The Laser:
a Historical Perspective

Orazio Svelto
Polytechnic School of Milano
National Academy of Lincei

Institute of Physics of the AS CR
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Plan of this Talk

- The race to make the first laser
- Early developments in laser science (1960-1970)
- The birth of nonlinear optics
- A bridge between nonlinear optics and laser physics: ultrafast laser science
- Historical remarks on Nobel Prizes
- Early developments in laser applications (1960-1970)

Very coarse review of some of most important achievements with a few anecdotes and curiosities

The race to make the first laser

Starting of the Race

- Race started with Schawlow and Townes paper (middle 1958)

A.L. Schawlow and C.H. Townes *Infrared and Optical Masers* Phys. Rev. **112**, 1940 (1958)

- Several laboratories, mostly in U.S., involved

Bell Labs, TRG, Columbia Un., IBM labs, Hughes, American Optical

Lebedev Inst., Moscow Power Inst., Oxford Univ.

A Strong Contender: Gordon Gould

- October 1957: Graduate student at Columbia University, after talking with Townes, Gould asks a notary public to authenticate a first laboratory notebook (9 pages) containing several ideas about lasers
- August 1958: after receiving reprint of Schawlow and Townes paper, Gould asks a City College professor to sign (as read and understood) a second notebook (23 pages)

The Thirty-Year Patent War

- Two notebooks ⇒ thirty-year patent war (particularly against Schawlow-Townes patent)
- After several defeats, Gould won his patent suit
- Gould the real inventor of the laser?
- The "legal" truth does not always coincide with the "scientific" truth (i.e. **Gould won where he deserved to lose**)

Curiosity: Gordon Gould went to work at TRG, which was awarded a millionaire grant to make a laser according to the proposal by Gould. Gould was however prevented to work on his own ideas, since researches were done at a classified area in TRG.

The Invention of the first Laser

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

The scientific community was astounded: (a) The simplicity of the components used. (b) The 3-level nature of the laser transition. (c) The type of laser excitation (pulsed by a flashlamp)

Curiosity: T.H. Maiman, a young scientist at that time, won the race with a very limited investment by Hughes.

Th.H. Maiman Holding the first Laser

The History of Maiman Publication

- Physical Review Letters rejected his first publication (Optical Maser Action in Ruby, June 2010)
- A paper with similar content accepted by Nature (6 Aug. issue)
- During the press release organized by Hughes in N.Y., more extensive paper was taken away and published on a rather obscure 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 it worked better than the original one by Maiman!

End of the Race (1960)

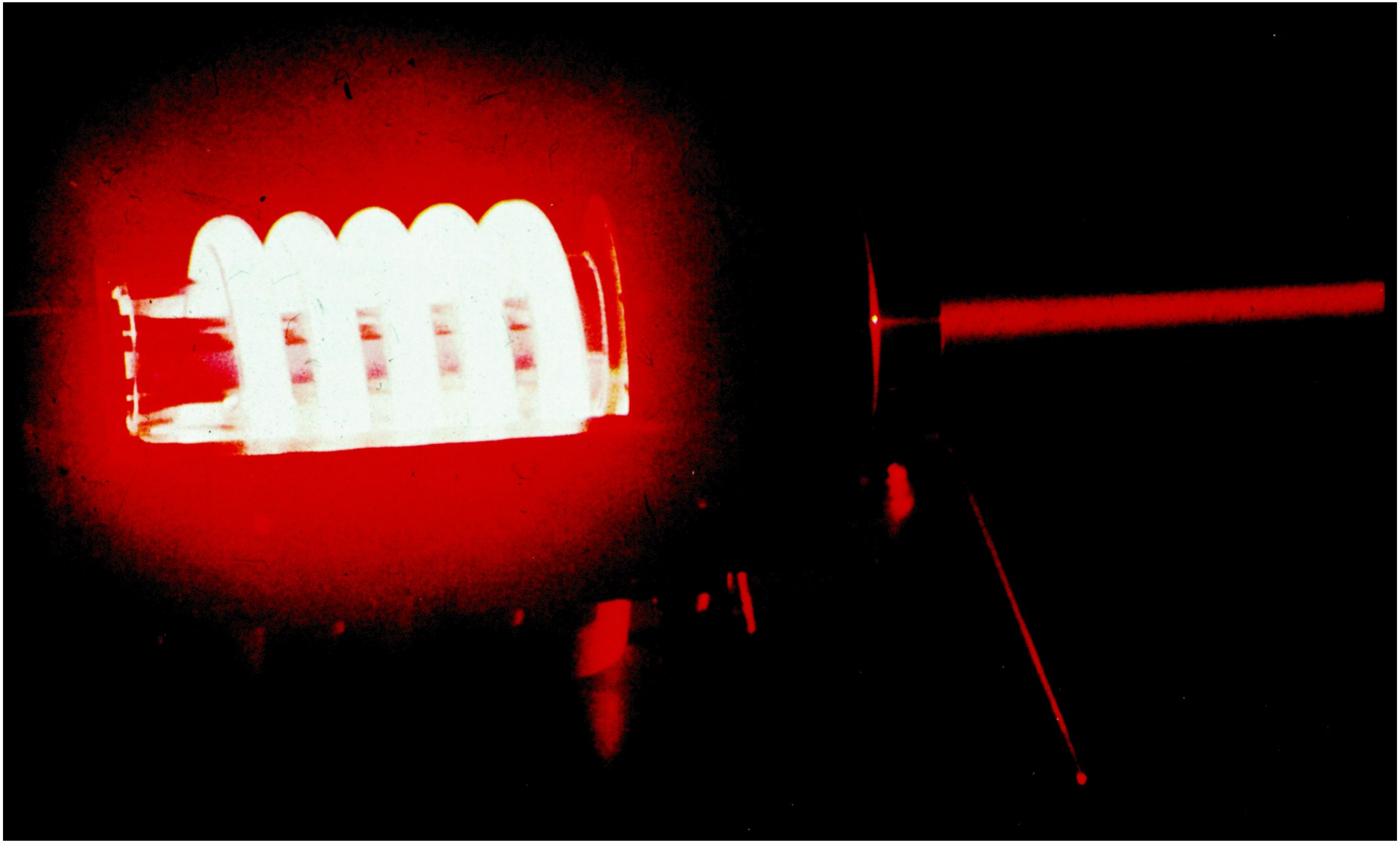
- May 16 1960:
  First laser demonstration by Maiman

