Early Developments in Laser Science and Nonlinear Optics

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Introduction

Birth of Laser: On May 16, 1960, first laser action was achieved by Theodore H. Maiman (Ruby Laser)

Birth of Nonlinear Optics: **June 28** 1961 Peter Franken et. al. PRL paper on second harmonic generation

Spotty review of some initial achievements with a few anedocts and curiosities

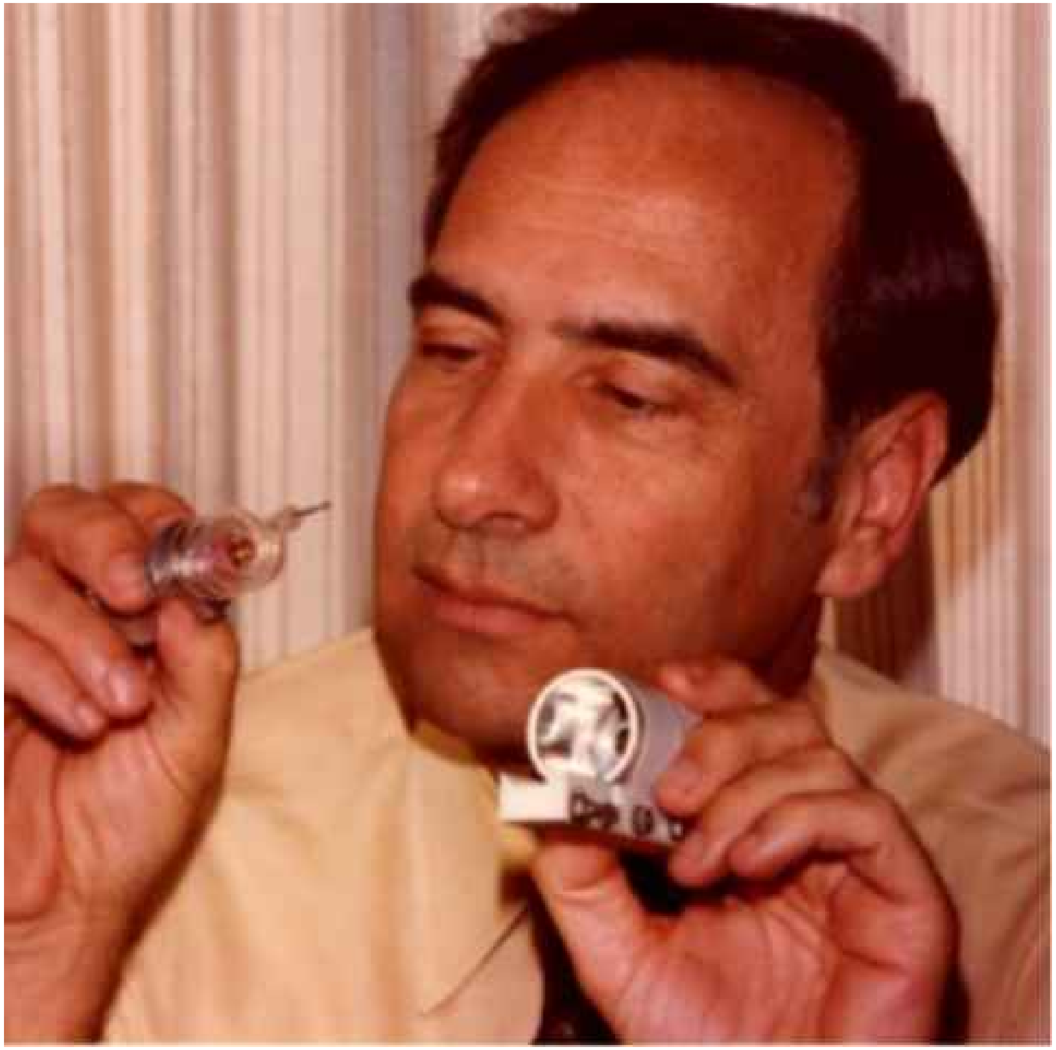
The first Laser

May 16, 1960

The ruby laser by Theodore H. Maiman

The scientific community was astounded: (a) The simplicity of the components used. (b) The characteristics of the energy levels of the laser transition. (c) The type of laser excitation (pulsed by a flashlamp)

Th.H. Maiman Holding the first Laser



The Fate of Maiman's Publications

- Physical Review Letters rejected his first account (Optical Maser Action in Ruby)
- A somewhat shorter account published by Nature (6 Aug. issue)
- During press release organized by Hughes in N.Y., more extensive paper, already accepted by JAP, stolen and published on a somewhat unknown British Journal

T.H. Maiman, *Stimulated Optical Radiation in Ruby Masers*, Nature, **187**, 493 (1960)

T.H. Maiman, *Optical Maser Action in Ruby*, Brit. Comm. and Electr. 674 (1960)

