THE OHIO STATE UNIVERSITY DEPARTMENT OF PHYSICS

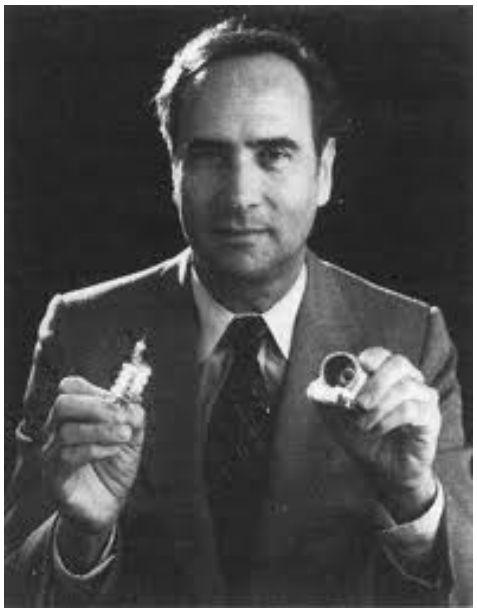
Birth of multiphoton physics at Moscow and Saclay 50 years later at OSU

P. Agostini

1st part

Multiphoton Processes at Moscow and Saclay in the 60's and 70's

It all begins with



1961

Interactions between Light Waves
in a Nonlinear Dielectric

J. A. Armstrong, N. Bloembergen, J. Ducuing, P. S. Pershan

Phys. Rev. 127, 1918, 1962.

$$P_i = \chi_{ij} E_j + \chi^{(2)}_{ijk} E_j E_k + \chi^{(3)}_{ijkl} E_j E_k E_l + \cdots$$

Complex Nonlinear
susceptibilities

A new toy in the lab

The production of sparks in air, though not detailed in the literature, has become a part of the repertoire of laser parlor tricks along with razor blade piercing and balloon bursting.

PRL 14, 60 (1965)

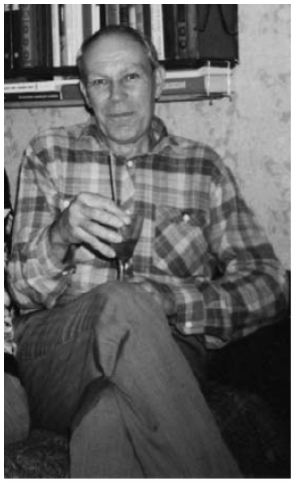
Lebedev Physics Institute

N G Basov

A M Prokhorov

1964 Nobel Prize

"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".



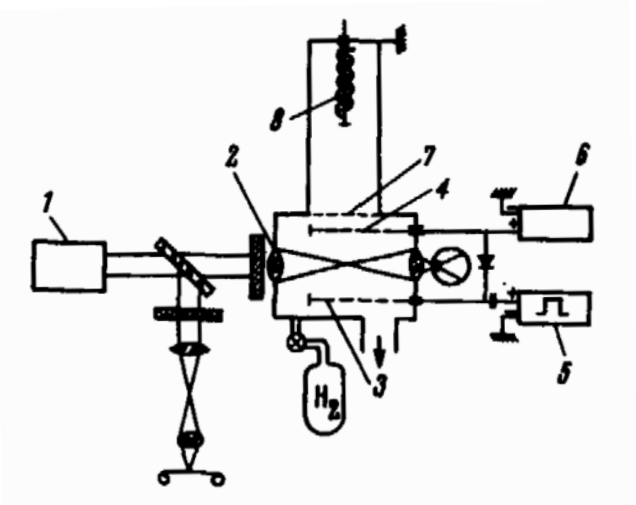
N Delone

L V Keldysh

Ionization of H_2 and rare gases at LPI

MULTIPHOTON IONIZATION OF THE HYDROGEN MOLECULE IN THE STRONG ELECTRIC FIELD OF RUBY LASER EMISSION

G. S. Voronov, G. A. Delone, N. B. Delone, and O. V. Kudrevatova
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 27 August 1965



Le Commissariat à l'énergie Atomique

1945 : By Général de Gaulle soon after WWII.
First "Haut Commissaire": F. Joliot (Chemistry Nobel prize in 1935)

Saclay in the 60's

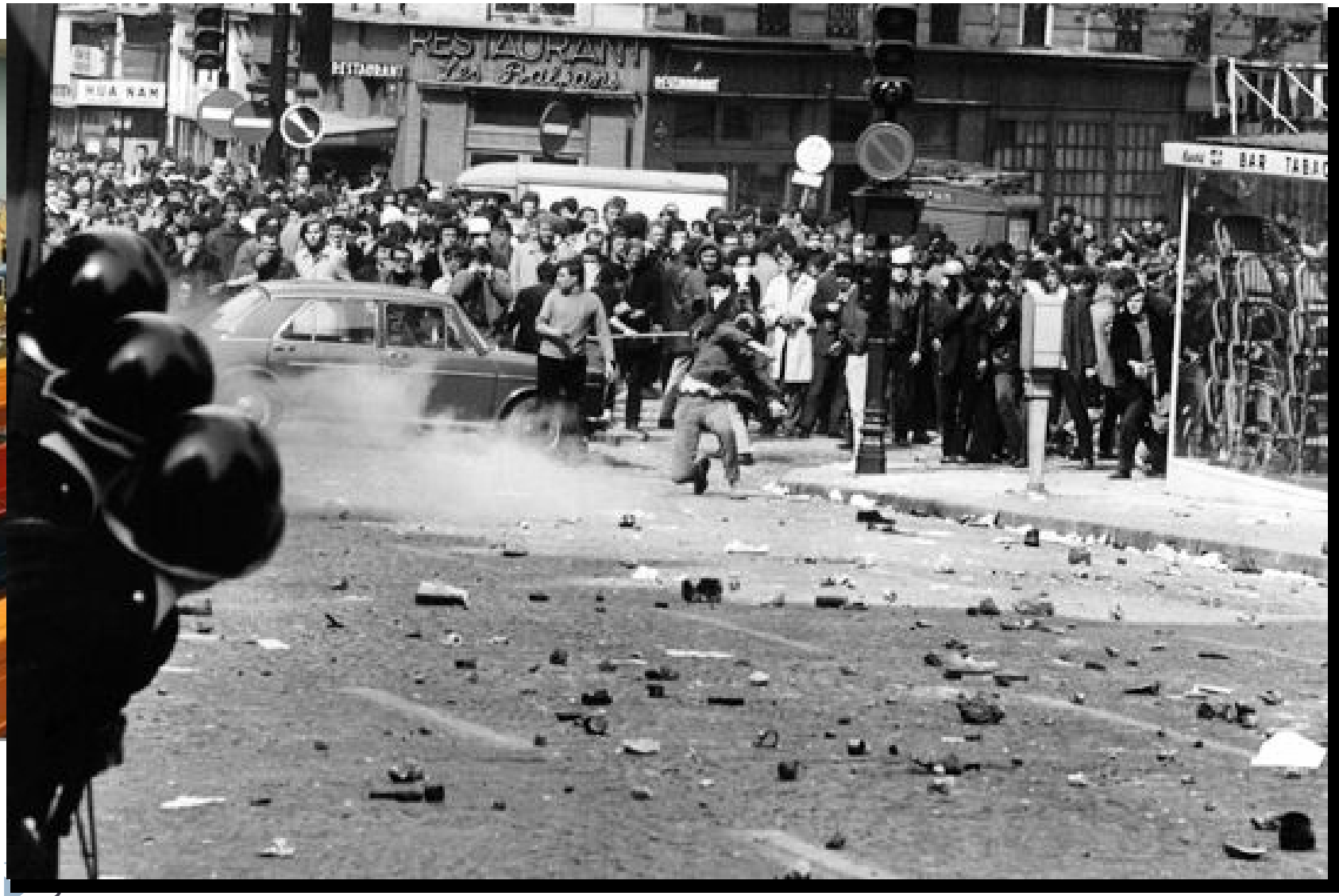
Claude Bloch

Jules Horowitz (1921-1995) débuta sa carrière au Service de physique mathématique ; il fut ensuite directeur des Piles atomiques, puis de la Recherche fondamentale du CEA.