- A few months later:
  P.P. Sorokin *et al*. U^{3+}:CaF_2 (2,5 μm) Sm^{2+}:CaF_2 (~700 nm) [4 level lasers, first rare-earth laser, cryogenic temperature]

- December 1960:
  A. Javan *et al.* He-Ne laser (1.15 μm); the first cw laser; the first gas laser; the first electrically excited

- By the end of 1960:
  quite different types of lasers were operated ⇒ door opened to all successive developments

The Working-Horse for Laser Physics



Directionality of a Laser Beam

Early Developments in Laser Physics

(1960-1970)

A very Exciting Period

- ♦ Most important new lasers and phenomena related to physics of lasers (Relaxation Oscillations, Q-Switching, Mode-Locking, Single-mode oscillation)
- ♦ Most important phenomena related to laser-matter interaction (e.g nonlinear optics, high-resolution spectroscopy, ultrafast optical sciences)

Q-Switching

- Attributed to:

  R.W. Hellwarth, *Control of Fluorescent Pulsations*
  in Advances in Quantum Electronics, Columbia. Un. Press, N. Y. 1961, p.334

- Actually

  The idea of Q-switching was already contained in one of two notebooks of G. Gould $\Rightarrow$ He lost his patent suit against Hughes (the legal "truth" did not coincide with the scientific truth i.e. Gould lost where he deserved to win and won where he deserved to lose)

Q-Switching

- Realized by

  F.J. McClung and R.W. Hellwarth, *Giant Optical Pulsations from Ruby*

  J. Appl. Phys. **33**, 828 (1962)

- Curiosity: Accidental discovery of stimulated Raman scattering

  E.J. Woodbury and W.K. Ng, *Ruby Laser Operation in the near IR*

  Proc. IRE **50**, 2367 (1962)

Mode-Locking

- First demonstration of synchronous intracavity modulation:
  Karl Gürs, *Innere Modulation von optischen Masern*
  Z. für Physik, **172**, 163 (1963)
  L.E. Hargrove *et.al.*, Appl. Phys. Lett. **5**, 4 (1964)

- Explanation in terms of mode-locking
  M. DiDomenico, J. Appl. Plys. **35**, 2870 (1964)

- Passive ML of Q-switched lasers (beginning of ultrafast sciences):
  H. W. Mocker and R.J. Collins, Appl. Phys. Lett. 7, 270 (1965)
  A.J. DeMaria *et. al*, Appl. Phys. Lett. 8, 174 (1966)

- Curiosity:
  Initial experiments performed for optical communications

The Birth of Nonlinear Optics

Second Harmonic Generation

- First discovery

  P.A. Franken et al., *Generation of Optical Harmonics*
  Phys. Rev. Lett. **7**, 118 (1961)

- The door to real-word applications

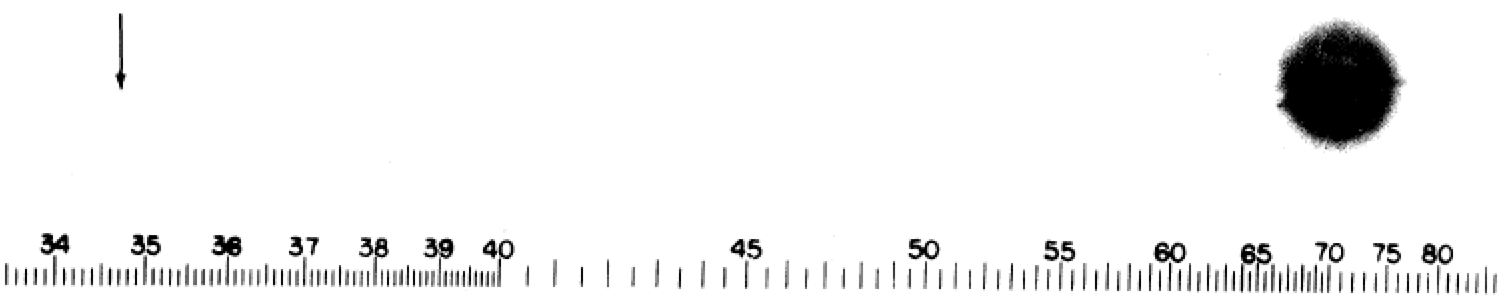
  J.A. Giordmaine, *Mixing of Light Beams in Crystals*
  Phy. Rev. Lett. **8**, 19 (1962)
  P.D. Maker et al., *Effects of Dispersion and Focusing on the Production of Optical Harmonics*
  Phy. Rev. Lett. **8**, 21 (1962)

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."