The Press Release

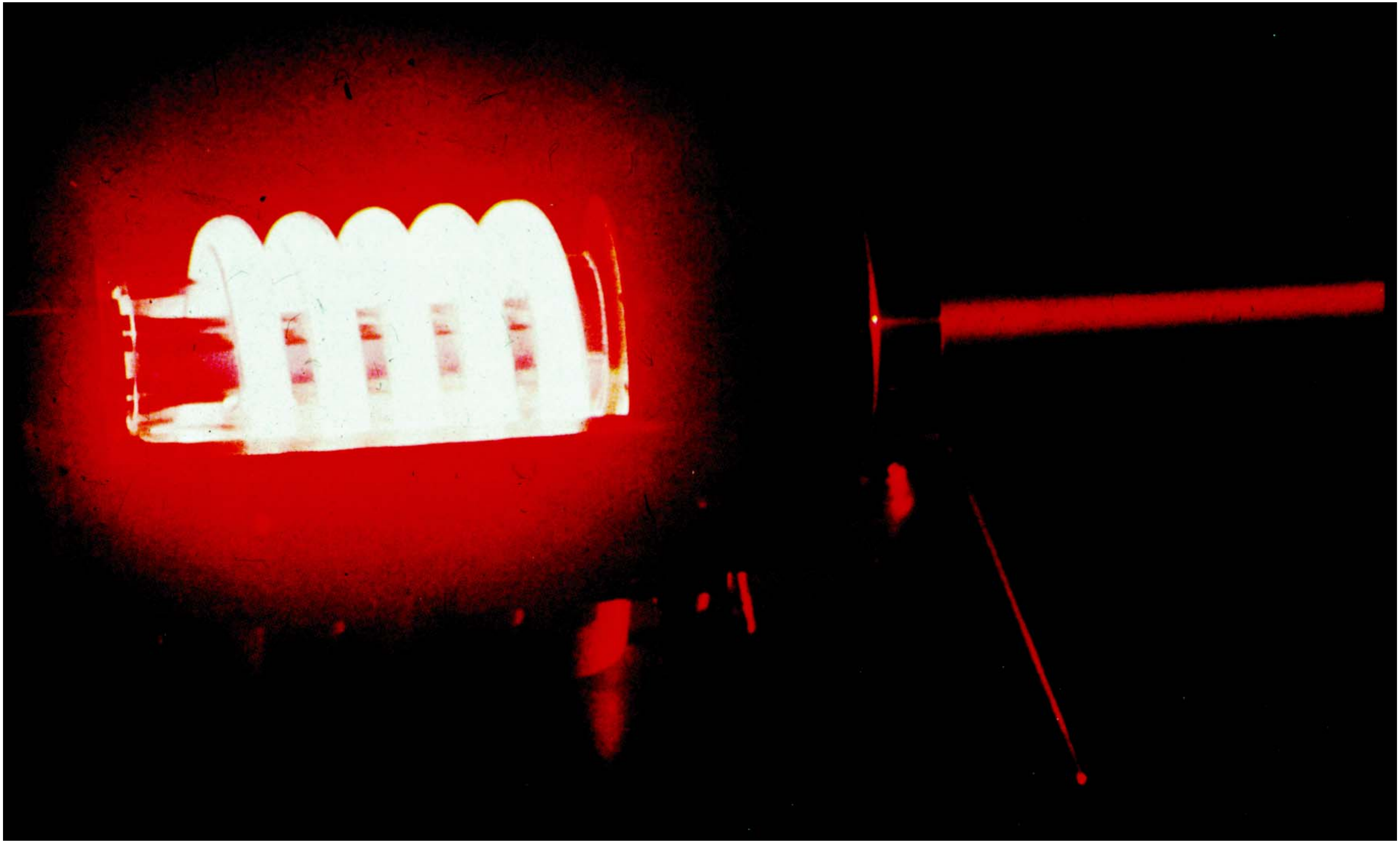
July 7, 1960 New York

Not the true first laser!

Immediately duplicated in many labs (TRG, IBM, **Bell Labs**)

Actually worked better than the original one!

The Working-Horse for Laser Physics



Was it Really Laser Action?

- A few authoritative people doubted about Maiman's results
  Large beam divergence
  Large spectra bandwidth
  Absence of laser spiking

- Indeed, on May 16 1960, Maiman did observe laser action of a special kind

- Anyway Maiman is to be celebrated as the creator of the first laser

Charles H. Townes, *How the Laser Happened*, Oxford University Press (New York, 1999)

D.F. Nelson, R.J. Collins and W. Kaiser, *Bell Labs and the Ruby Laser*, Phys. Today **63** 40 (2010)

T. H. Maiman, *The Laser Odyssey*, Laser Press, Blaine, WA (2000)

A few Curiosities about Dye Lasers

First exciting example of widely tunable laser
The working-horse for femtosecond laser research
and nonlinear optics in the 1980s

- First laser action independently achieved by:

P.P. Sorokin and J.R. Lankard,
Stimulated Emission observed from an Organic Dye, Chloro-Aluminum Phtalocyanine
IBM J. Res. Dev. **10**, 162 (1966)

F.P. Schäfer, W. Schmidt, J. Voltze
Organic Dye Laser Solution
Appl. Phys. Lett. **9**, 305 (1966)

Dye Lasers were just Great

- You could eat it

  The edible laser (Arthur L. Schawlow)
- You could drink it

  The drinkable laser (Eastman Kodak Labs Rochester)
- You could make life quite colorful

The Birth of Nonlinear Optics

- Second-harmonic generation

  P.A. Franken et al., *Generation of Optical Harmonics*

  Phys. Rev. Lett. **7**, 118 (1961)

- The door to real-word applications

  J.A. Giordmaine, *Mixing of Light Beams in Crystals*

  Phy. Rev. Lett. **8**, 19 (1962)

  P.D. Maker et al., *Effects of Dispersion and Focusing on the Production 0f Optical Harmonics*

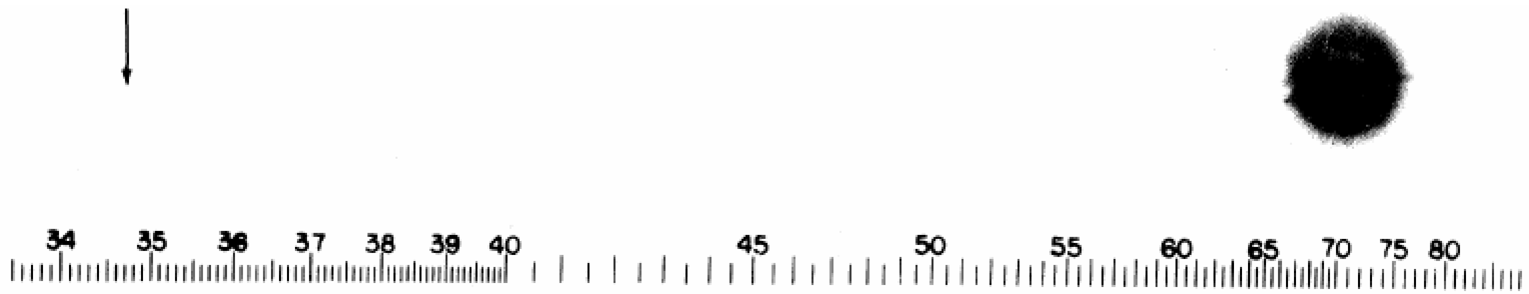
  Phy. Rev. Lett. **8**, 21 (1962)

The Peter Franken PRL Paper

VOLUME 7, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1961

GENERATION OF OPTICAL HARMONICS*

P. A. Franken, A. E. Hill, C. W. Peters, and G. Weinreich
The Harrison M. Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan
(Received July 21, 1961)



"…The arrow at 3472 A indicates the small but dense image produced by the second harmonic. The image of the primary beam at 6943 A is very large due to halation."

Role of different authors

Stimulated Raman Scattering

- Accidentally discovered by Woodbury and Ng

  (following demonstration of Q-switching by F.J. McClung and R.W. Hellwarth using a nitrobenzene filled Kerr cell)

  E.J. Woodbury and W.K. Ng, *Ruby Laser Operation in the near IR,* Proc. IRE **50**, 2367 (1962)

- Understood as SRS by Eckhardt et al.

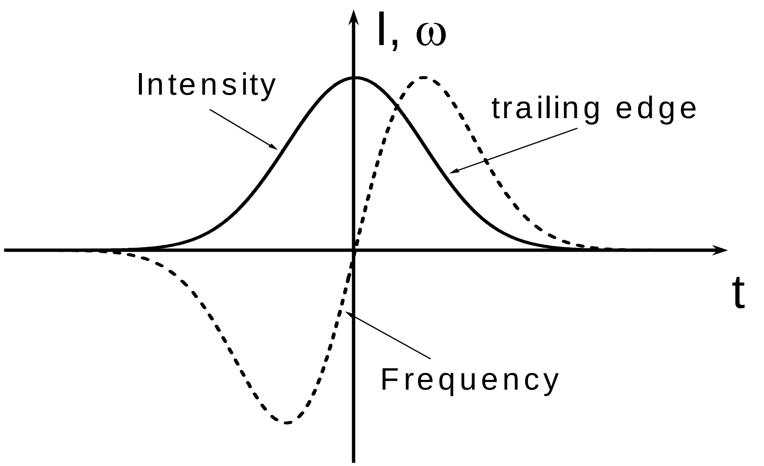
  G. Eckhardt, R.W. Hellwarth *et al*., *Stimulated Raman Scattering from Organic Liquids,* Phys. Rev. Letters **9**, 455 (1962)

