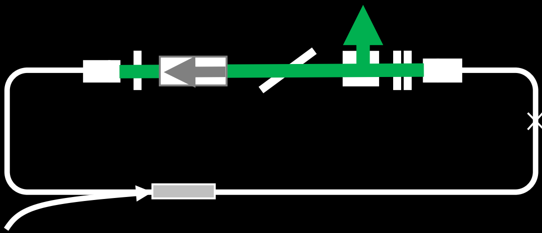
What is the best approach for mode-locking?

- Kerr lens (does not work for fiber, yet)

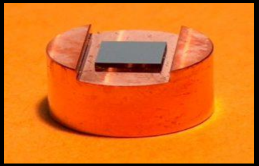


(Wikipedia)

- Nonlinear Polarization Evolution (NPE)

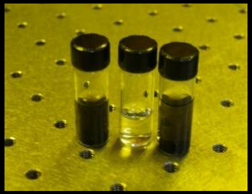


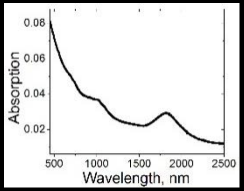
- SESAM



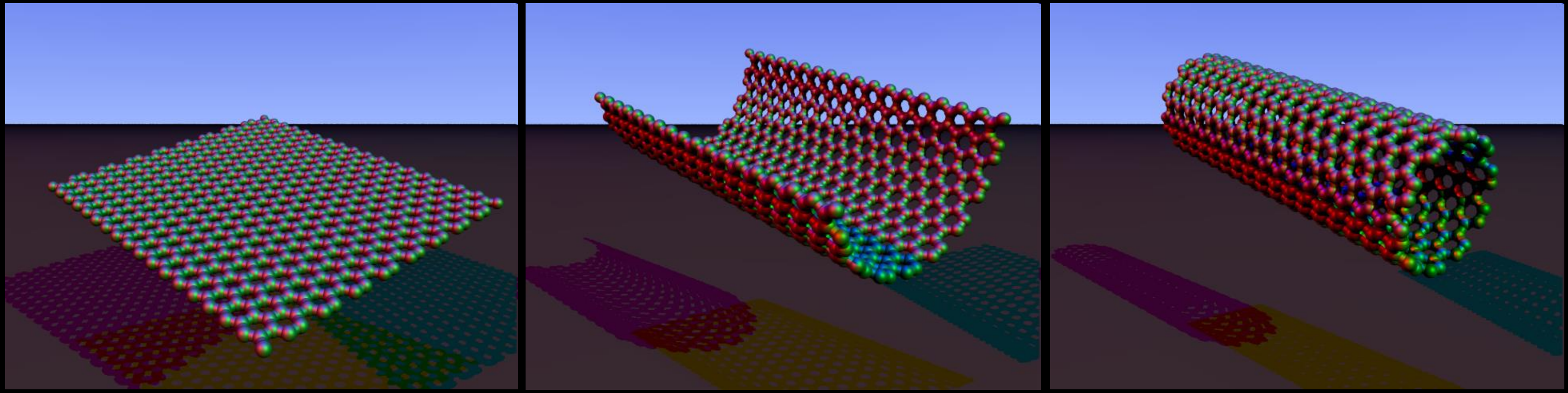
(Batop)

- Carbon nanotubes (CNT) and graphene





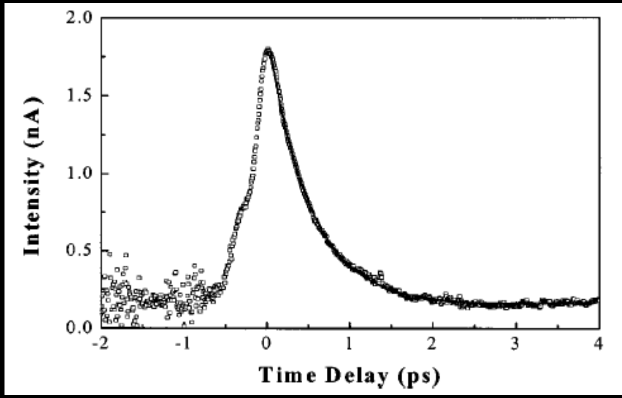
Carbon nanotube saturable absorber



(source: http://en.wikipedia.org/wiki/Carbon_nanotube)

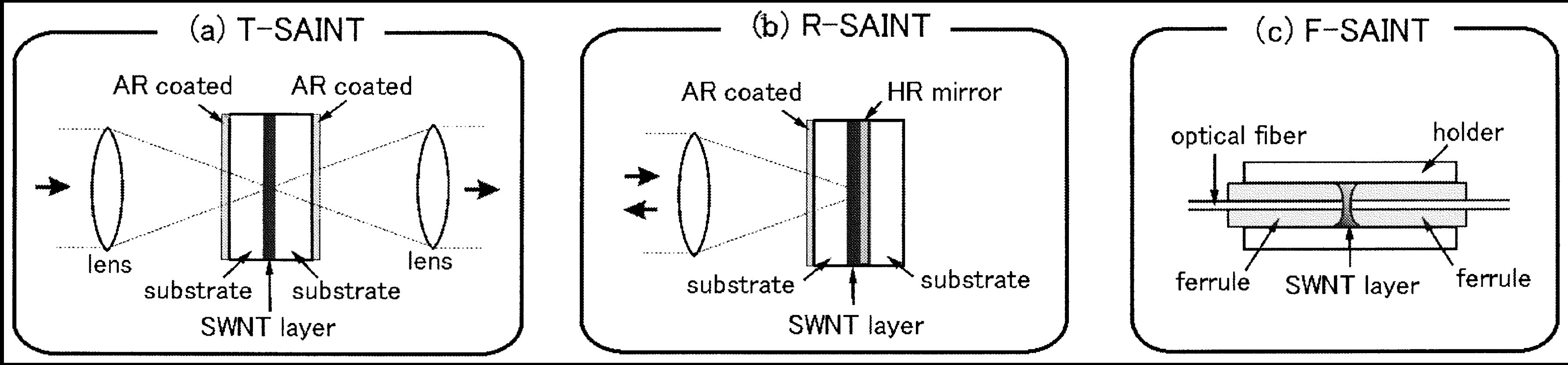
- ~1nm diameter
- Possess ultrafast carrier recovery time (<1ps)
- Robust
- Low cost

Great material for making saturable absorber!