A Bridge between Laser Science

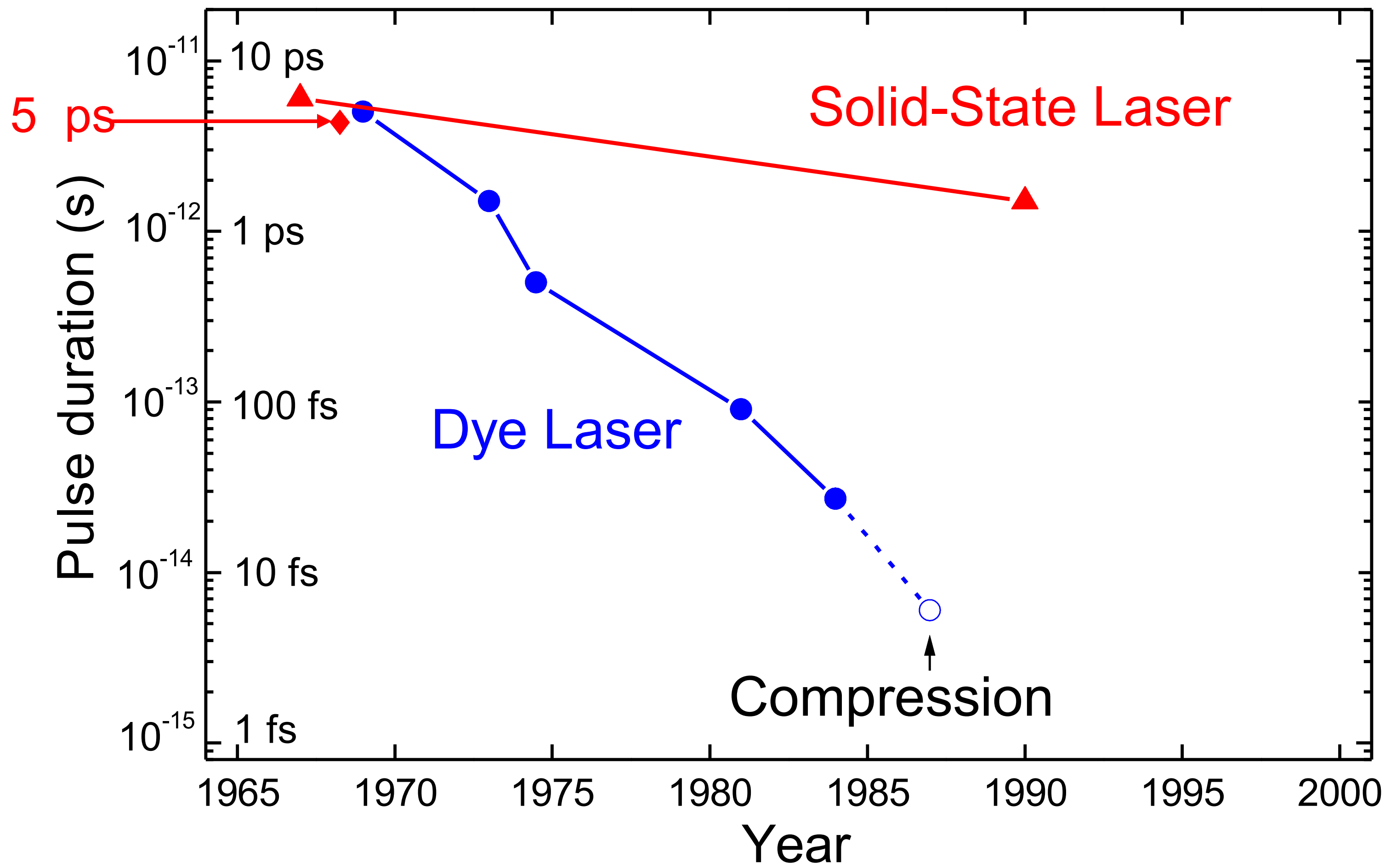
and Nonlinear Optics:

Ultrafast Laser Science

Historical Evolution of Pulse Duration (Phase 1)

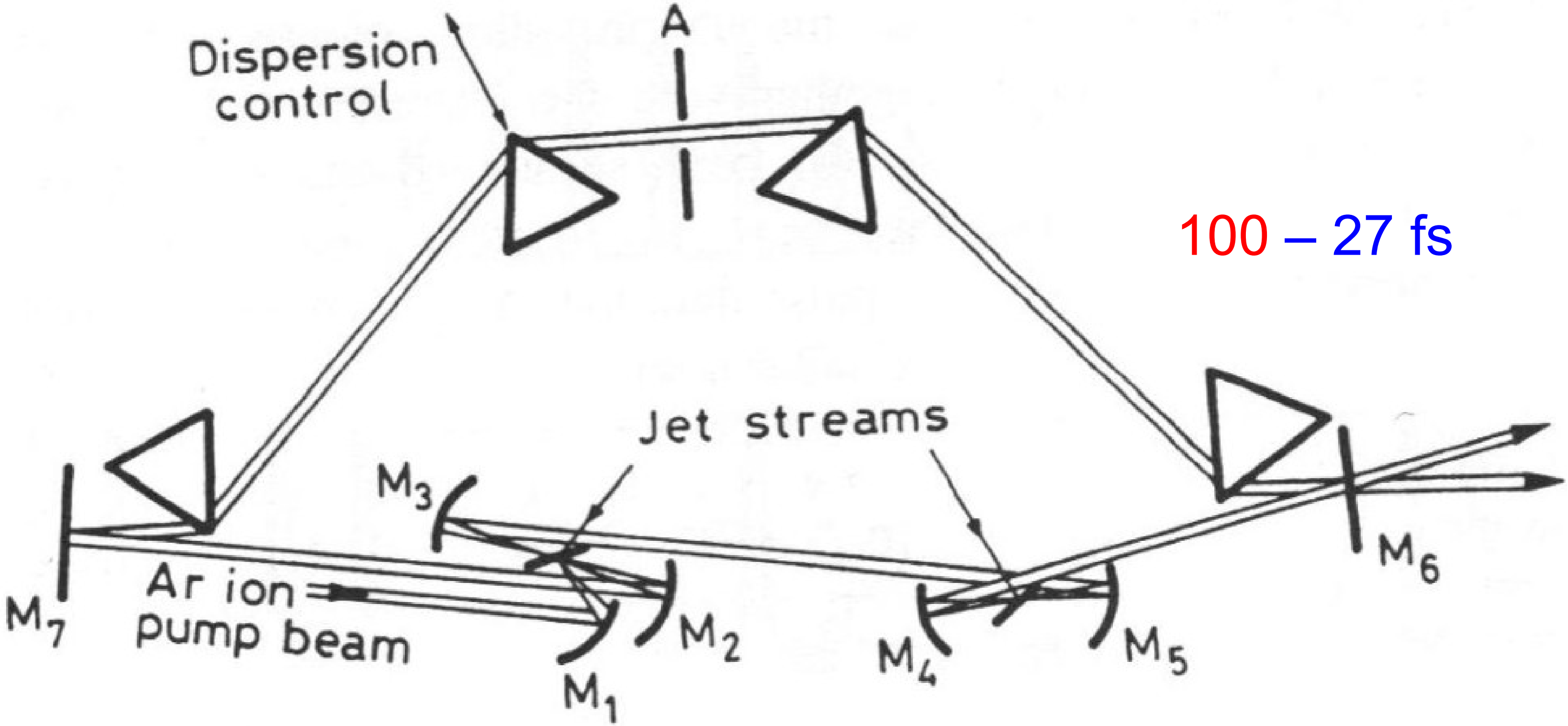
Solid state (Ruby and Nd) and Dye Lasers

From picosecond to subpicosecond



Breaking the Picosecond Barrier

The colliding-pulse mode-locked (CPM) dye laser
[E.P. Ippen and C.V. Shank (1974),
F.L. Fork, B.I. Greene]