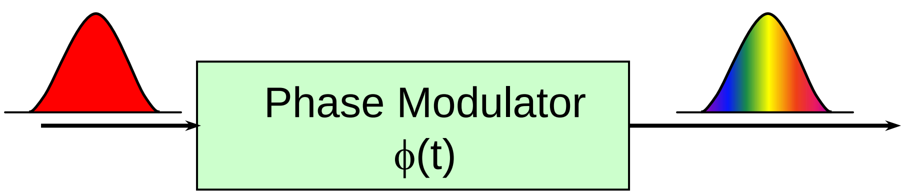
Self-Phase Modulation (SPM)

- Optical Kerr effect: $n(\mathbf{r},t) = n_0 + n_2\, I(\mathbf{r},t)$

$$\varphi(t) = \omega_0 t - k_0\, n(t)\, \ell$$

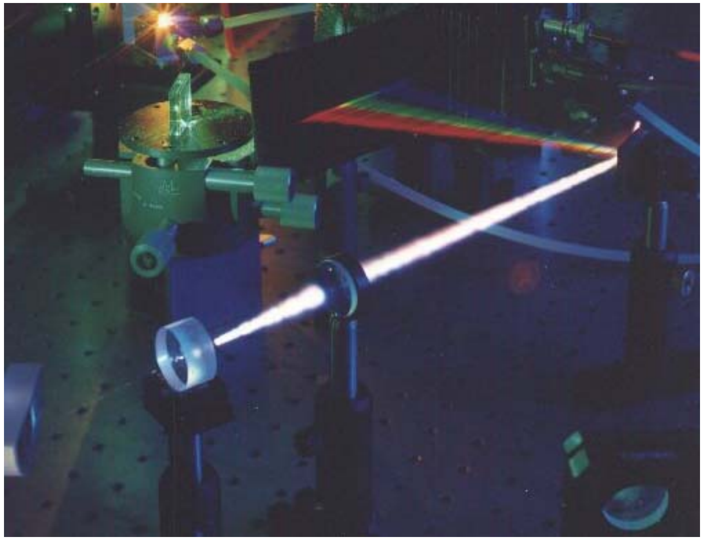
$$\omega(t) = \frac{d\varphi}{dt} = \omega_0 - k_0 n_2 \frac{dI(t)}{dt} \ell$$