(Y. C. Chen et al., Appl. Phys. Lett., Vol. 81, No. 6, 5 August 2002)

Early implementations



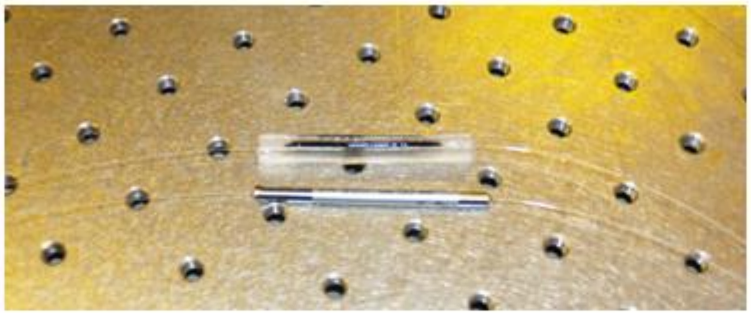
(source: Set *et al*., Quant. Elect., 2004)

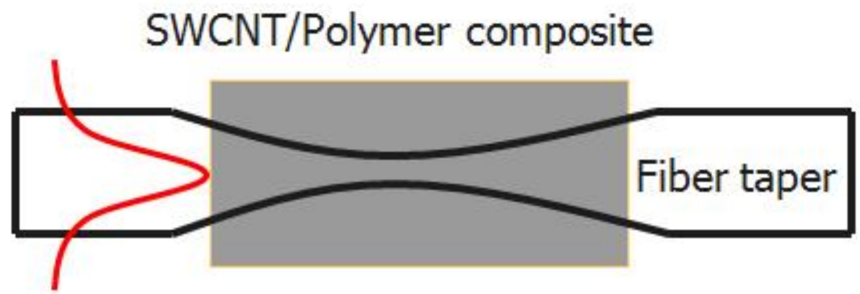
Drawbacks:

- Not fiber compatible
- Thin film geometry: very low damage threshold

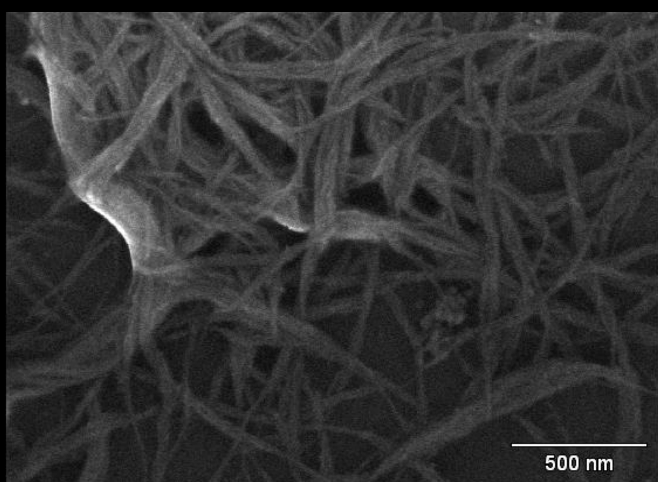
Fiber taper based CNT SA

Fiber taper-based CNT SA

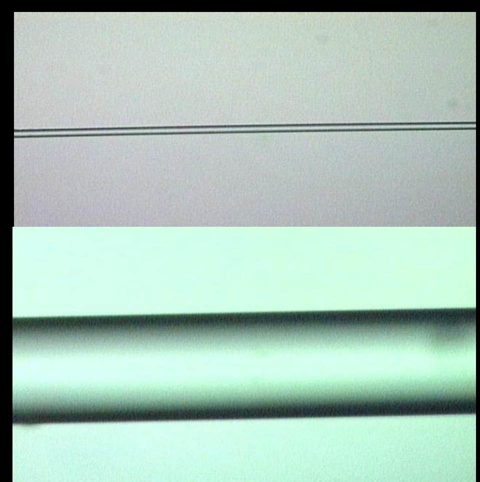




(K. Kieu and M. Mansuripur, Opt. Lett, 2007)



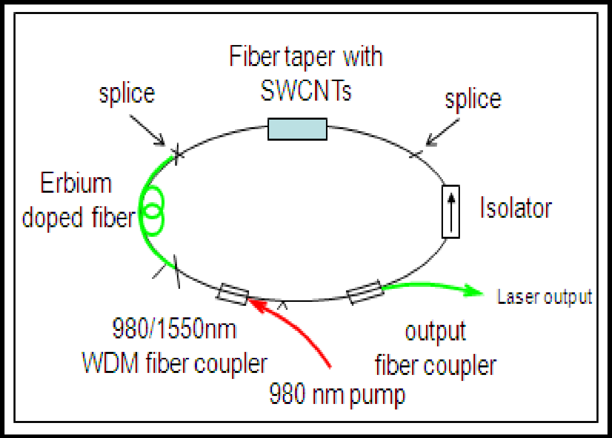
Carbon nanotube bundles

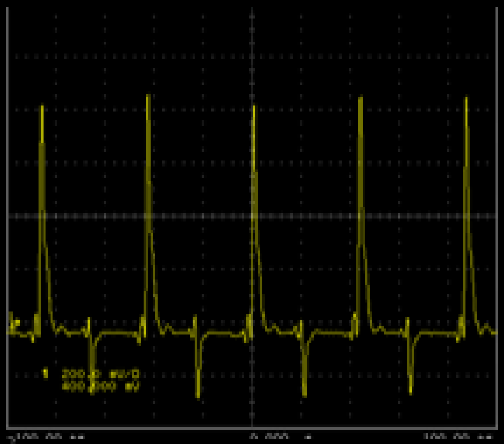


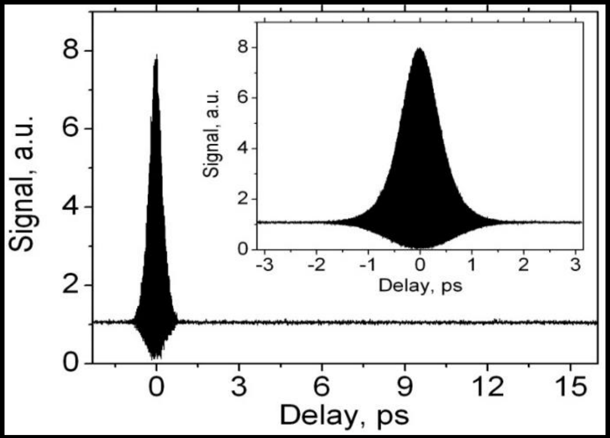
Fiber taper (top) and standard fiber (bottom)

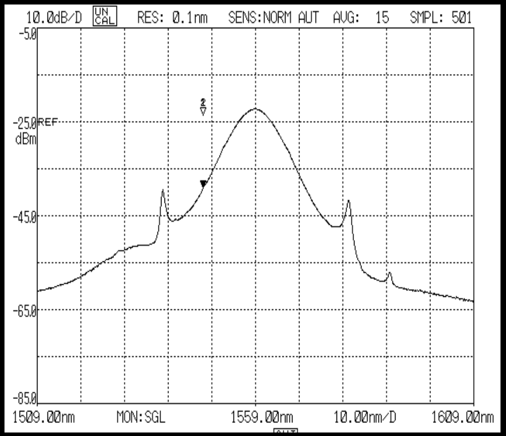
First battery operated femtosecond fiber laser in the market