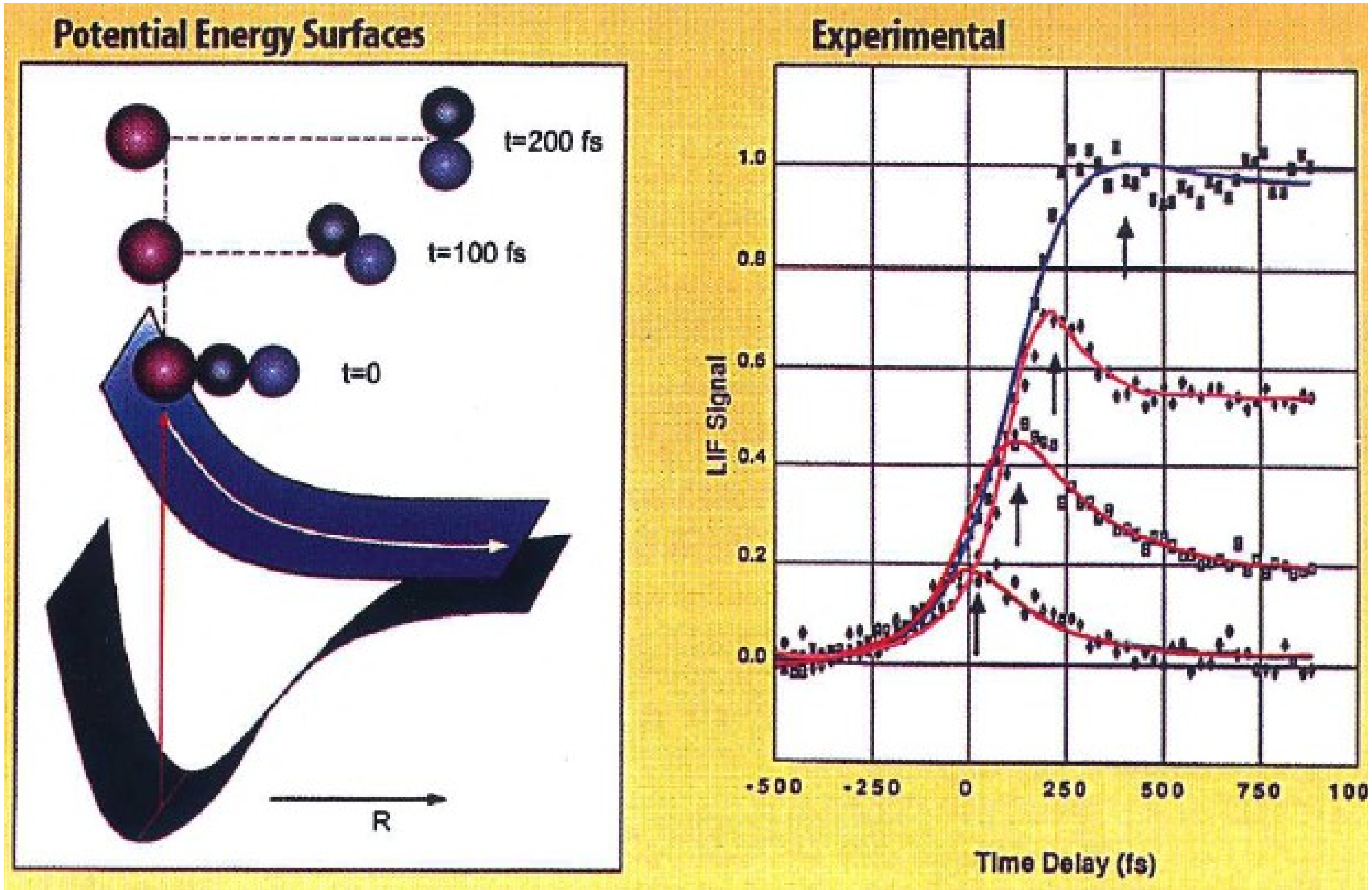


100 – 27 fs

Application: Femtochemistry

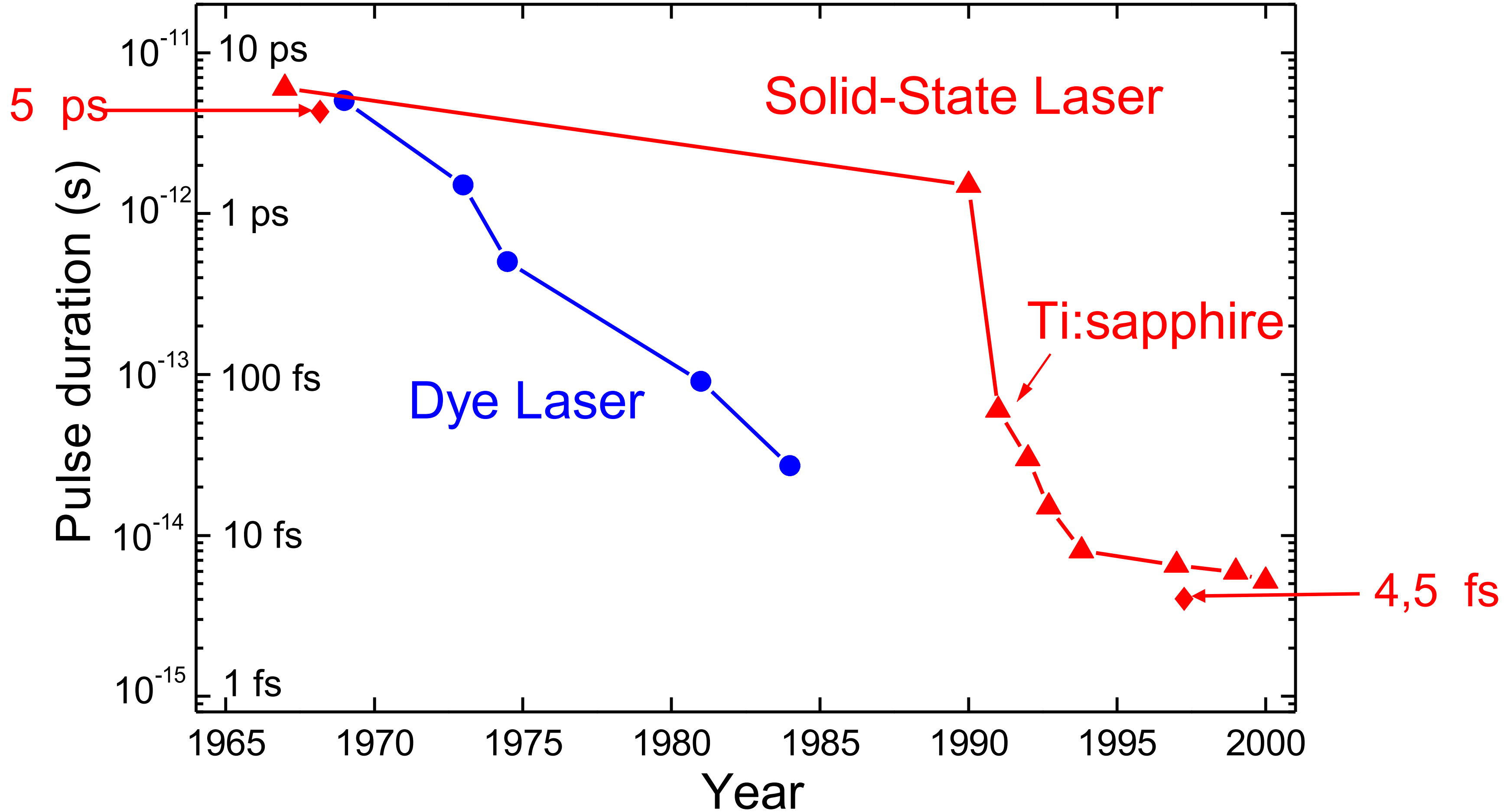
Ahmed H. Zewail, Nobel Prize in Chemistry (1999)