Albert Messiah

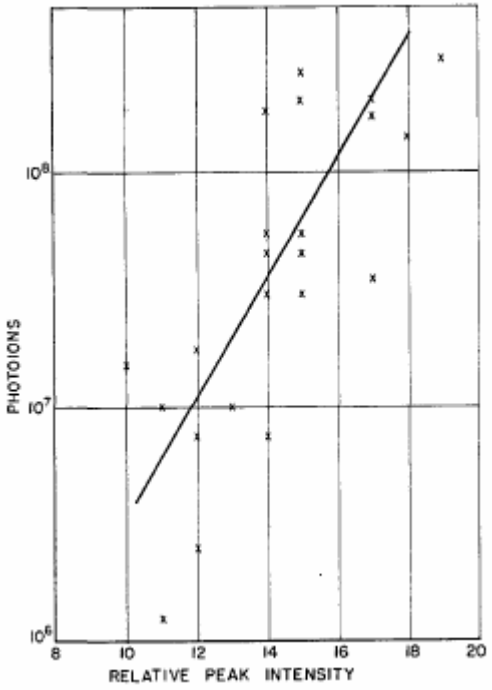
Exciting times

its



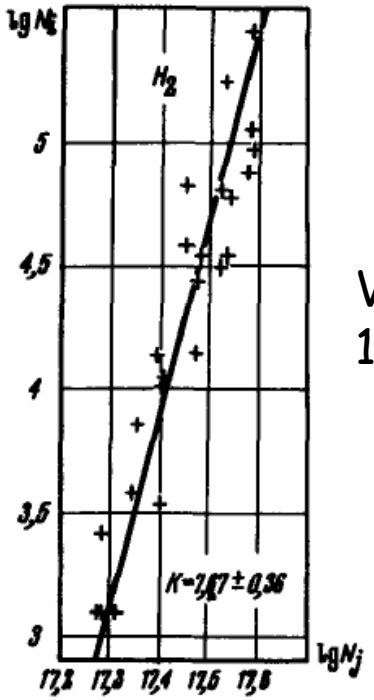
Interpretation depends on paper ruling

Lin-Log



Damon
Appl. Opt.
1963

Log-Log



Voronov JETP
1965

Main trends

THE OHIO STATE UNIVERSITY DEPARTMENT OF PHYSICS

THE
PHYSICAL REVIEW
A journal of experimental and theoretical physics established by E. L. Nichols in 1893
SECOND SERIES, VOL. 143, NO. 1 4 MARCH 1966

Multiphoton Ionization of Hydrogen and Rare-Gas Atoms*†

H. BARRY BEBB‡ AND ALBERT GOLD
Institute of Optics, University of Rochester, Rochester, New York
(Received 8 October 1965)

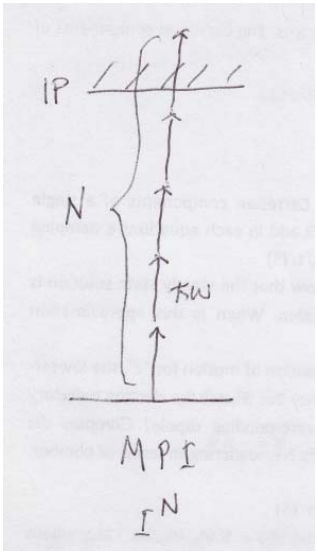
SOVIET PHYSICS JETP VOLUME 20, NUMBER 5 MAY, 1965

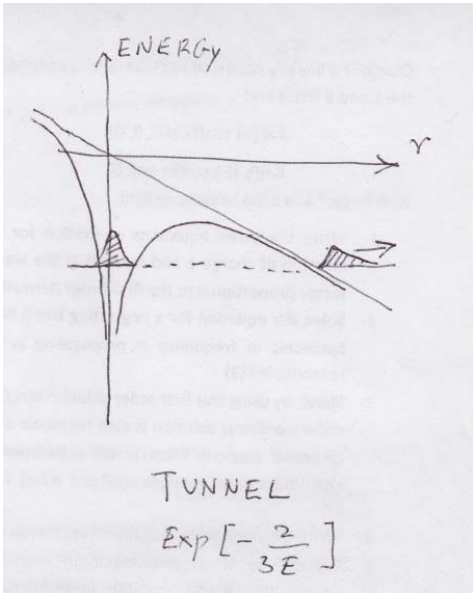
IONIZATION IN THE FIELD OF A STRONG ELECTROMAGNETIC WAVE

L. V. KELDYSH

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor May 23, 1964
J. Exptl. Theoret. Phys. (U.S.S.R.) 47, 1945-1957 (November, 1964)