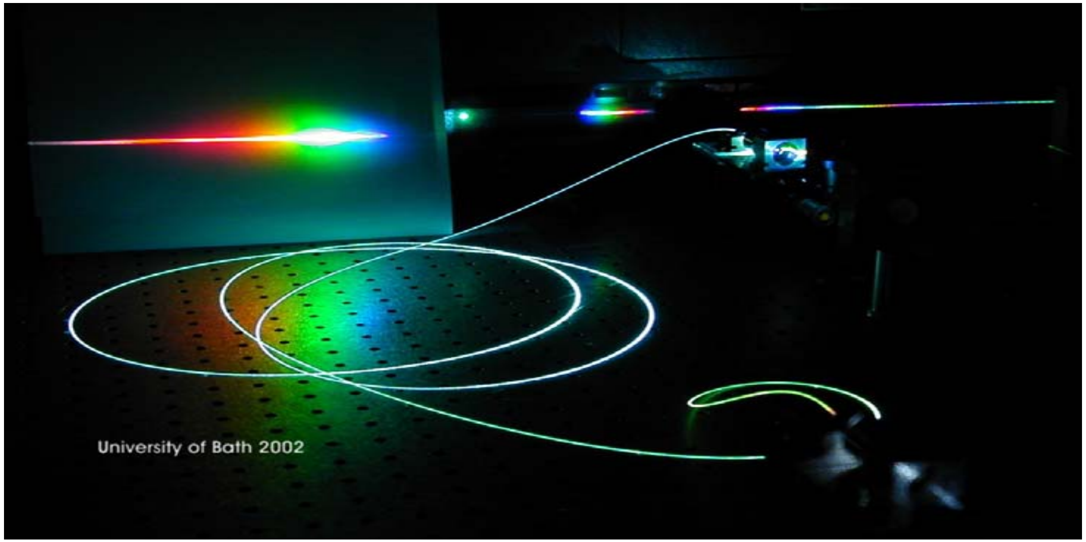


Spectral Broadening by SPM

In a bulk piece of glass:
non uniform SPM



In a photonic crystal fiber: uniform SPM



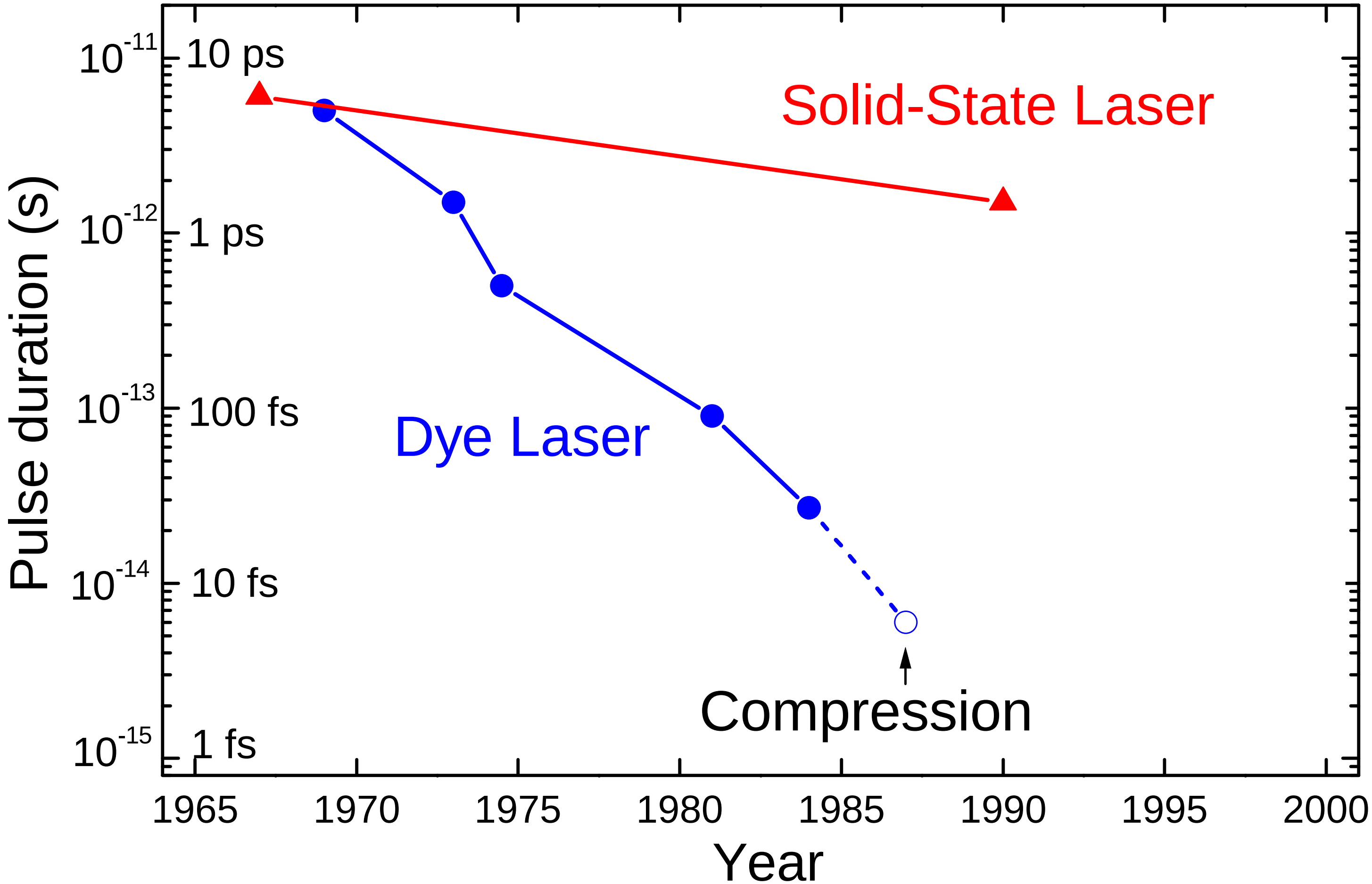
A Bridge between Laser Science

And Nonlinear Optics:

Ultrashort Laser Science

Historical Evolution of Pulse Duration (Phase 1)