ICN, paradigmatic molecule for dissociation reactions and photo-fragment spectroscopy



Historical Evolution of Pulse Duration (Phase 2)

From sub-picoseconds to femtoseconds
High peak-intensity lasers



Newcomers:
Tunable Solid State Lasers

- Laser-pumped solid-state lasers (beginning of nineties)

  Alexandrite

  Cr:LISAF

  Cr:YAG

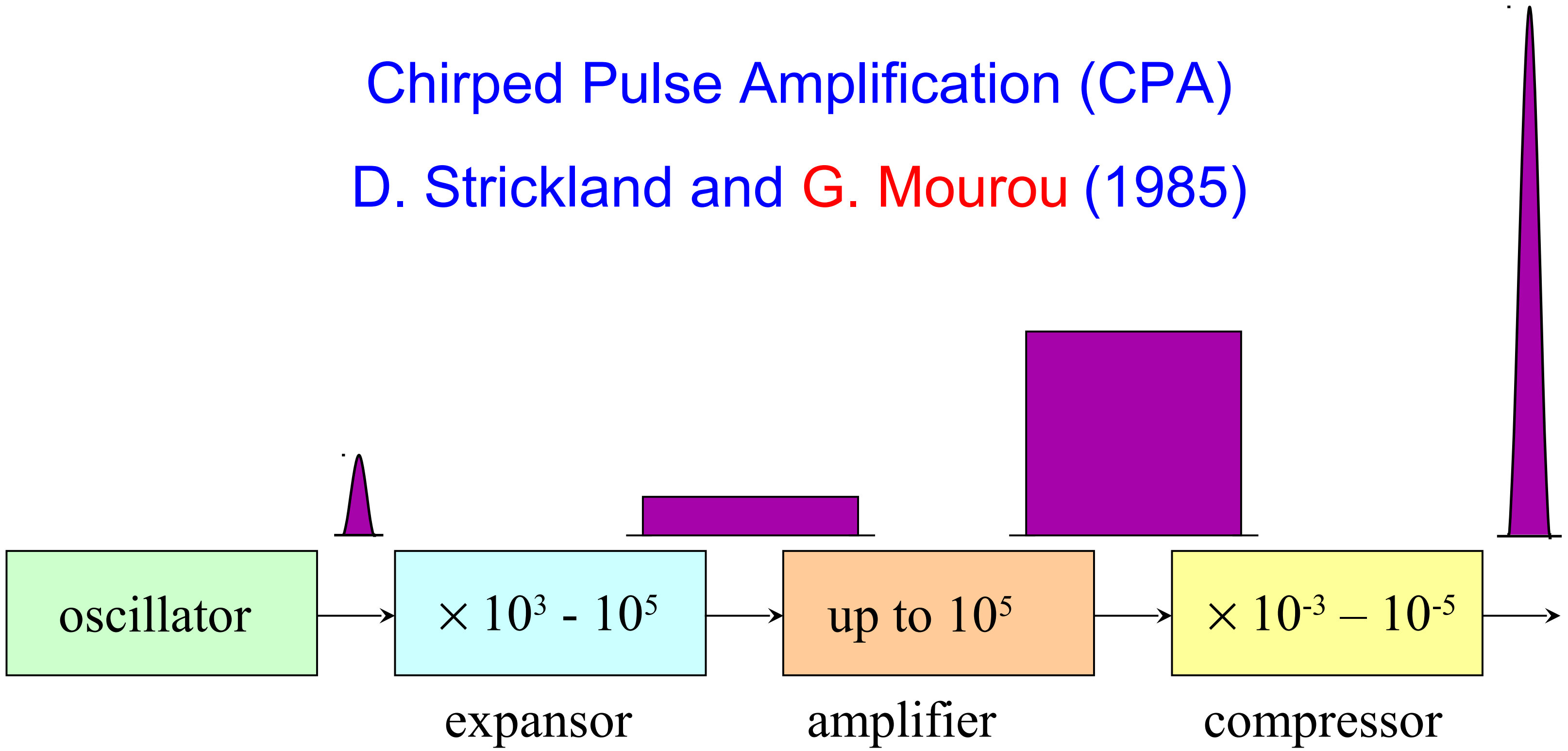