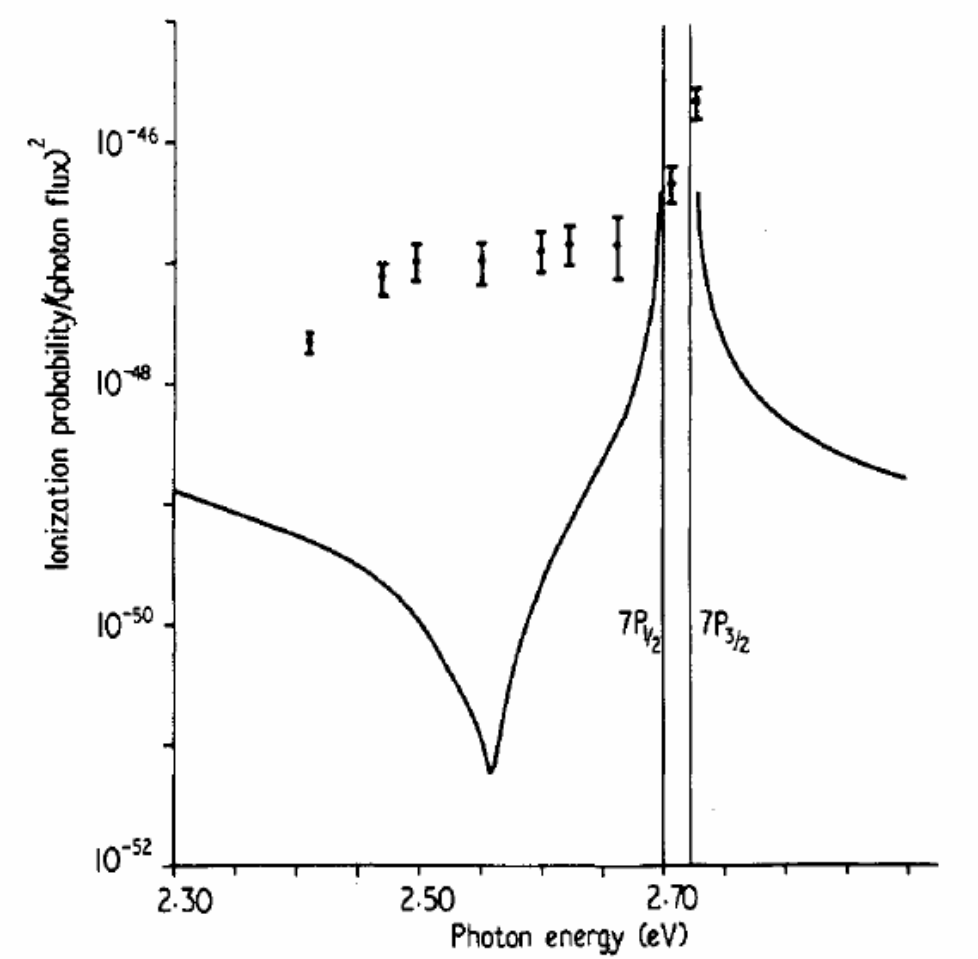
Challengers…

VOLUME 33, NUMBER 16 PHYSICAL REVIEW LETTERS 14 OCTOBER 1974

Focal-Length Dependence of Air Breakdown by a 20-psec Laser Pulse: Theoretical Interpretation through the Effective-Photon Concept

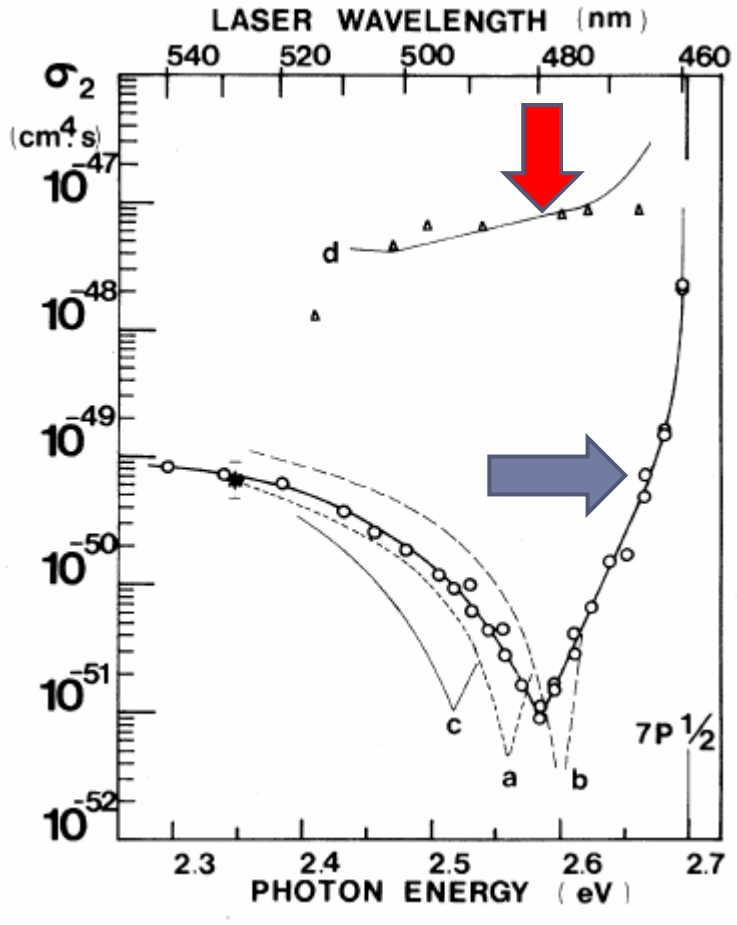
$$\epsilon = h\nu / [1 - \beta_\nu f(I)]$$

Extraordinary findings…



JPB 8, 1617 (1975)

Theory up to experiment!



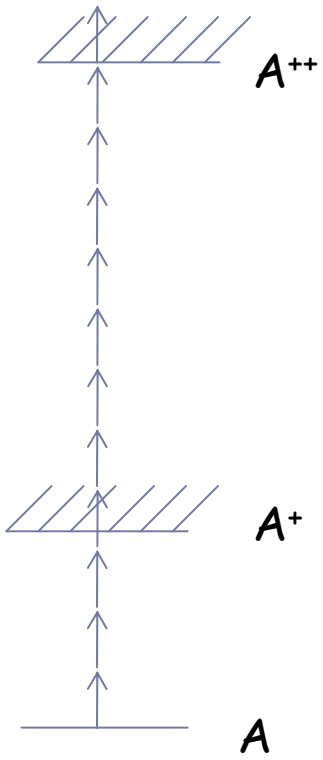
PRL 44, 1394 (1980)

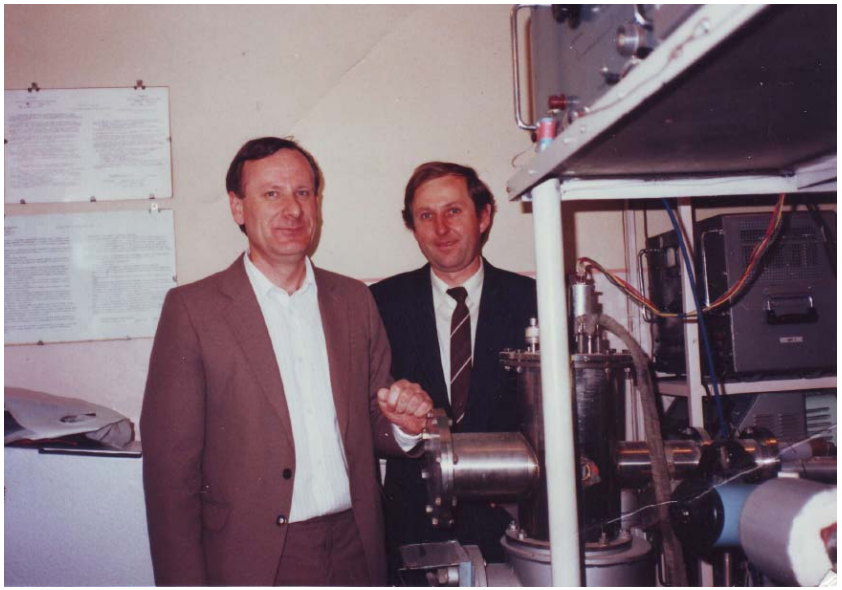
Giant steps in the 80's

The times of…

- Above Threshold Ionization 1979
- Multiple Multiphoton Ionization 1983
- Adiabatic stabilization 1984
- Freeman resonances 1986
- High Harmonic Generation 1987
- Attophysics 2001