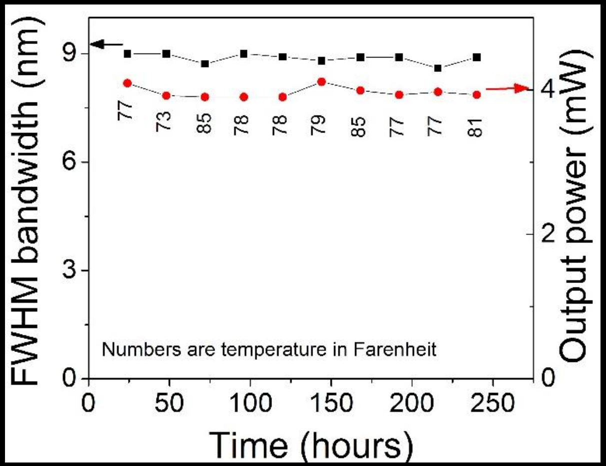
Compact ML fiber laser



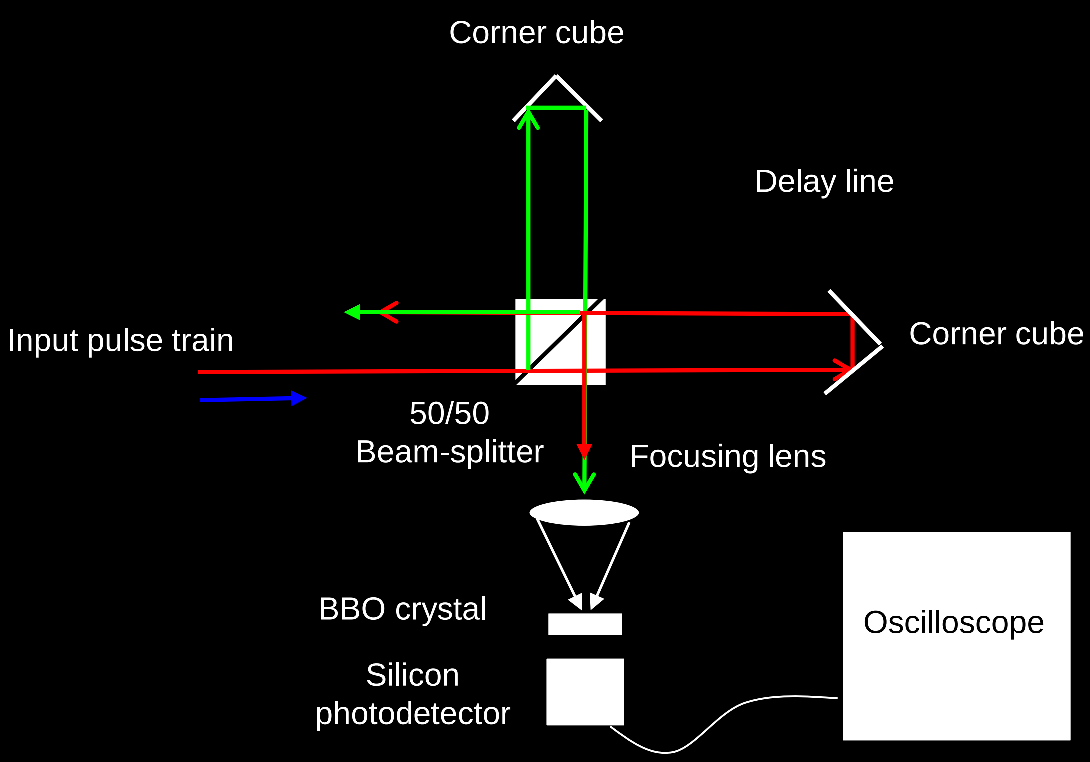


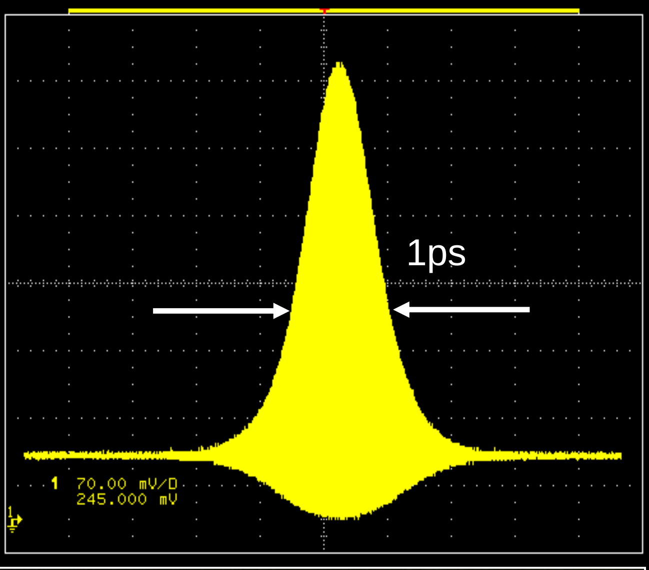






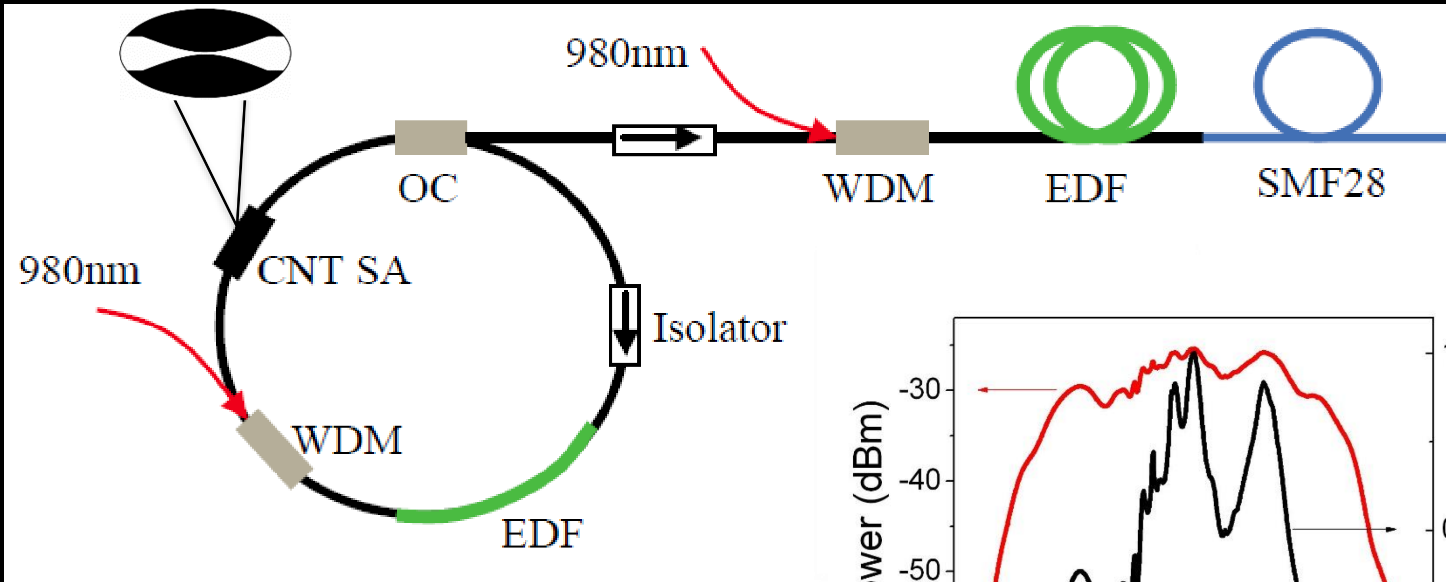
Autocorrelation measurement

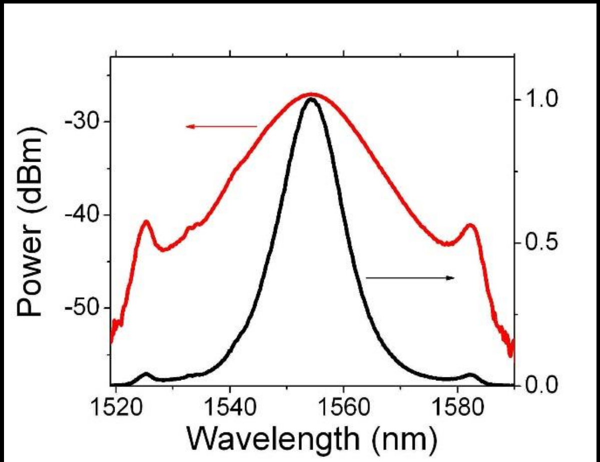




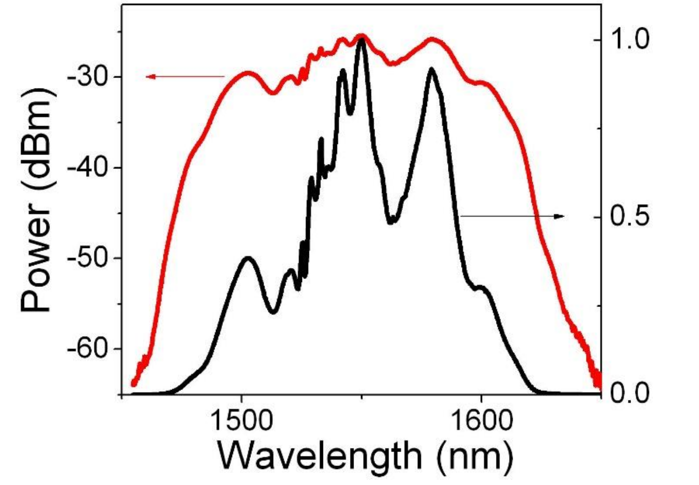
Amplified pulses at ~ 1550nm

Fiber taper embedded in CNT/polymer composite