  Ti:Sapphire

Bye-bye to dyes

High Peak Intensities Lasers

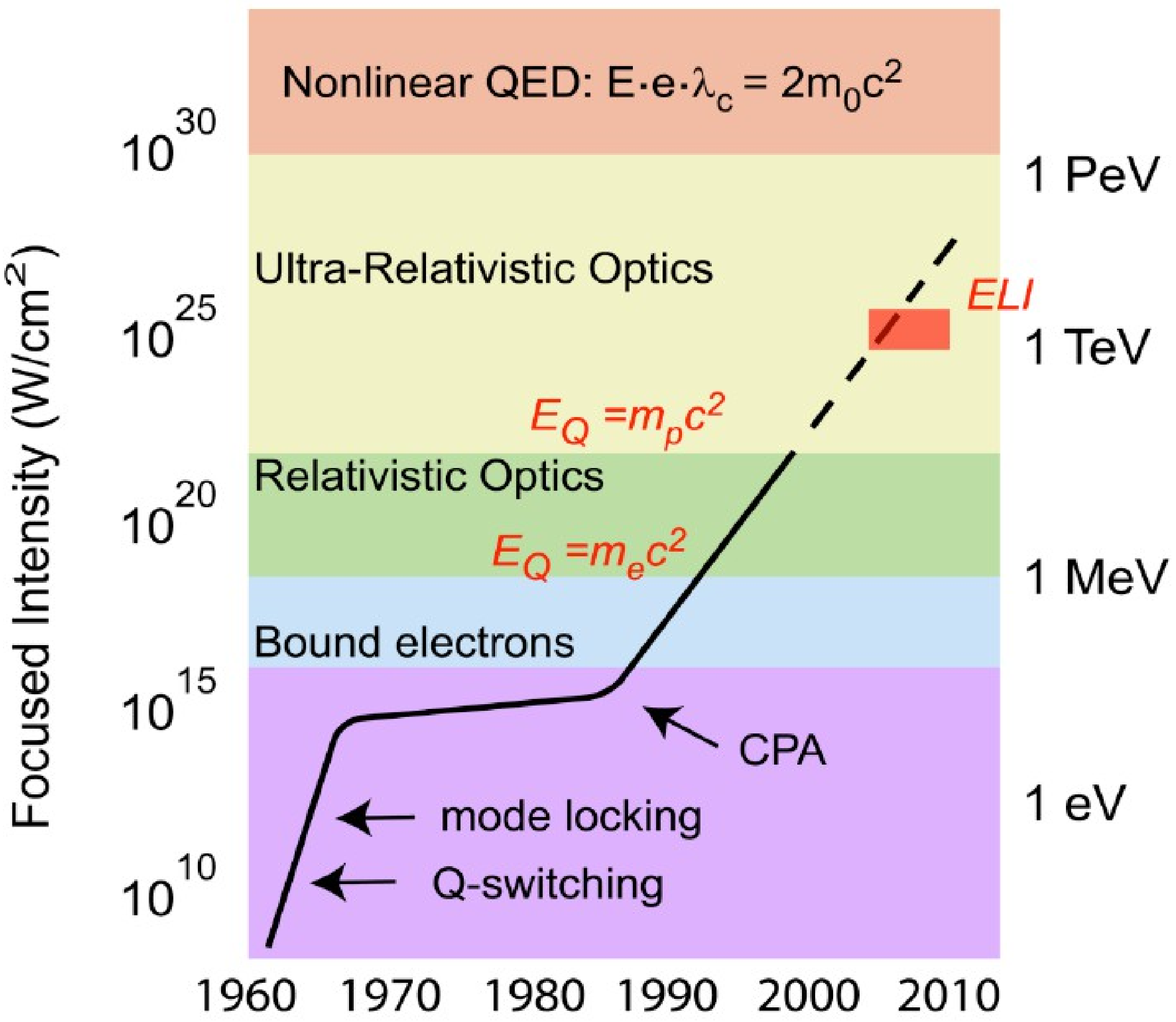
Chirped Pulse Amplification (CPA)

D. Strickland and G. Mourou (1985)



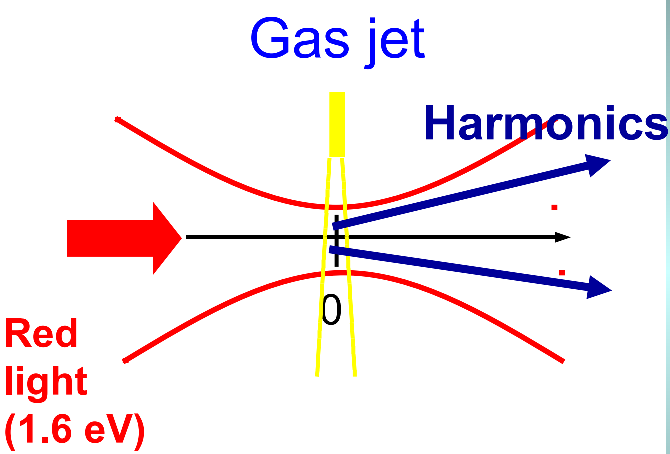
- Ti:Al_2O_3: 1-10 mJ; f = 1-10 kHz
- TTT [Terawatt Table Top] Lasers : 100 TW (5 J, 50 fs)
- Petawatt-class Lasers (1,5 PW, i.e. 580 J and 460 fs)