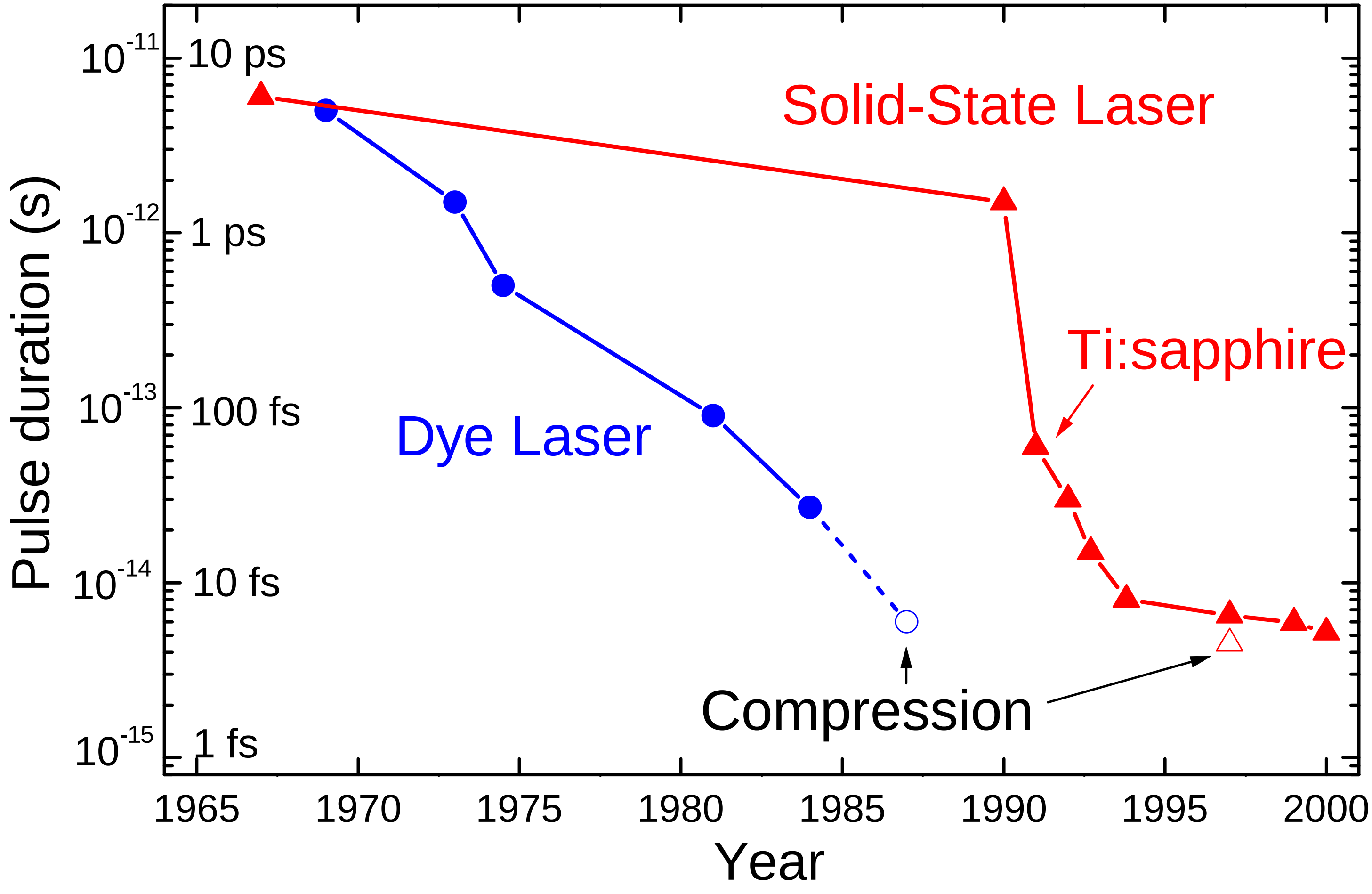
From Picosecond to ~ 100 femtosecond



Historical Evolution of Pulse Duration (Phase 2)

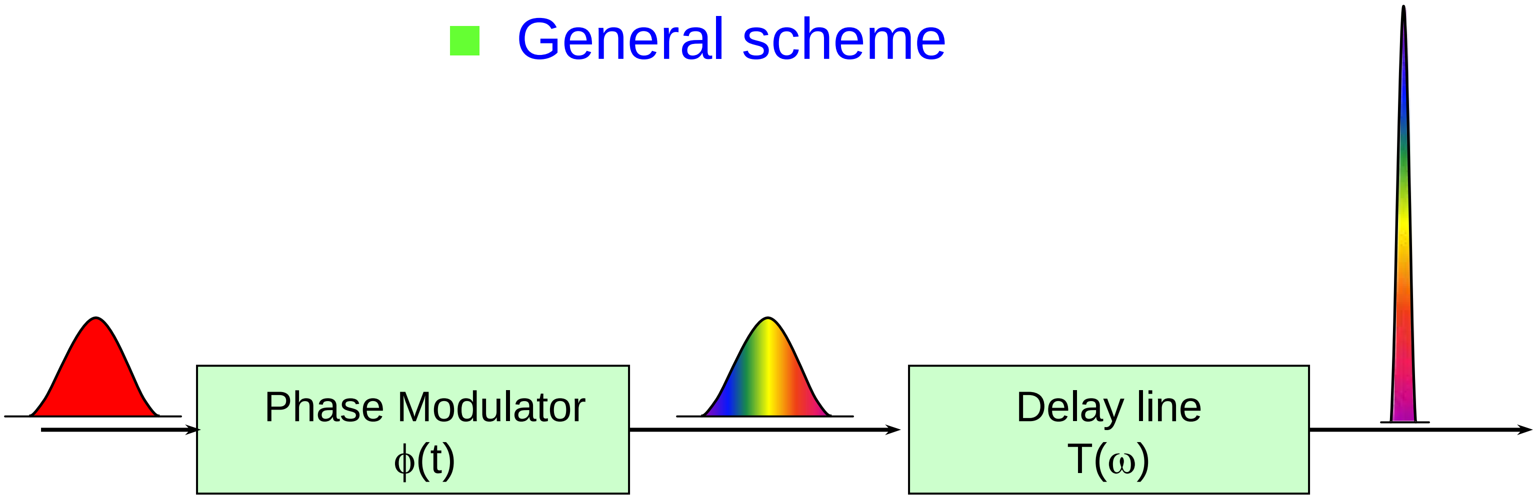
Tunable solid-state lasers

from ~ 100 fs to a few fs, by-by to dyes



Compression of Light Pulses

- General scheme



Phase Modulator ⇒ Self Phase Modulation (SPM)