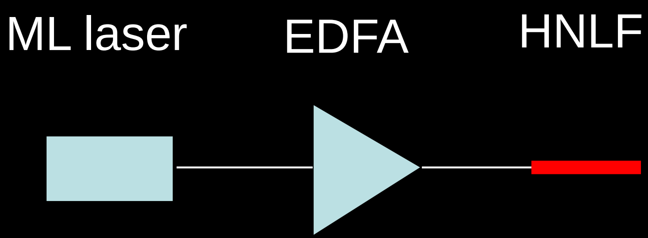
Laser oscillator spectrum



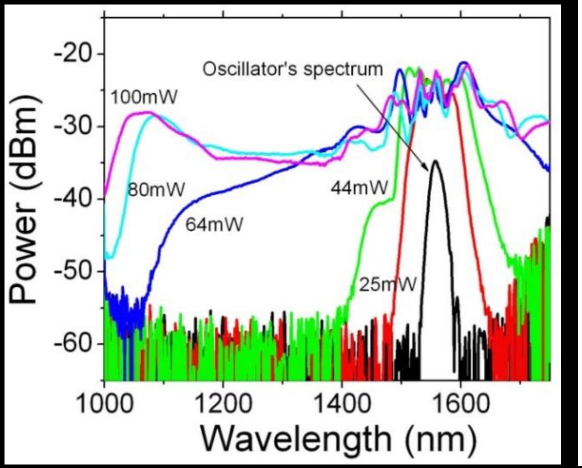
Laser spectrum after amplifier

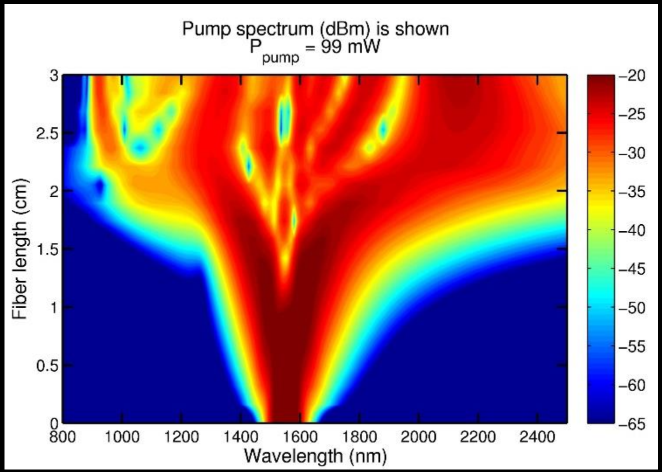
100 mW average output
100 MHz repetition rate
compressed to ~ 65 fs with SMF28
Peak power > 10kW

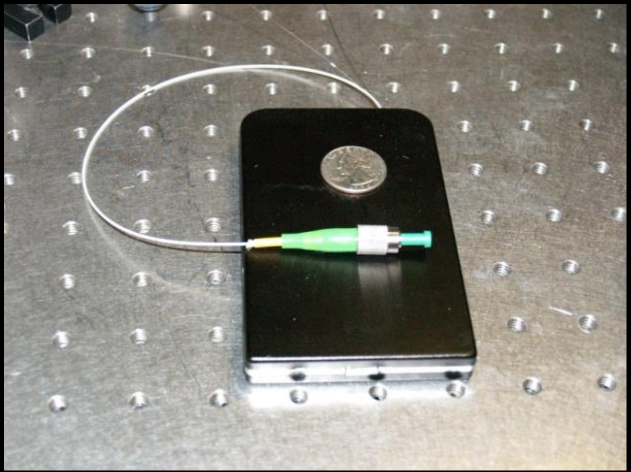
Supercontinuum generation



Octave spanning SC in 3 cm of HNLF!