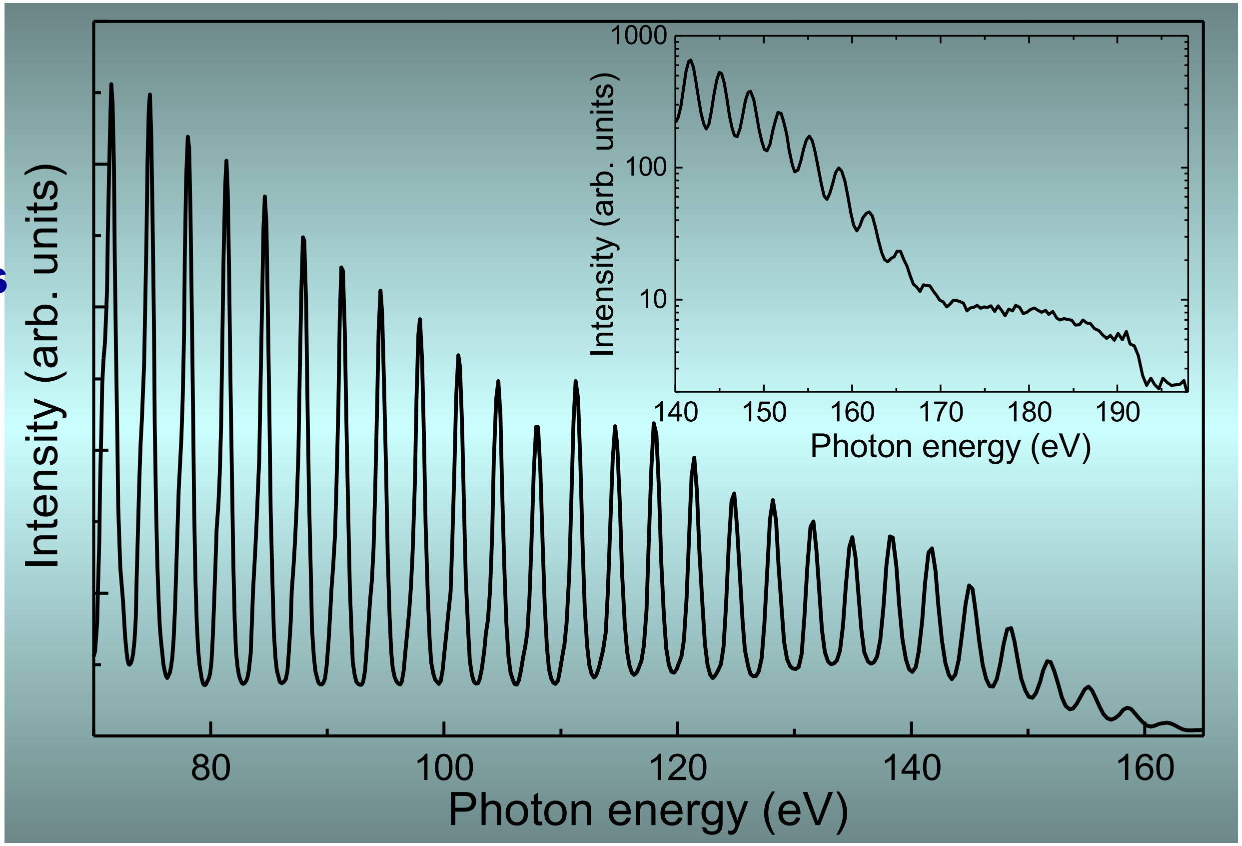
Historical Evolution of Peak Intensity



High Order Harmonic Generation HHG

Very-short pulses in the X-UV range



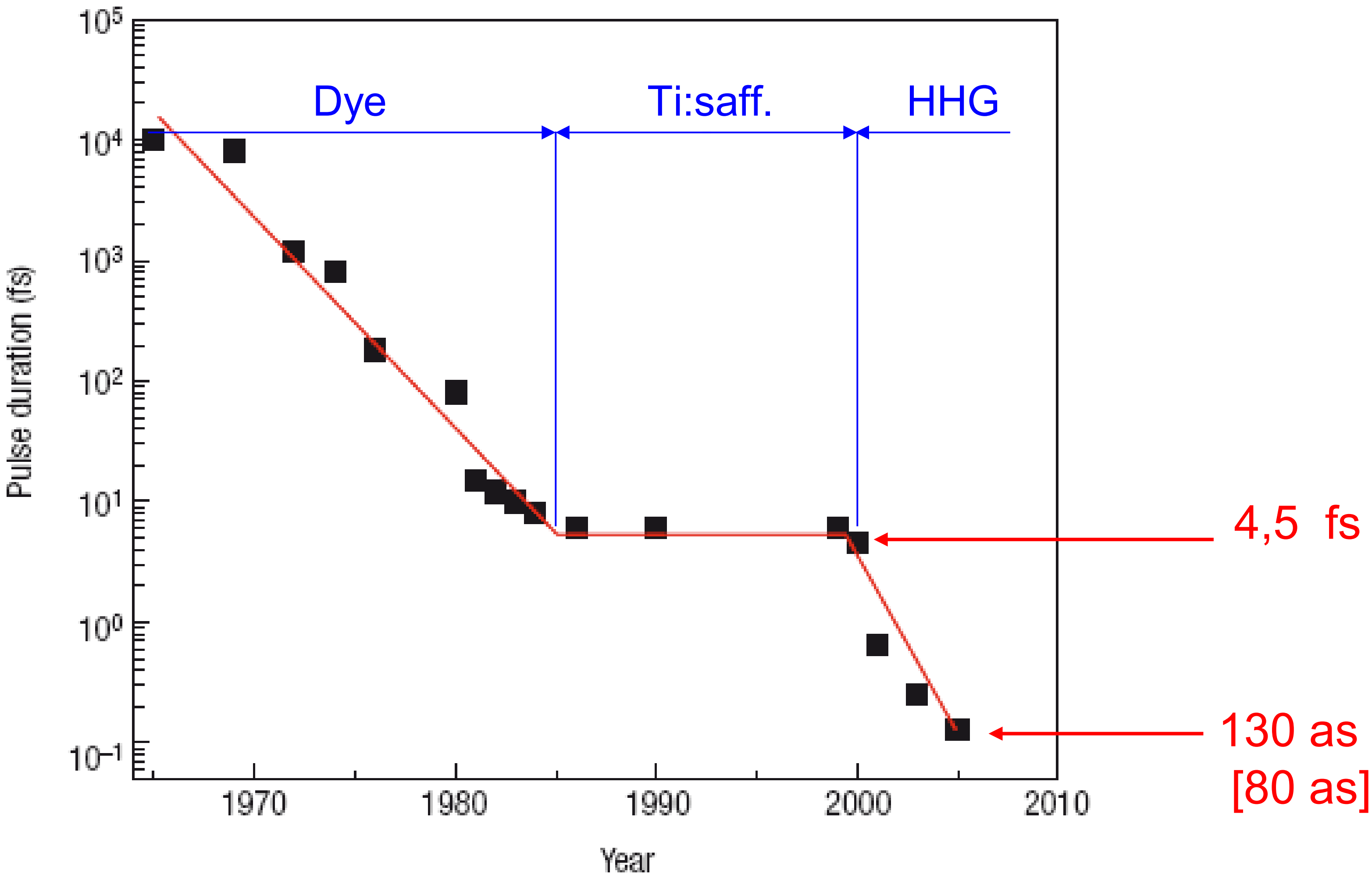


Anne L'Huillier pioneering work [PRL **70**, 774 (1993)
P.B. Corkum, PRL **71**, 1994 (1993)

➔ Odd harmonics of the red light are generated up to the soft X ray region

Historical Evolution of Pulse Duration (Phase 3)