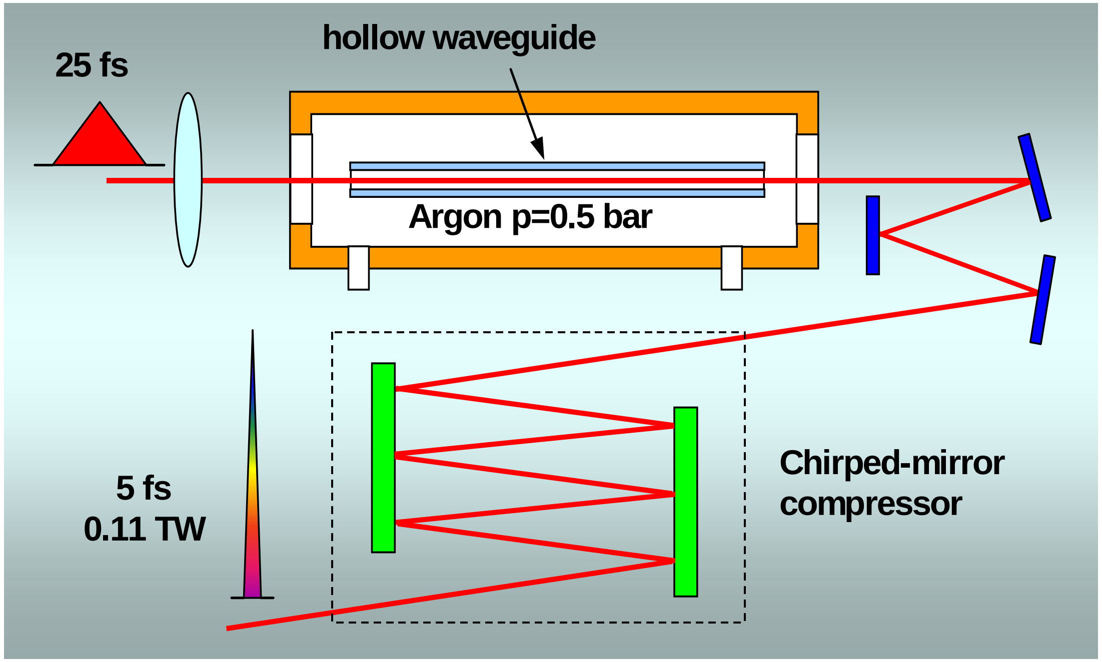
Uniform SPM ⇒ Use of a waveguiding structure

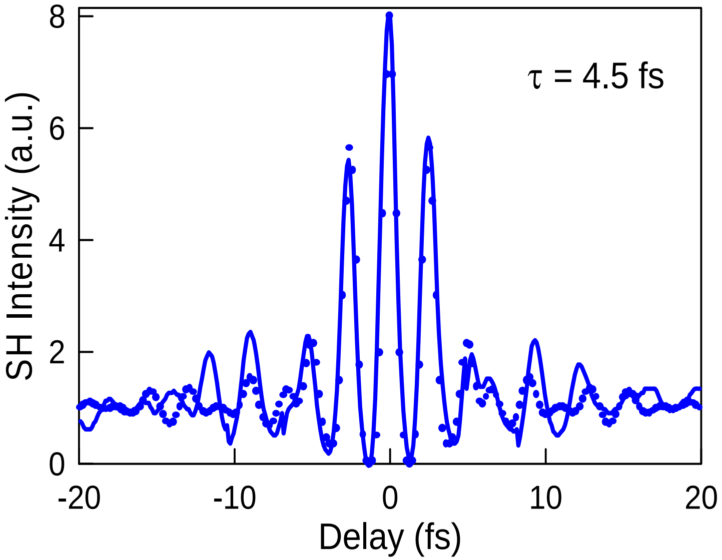
Delay line ⇒ grouping of all frequency components

R.A. Fisher, P.L. Kelley and T.K. Gustafson, *Subpicosend Pulse Generation Using Optical Kerr Effect*, Appl. Phys. Letters **14**, 140 (1969)

High-Energy Pulse Compression

Hollow-fiber Compressor (1-10 mJ)