Multiple ionization



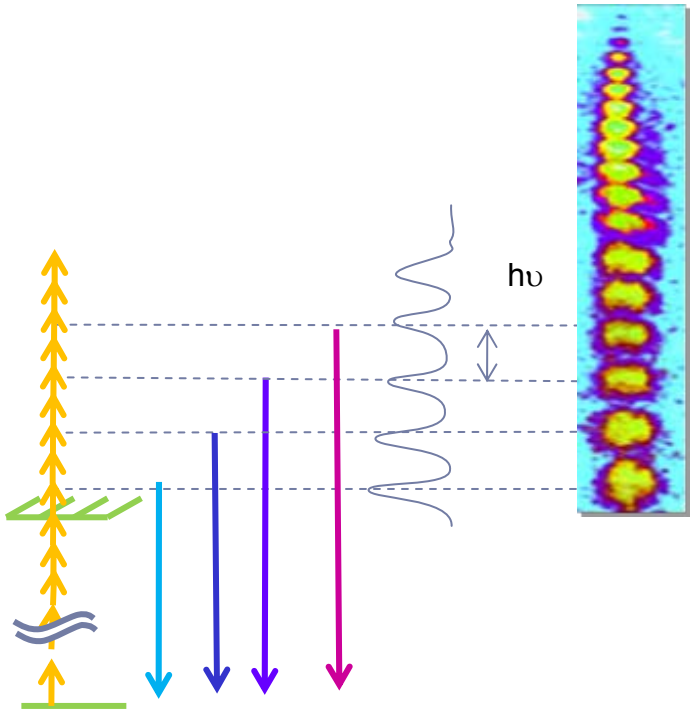


1975

Suran and Zapesnochniy

Extreme Nonlinear Optics

High Harmonics



C K Rhodes
Chicago

Anne L'Huillier
Saclay

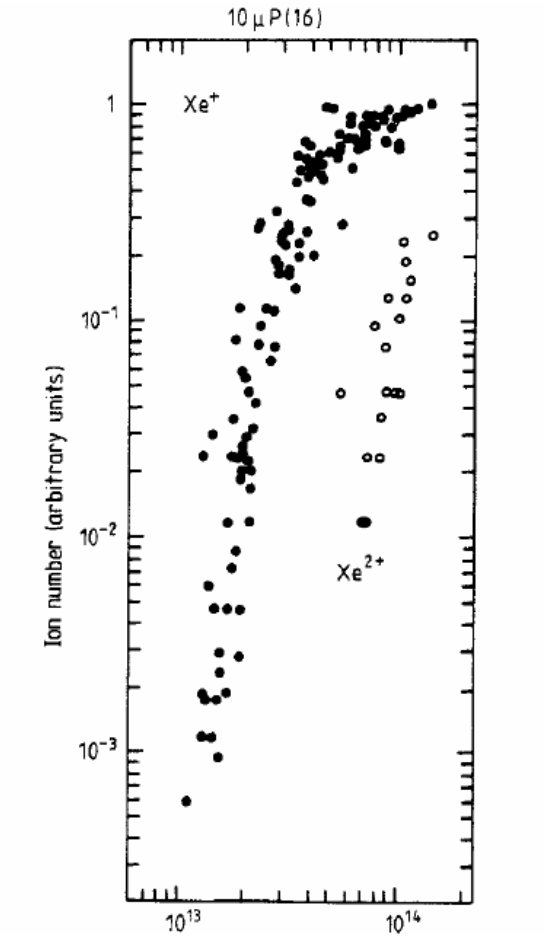
Tunneling

1985

SL Chin

CO_2 laser

1985



CPA

1987

http://spie.org/x41069.xml?ArticleID=x41069

Hard to believe!

1st TW laser at Saclay

2nd part

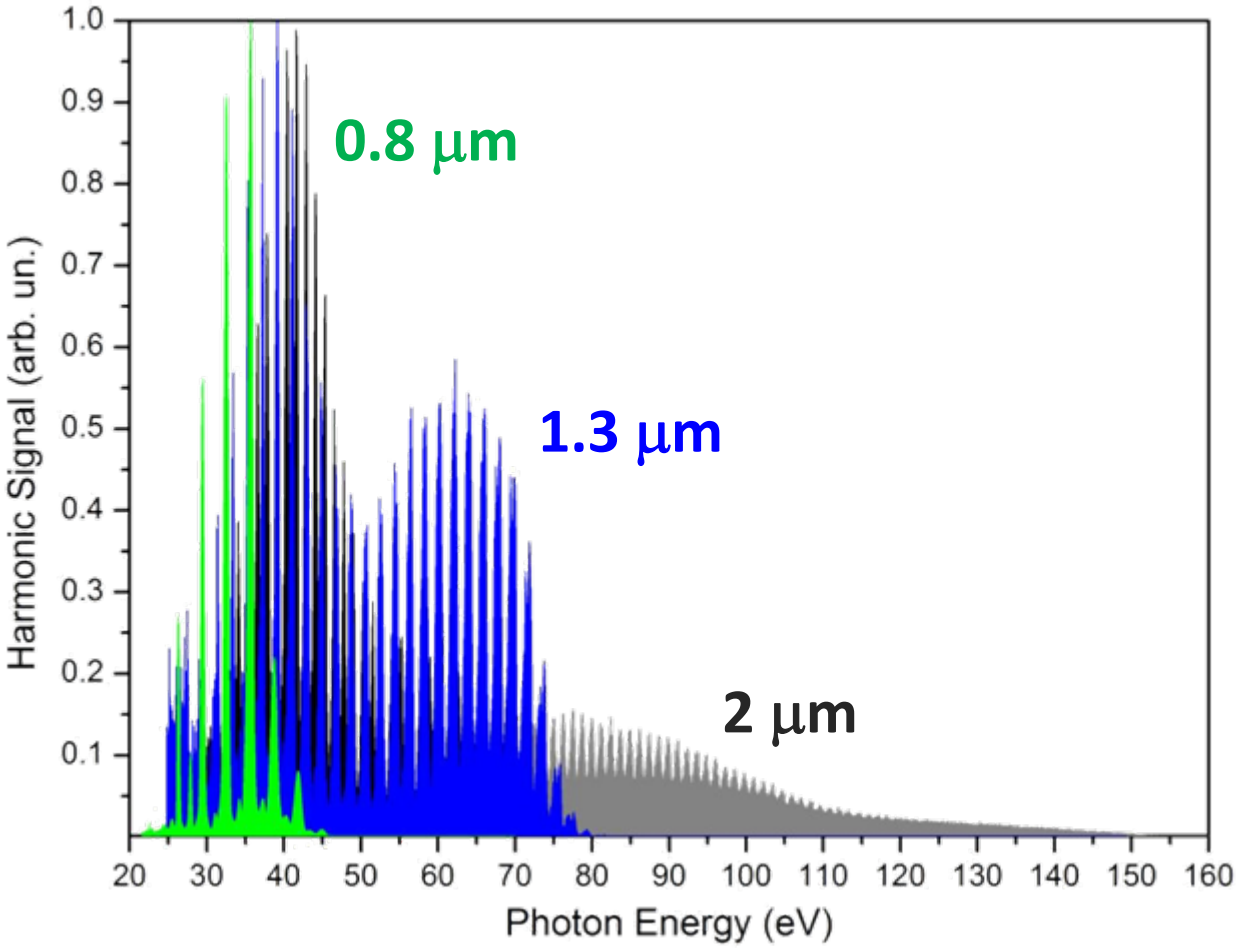
NLO with Mid-Infrared and Xray lasers

Why Mid InfraRed?