From Femtoseconds to Attoseconds



The Future of Ultrafast Sciences

- Extremely-high peak intensity ($10^{22} \div 10^{25}$ W/cm^2)

  High-field Physics

- Extremely-short time duration (100 ÷ 10 as)

  Attosecond Science

Historical Remarks on Nobel Prizes

Period Number 1 (1964-1981)

- 1964, Physics
  C. H. Townes (1/2) and N.G. Basov and A. M. Prokhorov (1/2)
  for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle
- 1971, Physics
  Denis Gabor
  for his invention and development of the holographic method
- 1981, Physics
  Nicolas Bloembergen an Arthur L. Schawlow
  for their contributions to the development of laser spectroscopy

Period Number 2 (1997-2012)

- 1997, Physics
  Steven Chu, Claude Cohen-Tannoudji and William D. Philips
  for development of methods to cool and trap atoms with laser light
- 1999, Chemistry
  Ahmed H. Zewail
  for his studies of the transition states of chemical reactions using femtosecond spectroscopy
- 2000, Physics
  Zhores I. Alferov and Herbert Kroemer
  for developing semiconductot hetrostructures used in high-speed-electronics and -optoelectronics
- 2001, Physics
  Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman
  for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates

Period Number 2
(1997-2012)

- 2005, Physics
  Roy Glauber (1/2),
  for his contribution to the quantum theory of optical coherence
  John L. Hall and Theodore W. Hänsch (1/2)
  for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique
- 2009, Physics
  Charles K. Kao (1/2)
  for ground-breaking achievements concerning the transmission of light in fibers for optical communications
- 2012, Physics
  Serge Haroche and David Wineland
  for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems

Early developments in laser applications

(1960-1970)

A Very Frustrating Period (1960-1970)

Application-wise many initial attempts failed

- **Medicine**: retina photocoagulation, 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

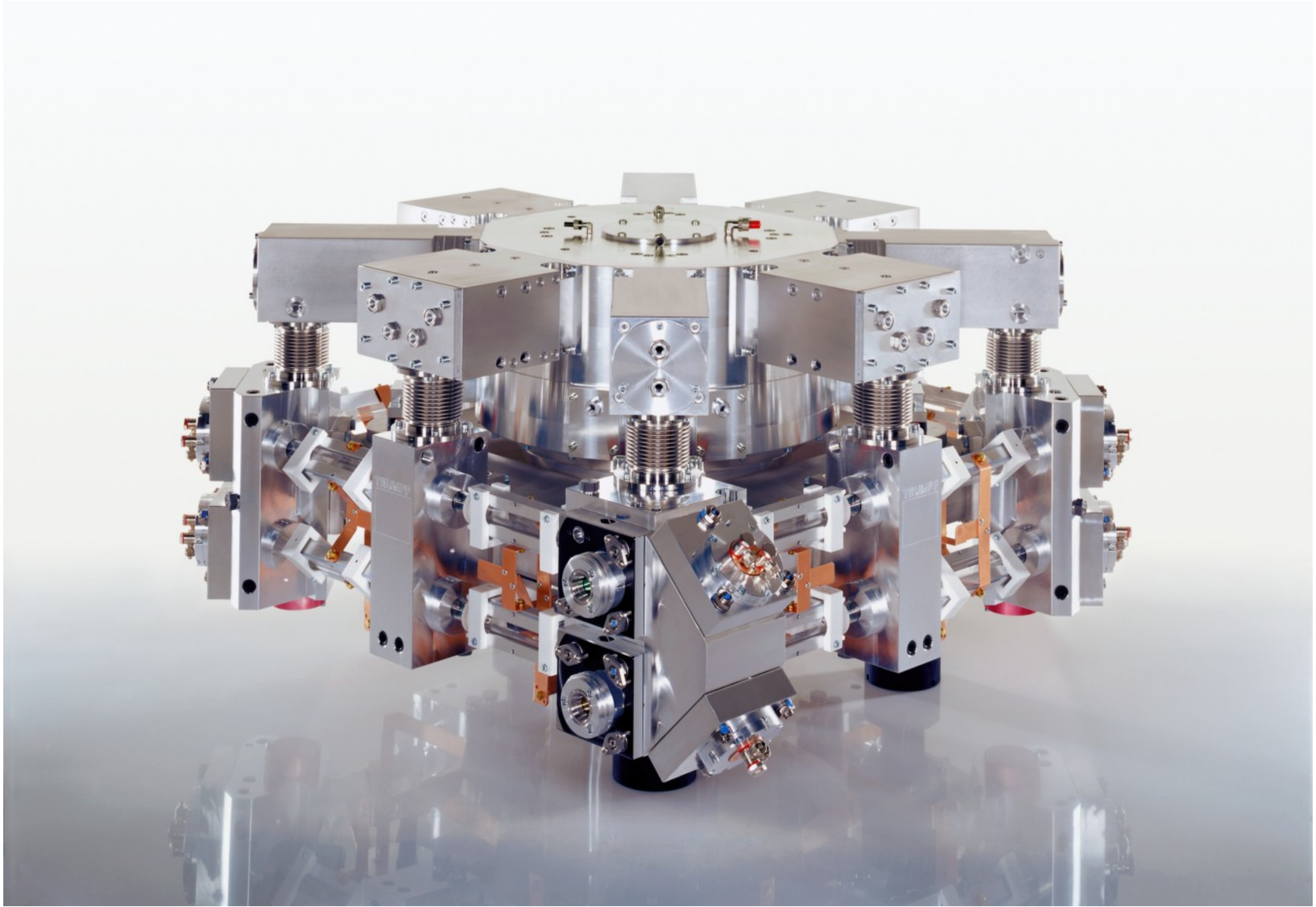
- Year seventies

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 longitudinal flow CO_2 laser (late seventies)

Fast Longitudinal Flow CO_2 Laser



Conclusions

- Laser, Early Days: A Bright Solution Looking for a Problem
- Laser, ~ Fifty Years Afterwards: The Bright Solution for many Problems in Science and Technology
- Bright solution in science : So far, 21 scientists have been awarded the Nobel Prize for researches on lasers or with lasers
- Bright solution in technology: “It has changed the way we live” (from letter of Barak Obama for the 50th anniversary of laser)
- It is one of the most important inventions of last century. It is going to play a even more important role in this century: The Century of the Photon. (2015: The Year of Light and Light Technologies)