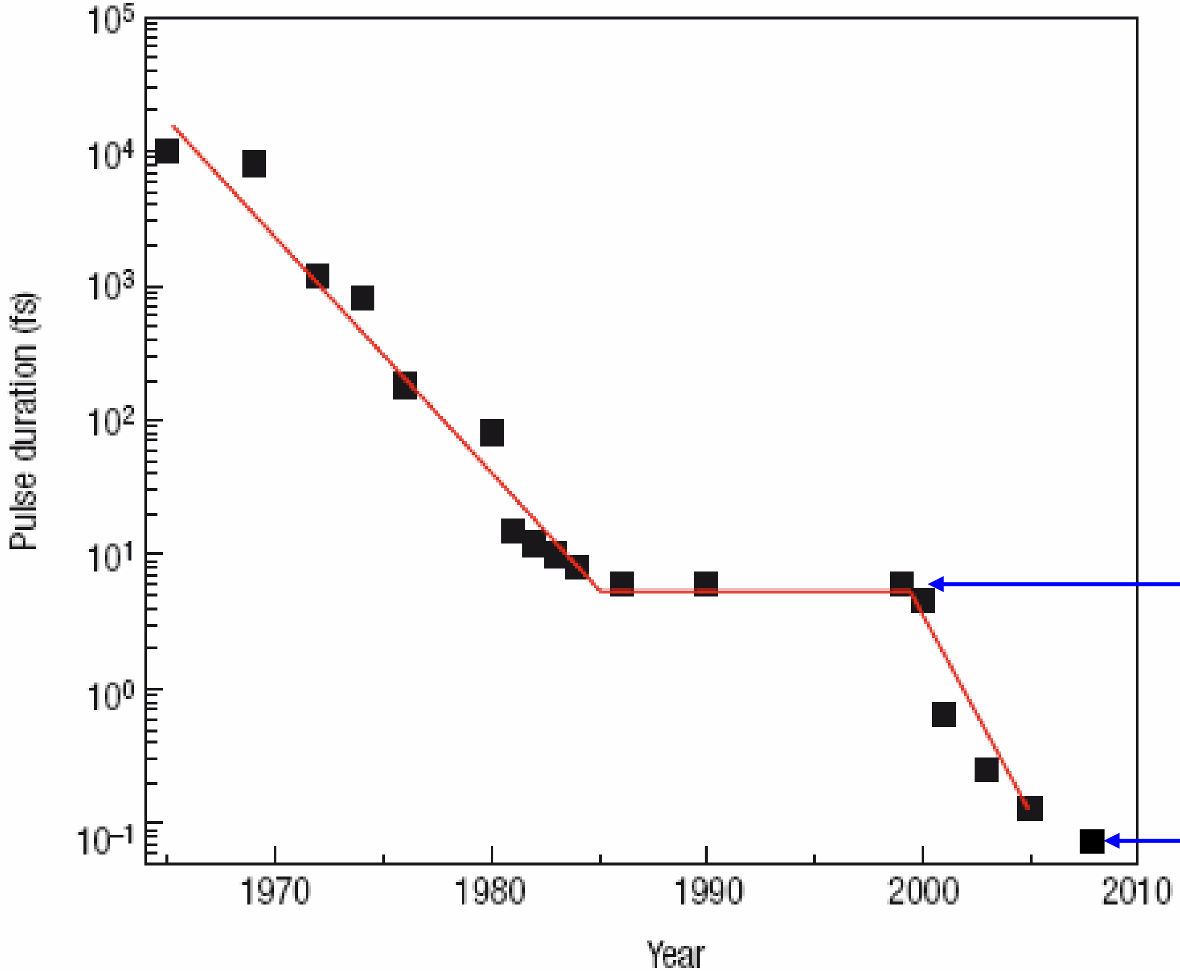


Few-cycle laser pulses

M. Nisoli, S. DeSilvestri, and O. Svelto, Appl. Phys. Lett. **68**, 2793 (1996)
M. Nisoli *et al.*, Opt. Lett. **22**, 522 (1997)

Historical Evolution of Pulse Duration (Phase 3)

From Femtoseconds to Attoseconds



High-order Harmonic Generation (HHG)

4 fs

80 as: E. Goulielmakis *et. al*., Science **320**, 1614 (2008)

A few tips about laser applications

A Very Frustrating Period (1960-1970)

Application-wise many initial attempts failed

- **Medicine**: retina photocoaugulation, port-wine stains, melanoma (pulsed ruby)
- **Optical Communications** (Ruby or He-Ne, hollow-fibers or periodic gas lenses; optical fibers 1000 dB/km)
- **Material working** (50 W/m, slow-axial-flow CO_2 laser)

A bright solution looking for a problem

A 2 kW CO_2 Laser

A Magic Turning Point

- Year seventies

  Medicine: retina photocoaugulation (Ar^+ ion), port-wine stains (pulsed dye lasers), melanoma (forget about it)

  Optical Communications: DH semiconductor laser (Alferov, 1970), Optical Fibers (Kao, 1966, Corning 17 dB/km, 1970)

  Material working: fast transverse flow (beginning of seventies) and fast longitudinal flow (late seventies) CO_2 laser

Conclusions

- **Laser, Early Days:**

  A Bright Solution Looking for a Problem

- **Laser and Nonlinear Optics (**Fifty Years Afterwards**):**

  One of the most active fields during last century
  Going to play an even more important role in this century (the century of the photon)