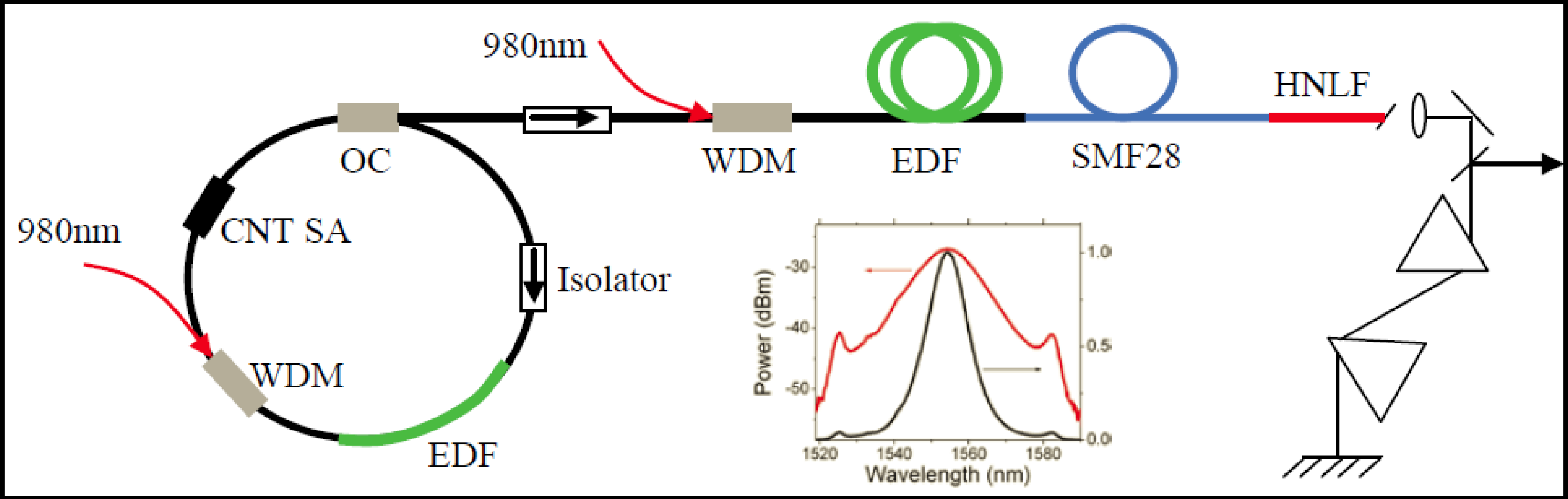


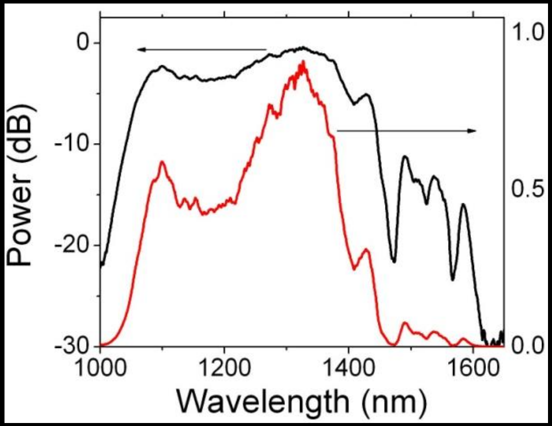


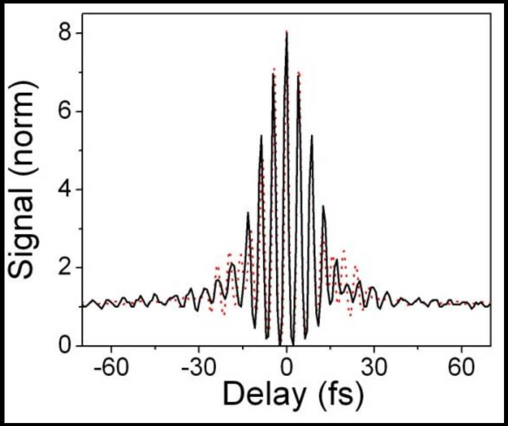


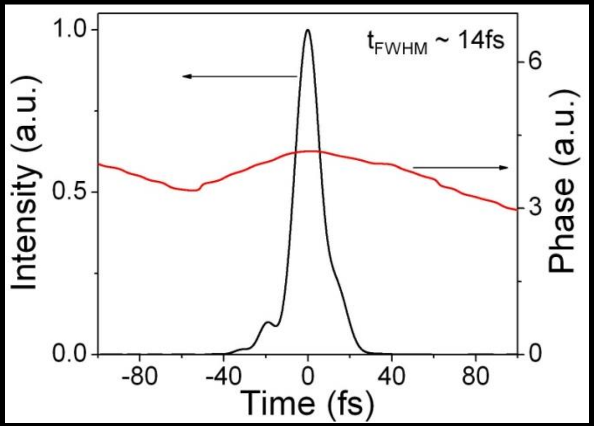
K. Kieu *et al.*, PTL. 2010

Few cycle pulse generation





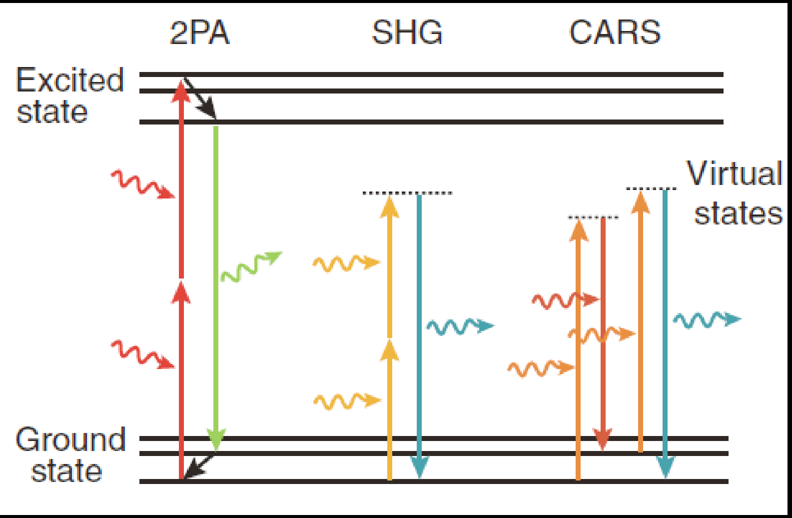


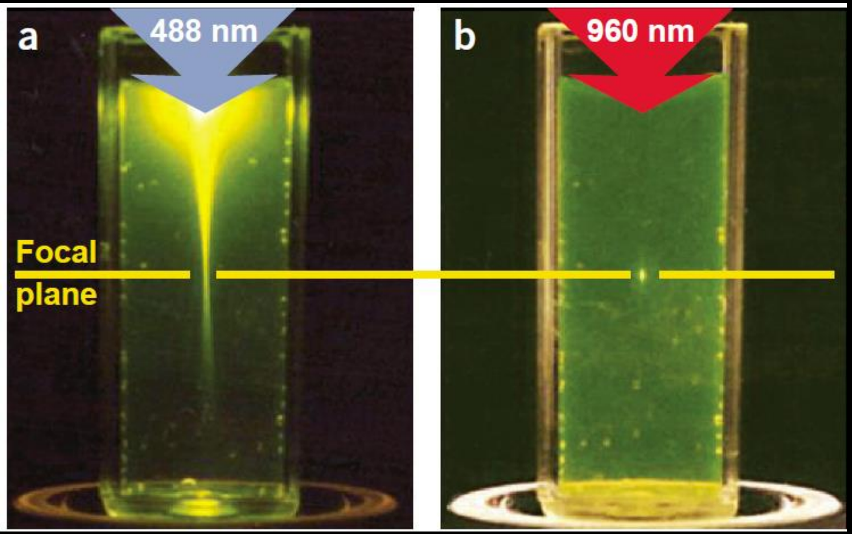


K. Kieu *et al.*, PTL. 2010