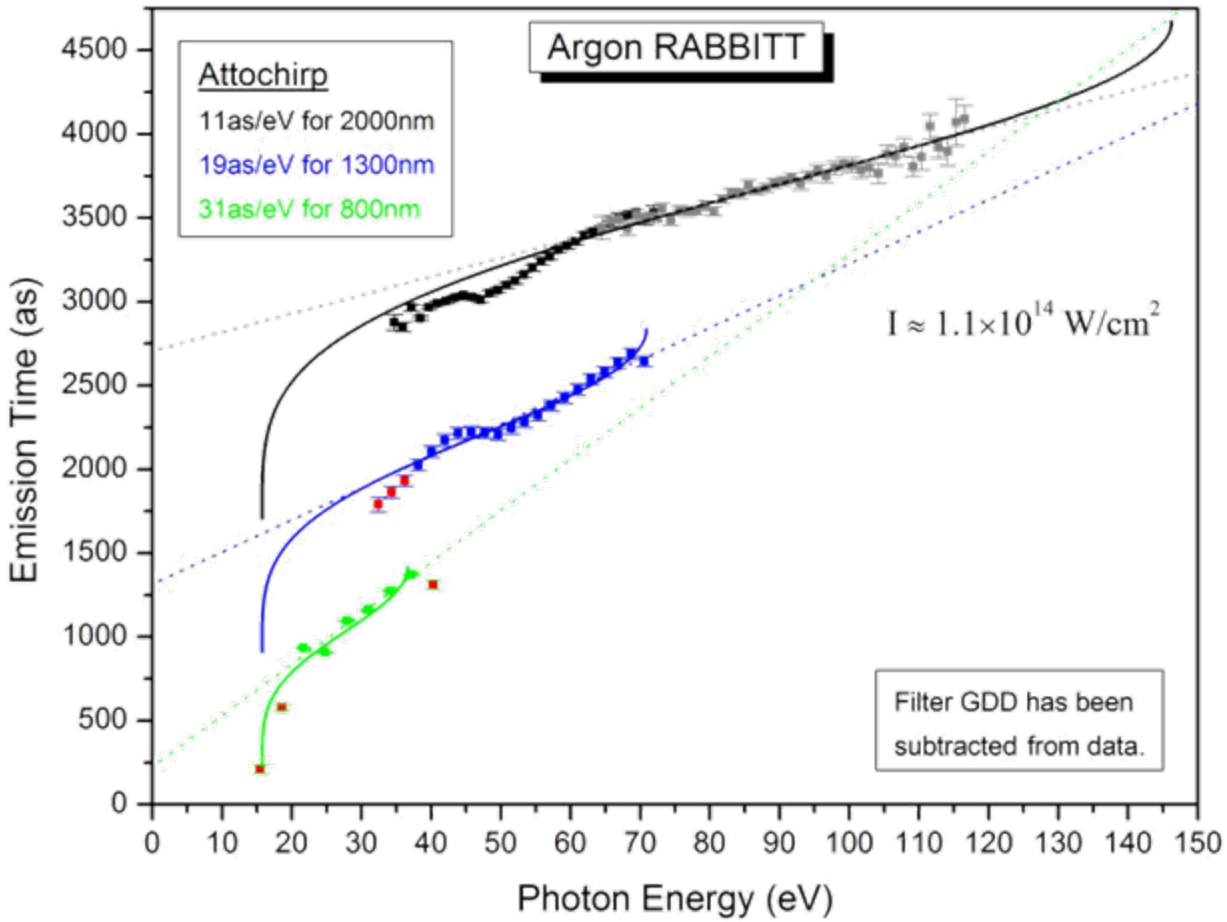
λ^2

OPA
OPCPA
DFG

High Harmonics of MIR lasers



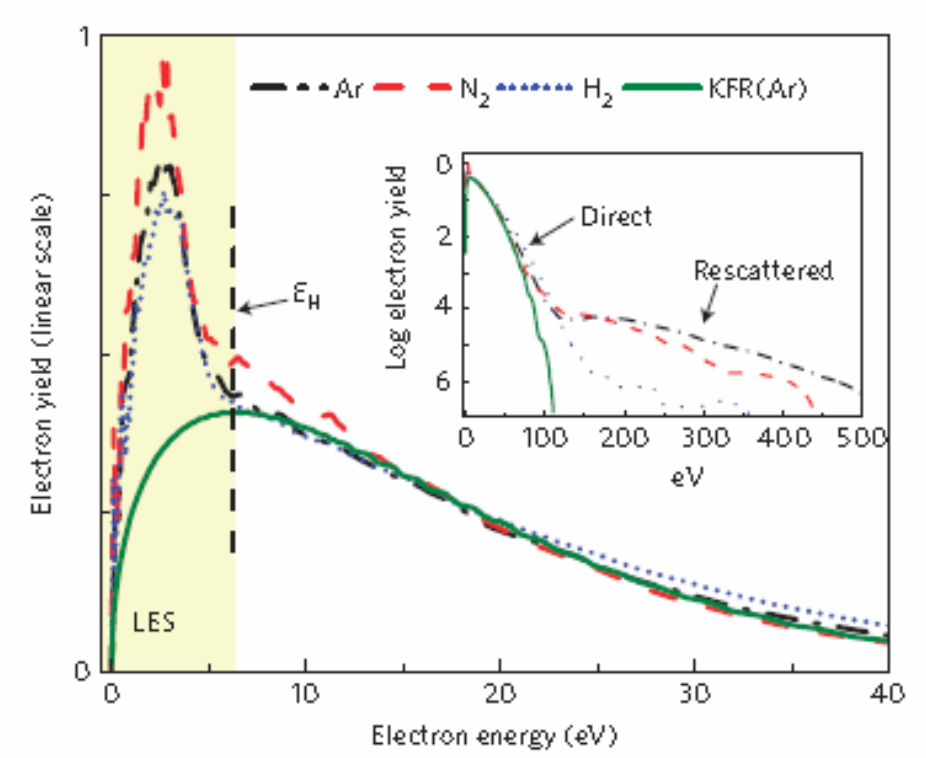
Group Delay Dispersion (RABBITT)



λ^{-1}

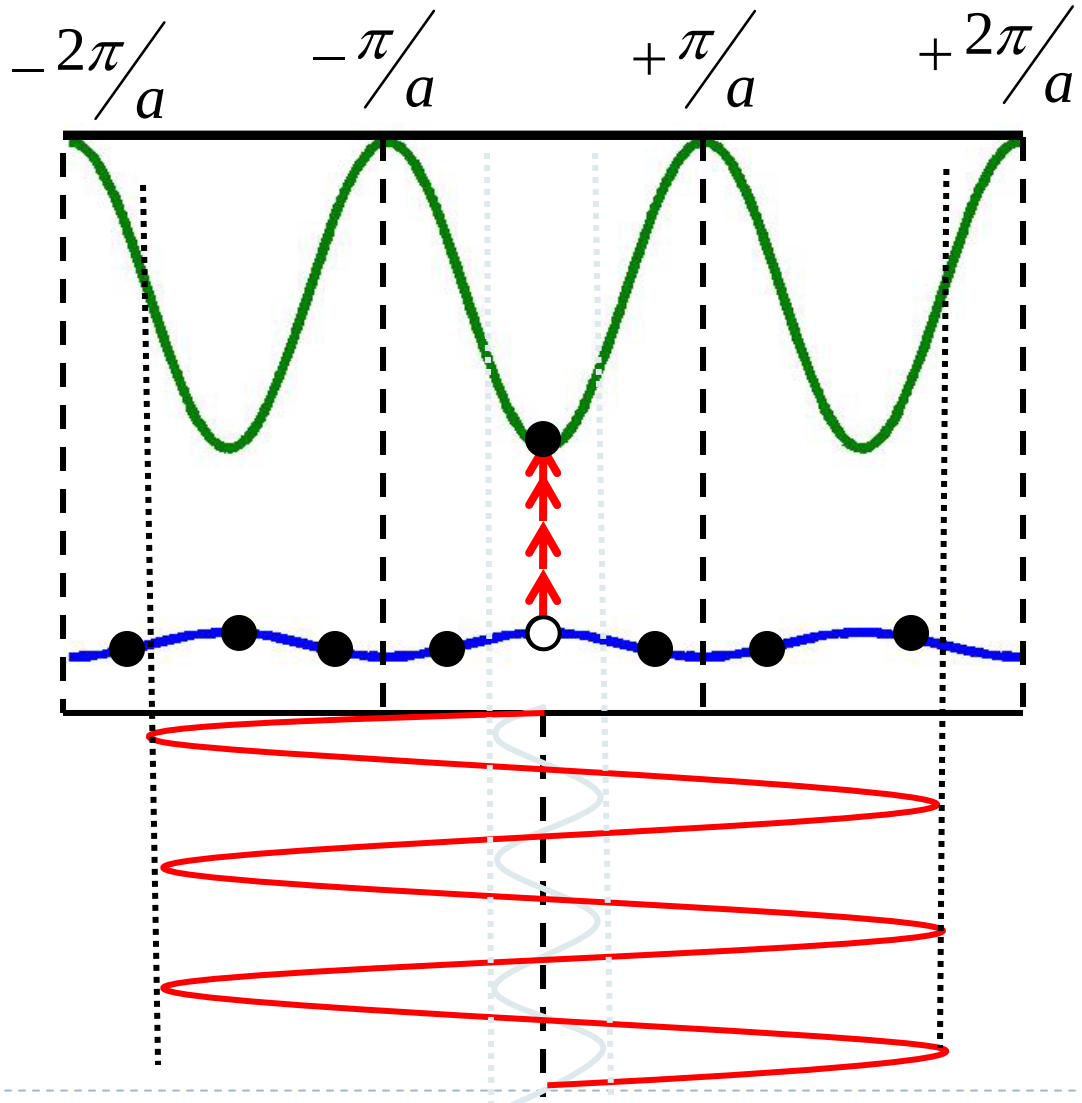
Chirila 2011

A surprise: LES in ATI spectra



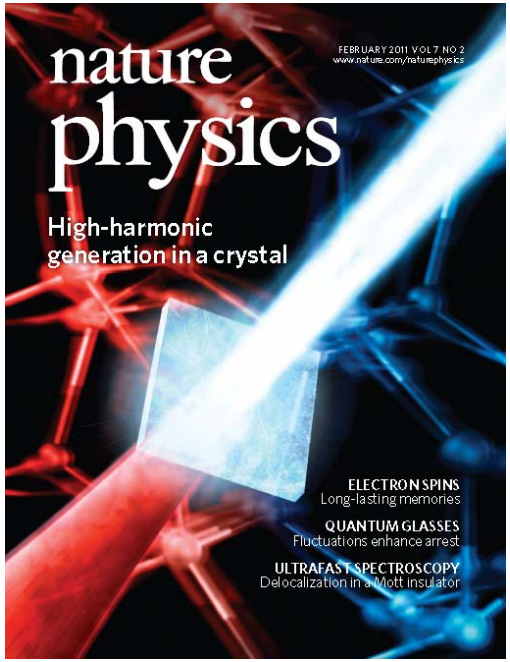
Blaga
Nat. Phys. 5, 335 (2009)