Multiphoton imaging

- 3D sectioning
- Non-invasive
- High resolution
- Chemical sensitivity (CARS)

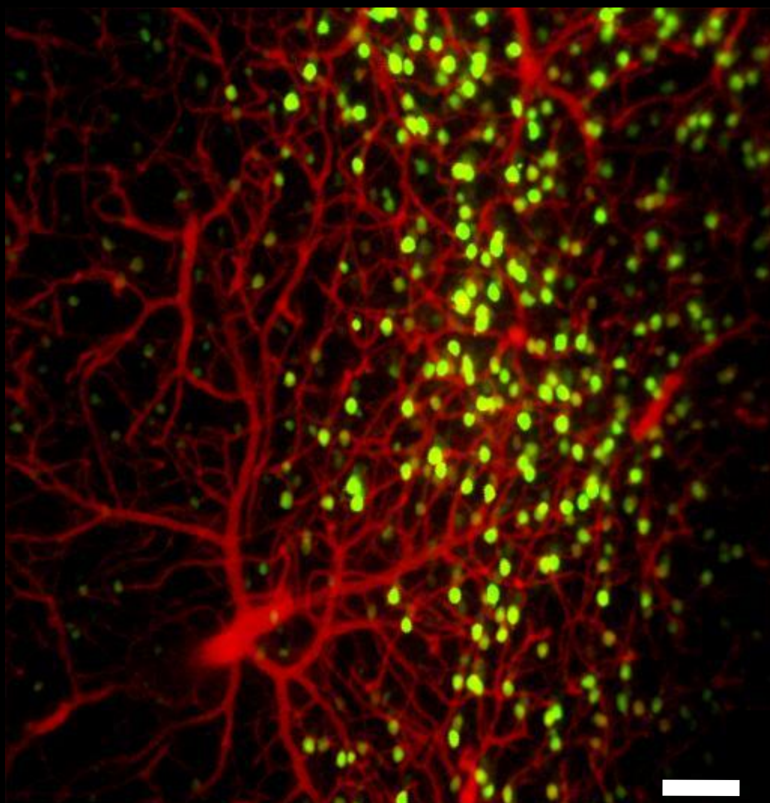


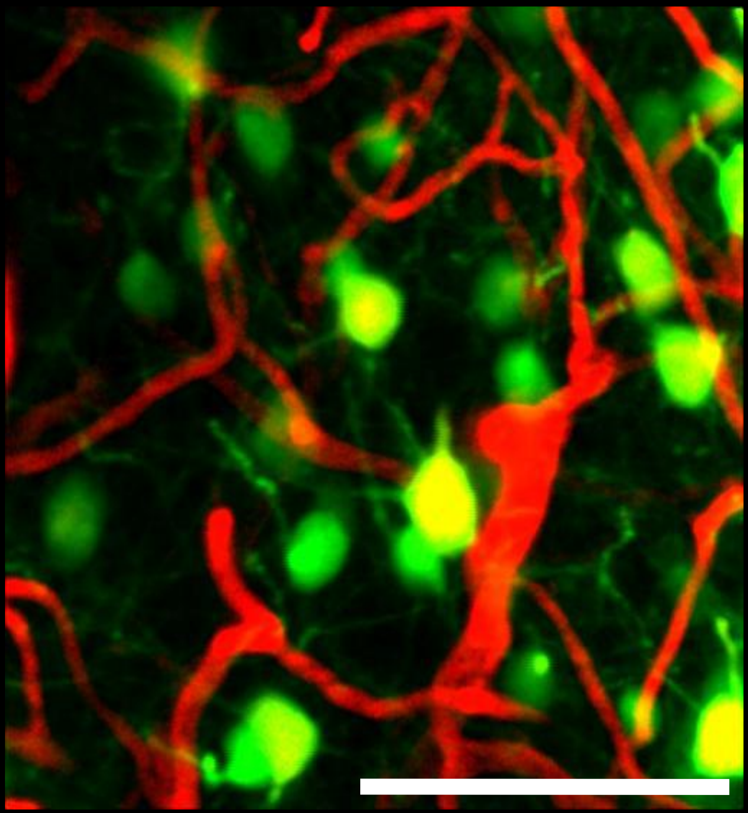


W. Zipfel *et al.*, nature 2003

Ultrafast fiber laser for brain imaging

(in collaboration with Prof. Wise and Prof. Schaffer at Cornell)