"Bloch" Harmonics

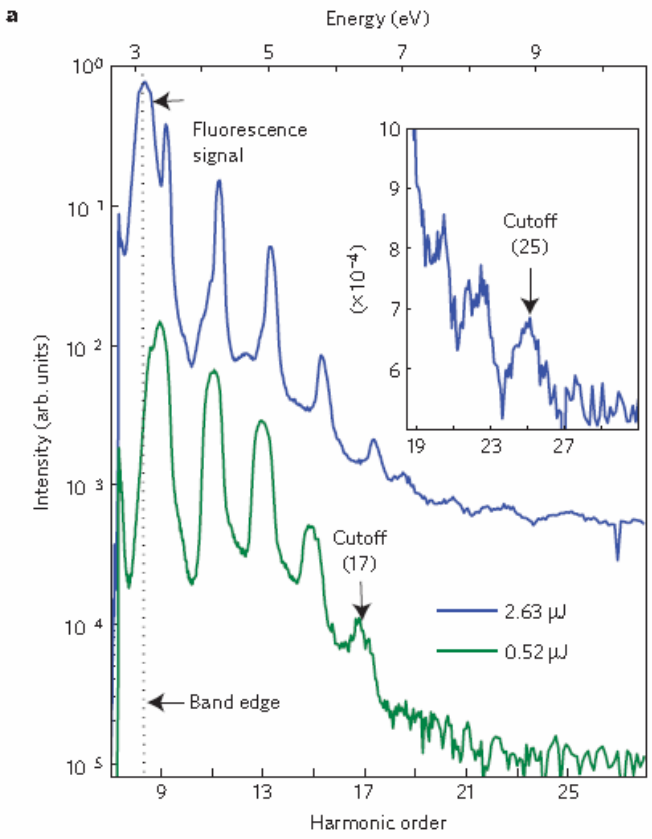


Stanford/OSU experiment

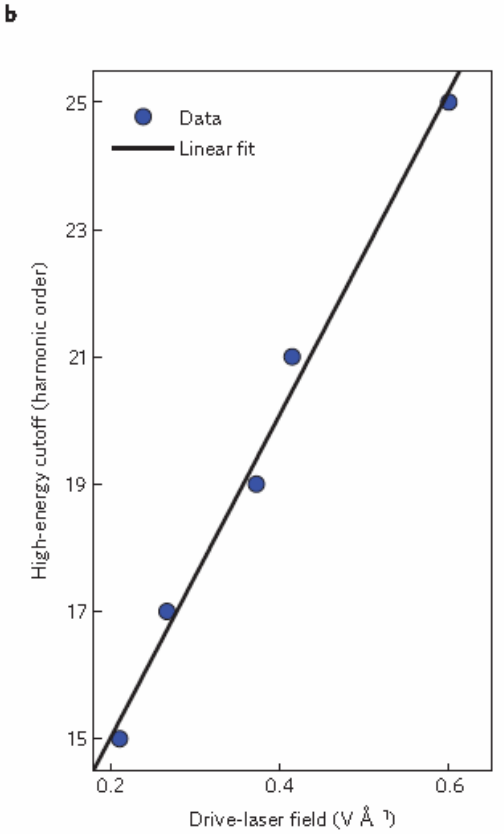
ZnO



S. Ghimire et al. 2011



HH

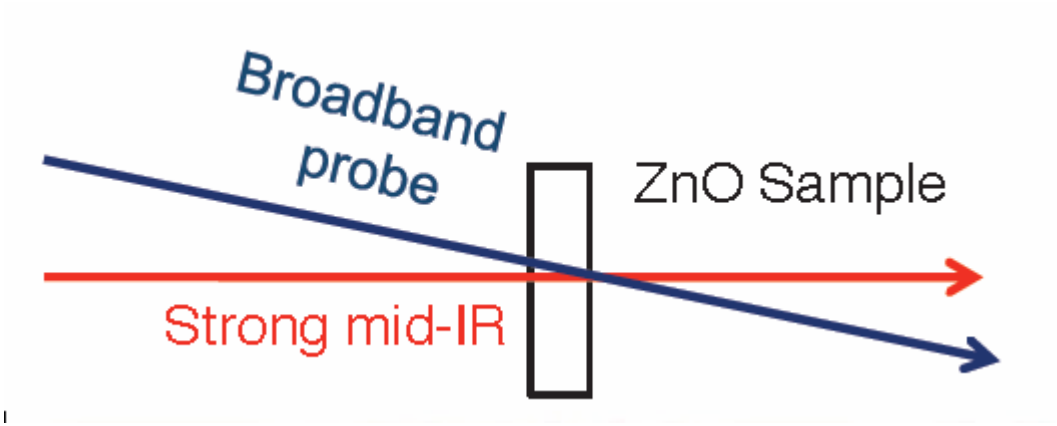


Cutoff □ E

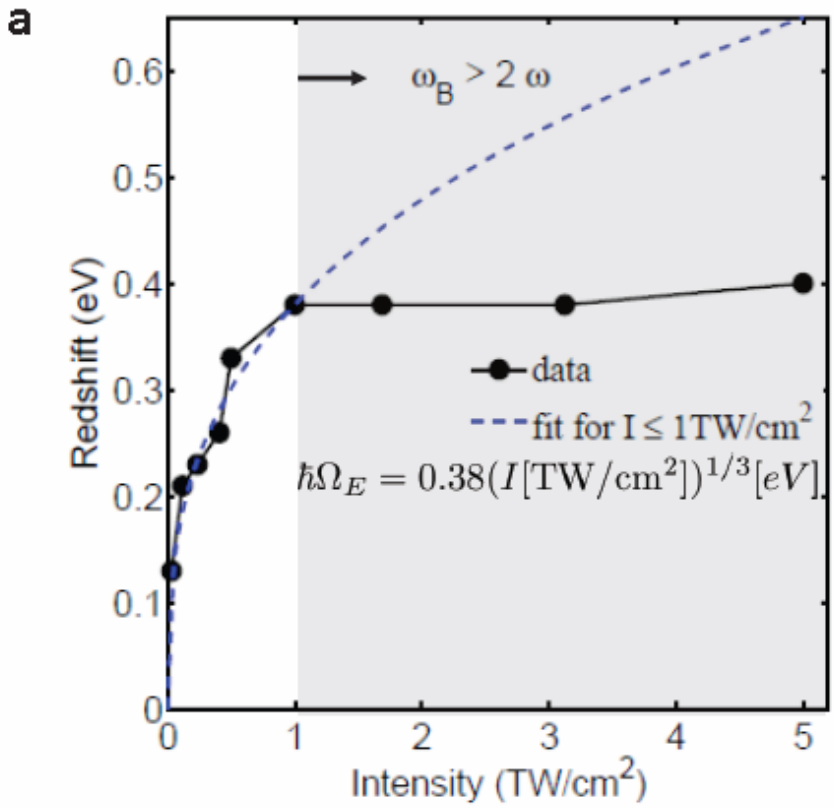
Franz-Kedysh effect

L. Keldysh, J. Exp. Theor. Phys. **34**, 788 (1958).

W. Franz, Z. Naturforsch **13**, 484 (1958).



Franz-Keldysh effect in the MIR



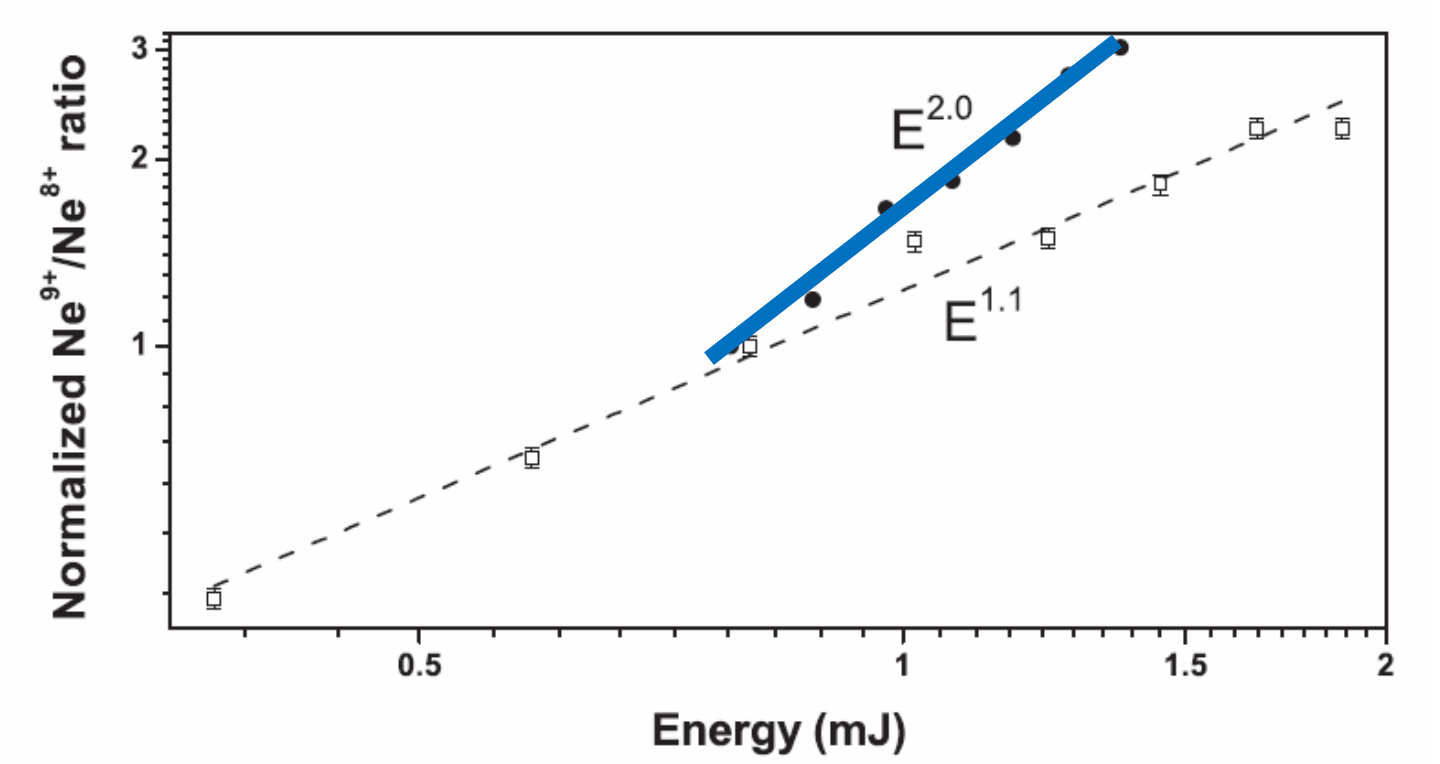
Breakdown! of FK Prediction for I > 1TW/cm^2

S. Ghimire et al. (PRL in press)

LCLS XR FEL

FEL
keV
10^{17} W/cm^2

$Ne^{8+} + 2\gamma \square Ne^{9+}$



Doumy PRL 2011

Xray FELTwo-Photon at SLAC

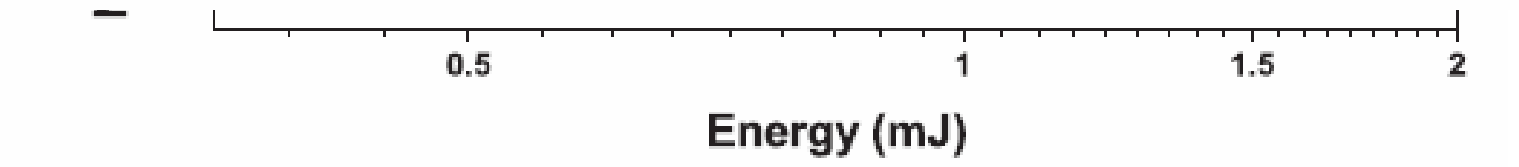
PRL 106, 083002 (2011) PHYSICAL REVIEW LETTERS week ending 25 FEBRUARY 2011

Nonlinear Atomic Response to Intense Ultrashort X Rays

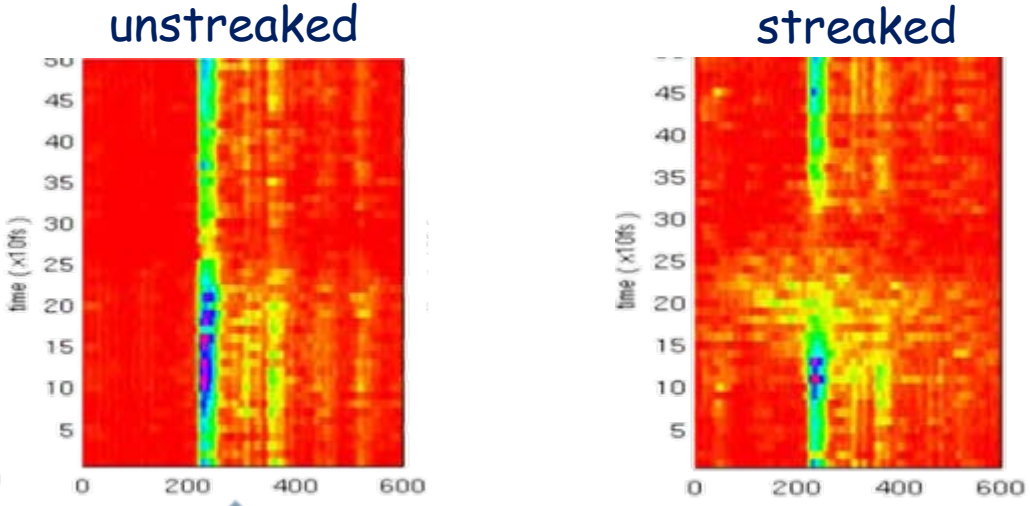
G. Doumy,[1,2] C. Roedig,[1] S.-K. Son,[3] C. I. Blaga,[1] A. D. DiChiara,[1] R. Santra,[3,4] N. Berrah,[5] C. Bostedt,[6] J. D. Bozek,[6] P. H. Bucksbaum,[7] J. P. Cryan,[7] L. Fang,[5] S. Ghimire,[7] J. M. Glownia,[7] M. Hoener,[5] E. P. Kanter,[2] B. Krässig,[2] M. Kuebel,[8] M. Messerschmidt,[6] G. G. Paulus,[8] D. A. Reis,[7] N. Rohringer,[9] L. Young,[2] P. Agostini,[1] and L. F. DiMauro[1]

[1]*The Ohio State University, Columbus, Ohio 43210, USA*
[2]*Argonne National Laboratory, Argonne, Illinois 60439, USA*
[3]*Center for Free-Electron Laser Science, DESY, 22607 Hamburg, Germany*
[4]*Department of Physics, University of Hamburg, 20355 Hamburg, Germany*
[5]*Western Michigan University, Kalamazoo, Michigan 49008, USA*
[6]*Linac Coherent Light Source, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[7]*Stanford PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[8]*Institute of Optics and Quantum Electronics, 07743 Jena, Germany*
[9]*Lawrence Livermore National Laboratory, Livermore, California 94551, USA*

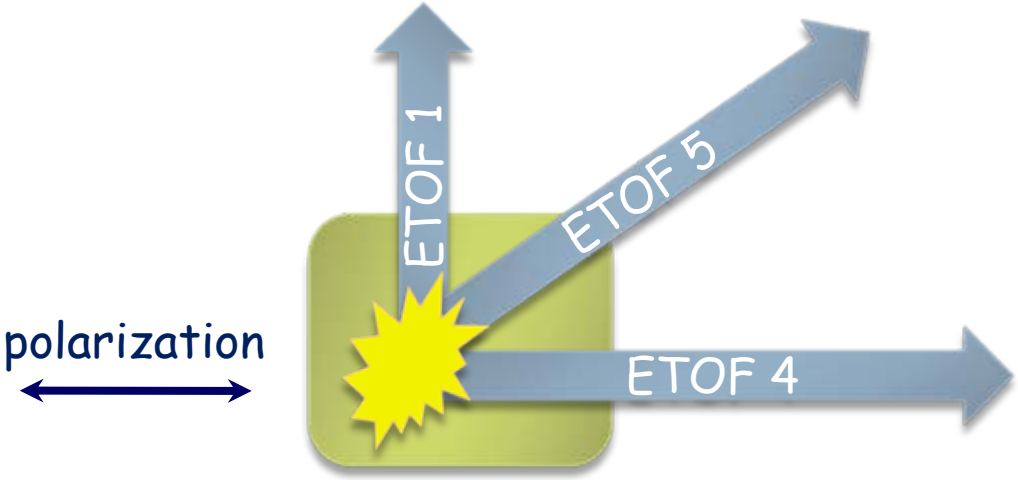
(Received 13 December 2010; published 24 February 2011)



Time-resolved KLL Auger decay in Ne



K,L,L Auger



Acknowledgments

G Mainfray
G Petite
N Rahman
F Fabre
J Morellec
D Normand
A L'Huillier
A.Maquet
Y. Gontier
M Trahin
LA Lompre

...

N Delone
V P Krainov
D T Alimov
M Movssessian
M Fedorov
D Zaretsky
S Fomichev
S Popruzhenko
L V Keldysh
....

And many more…

P Lambropoulos
G. Farkas
J Bergou
M D Levenson
S L Chin
H G Muller
R R Freeman
P H Bucksbaum
J Eberly
H R Reiss
W Becker
H Rottke
...

D Reiss
S Ghimire
L F DiMauro
A DiChiara
E Sistrunk
C Blaga
R Chirila
G Doumy
F Catoire

...

1st experiment on MPI?

Applied Optics

Letters to the Editor

Letters to the Editor should be addressed to the Editor,
APPLIED OPTICS, 1155 16th St., N.W., Washington 6, D.C.

Observation of Ionization of Gases by a Ruby Laser

Antenna Laboratory, Department of Electrical Engineering,
The Ohio State University, Columbus, Ohio.

Jeeebus gets enrolled as the patron saint of O-H-I-O State Buckeyes