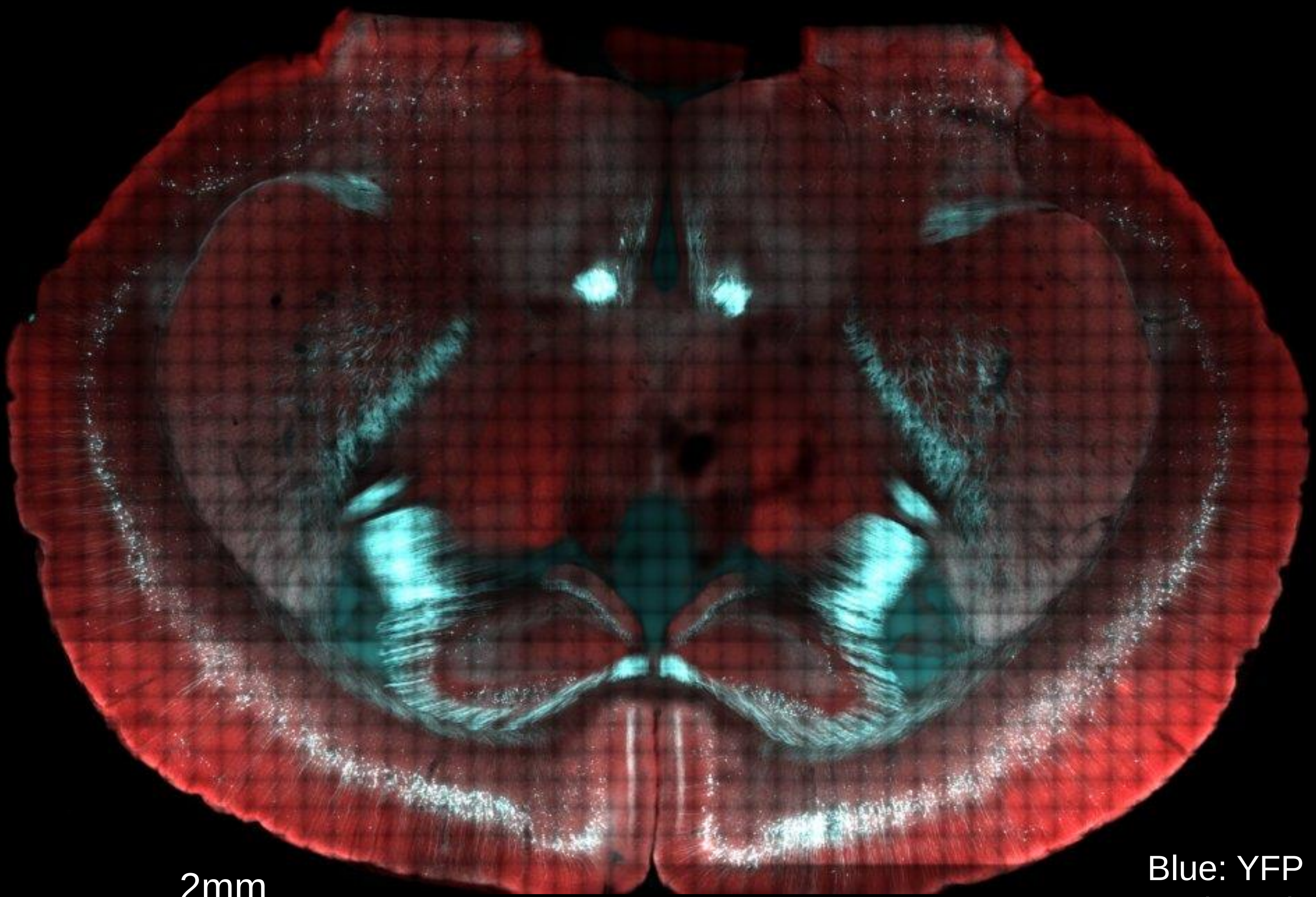


500 μm into mouse cortex, where the soma of layer 5 pyramidal neurons
are clearly visible surrounded by capillary beds
(scale bars are 75 μm)

K. Kieu, et al., OL 2009

Brain Imaging

(Collaboration with C. Barns, S. Cohen, A. Koshy, L. Madhavan)



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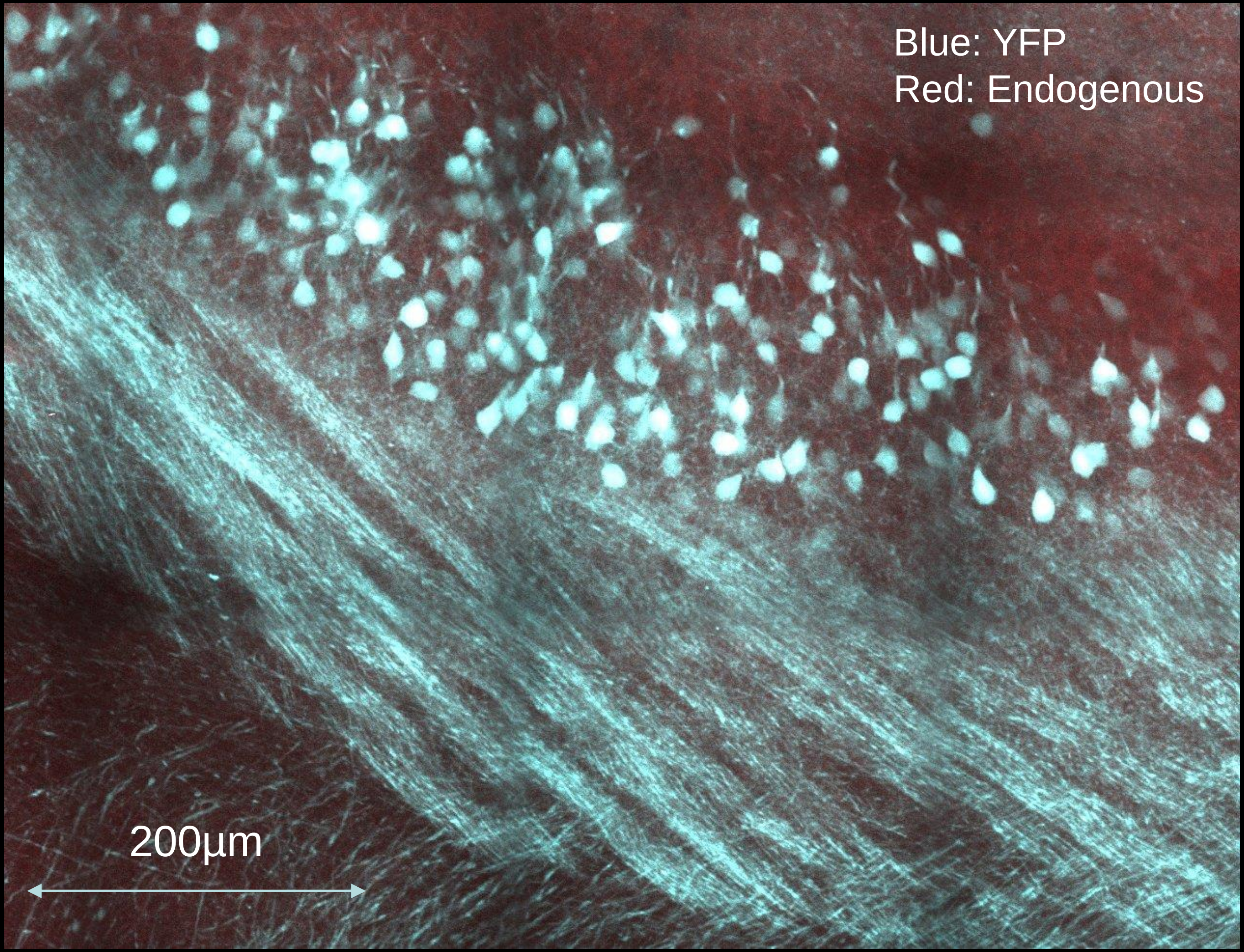
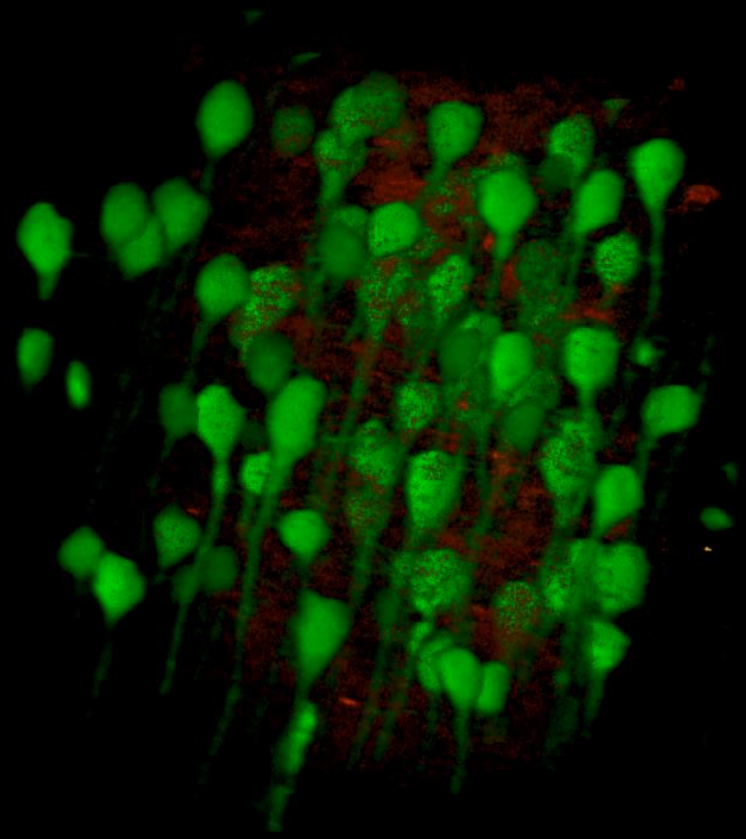
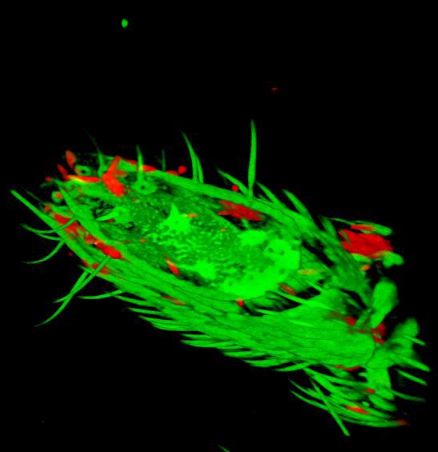
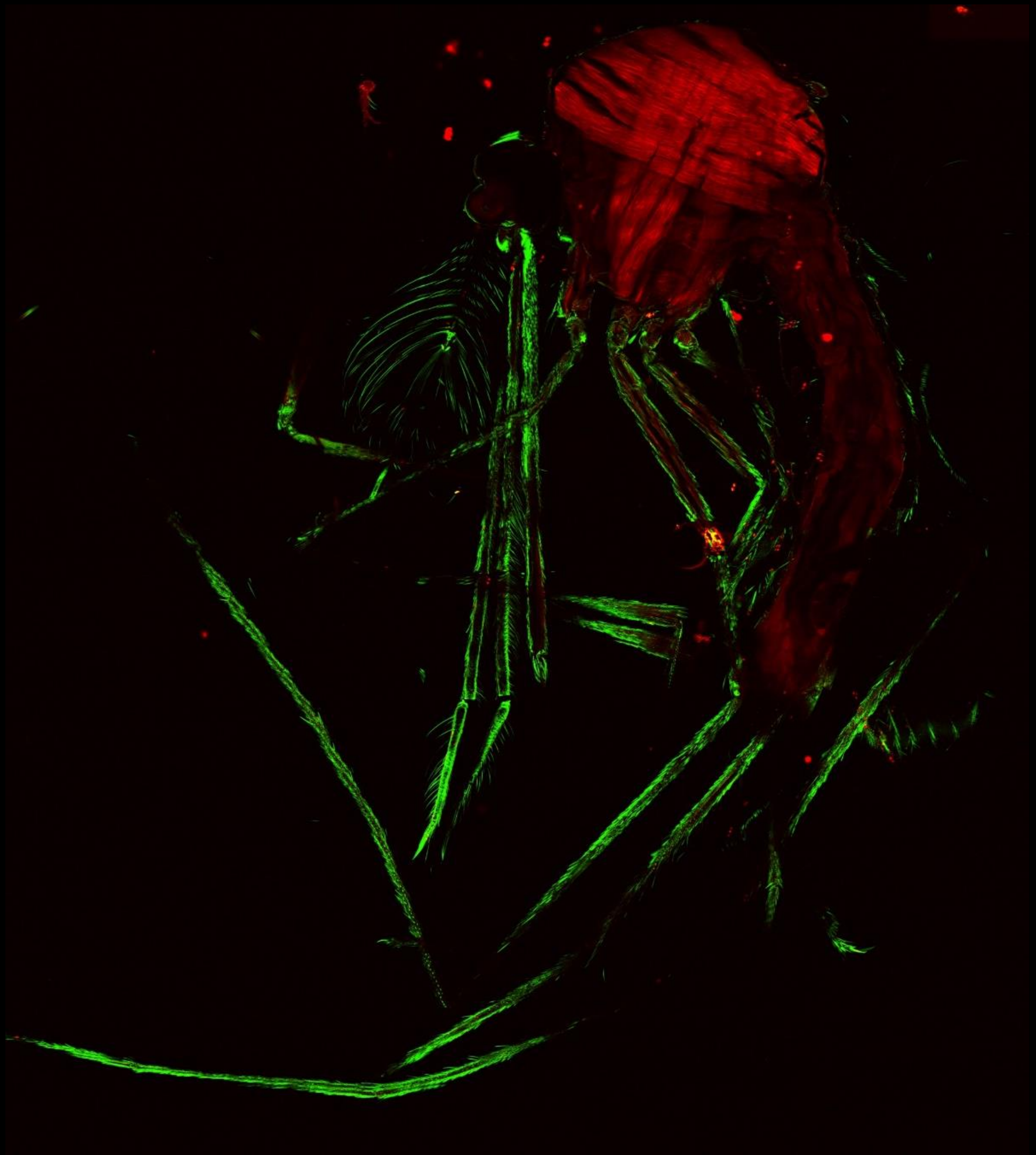


Brain Imaging



Whole body 3D imaging of small insects





Questions for thoughts

- Can fiber lasers be used for all applications?

  (Think of a application that current fiber lasers can not be used)

- What is the power limit of fiber lasers?
- Is that important to know exactly who invented the laser?
- How many more years are we going to do research on laser?
- Can we use lasers to predict earthquakes?