Coherent x-ray sources and applications

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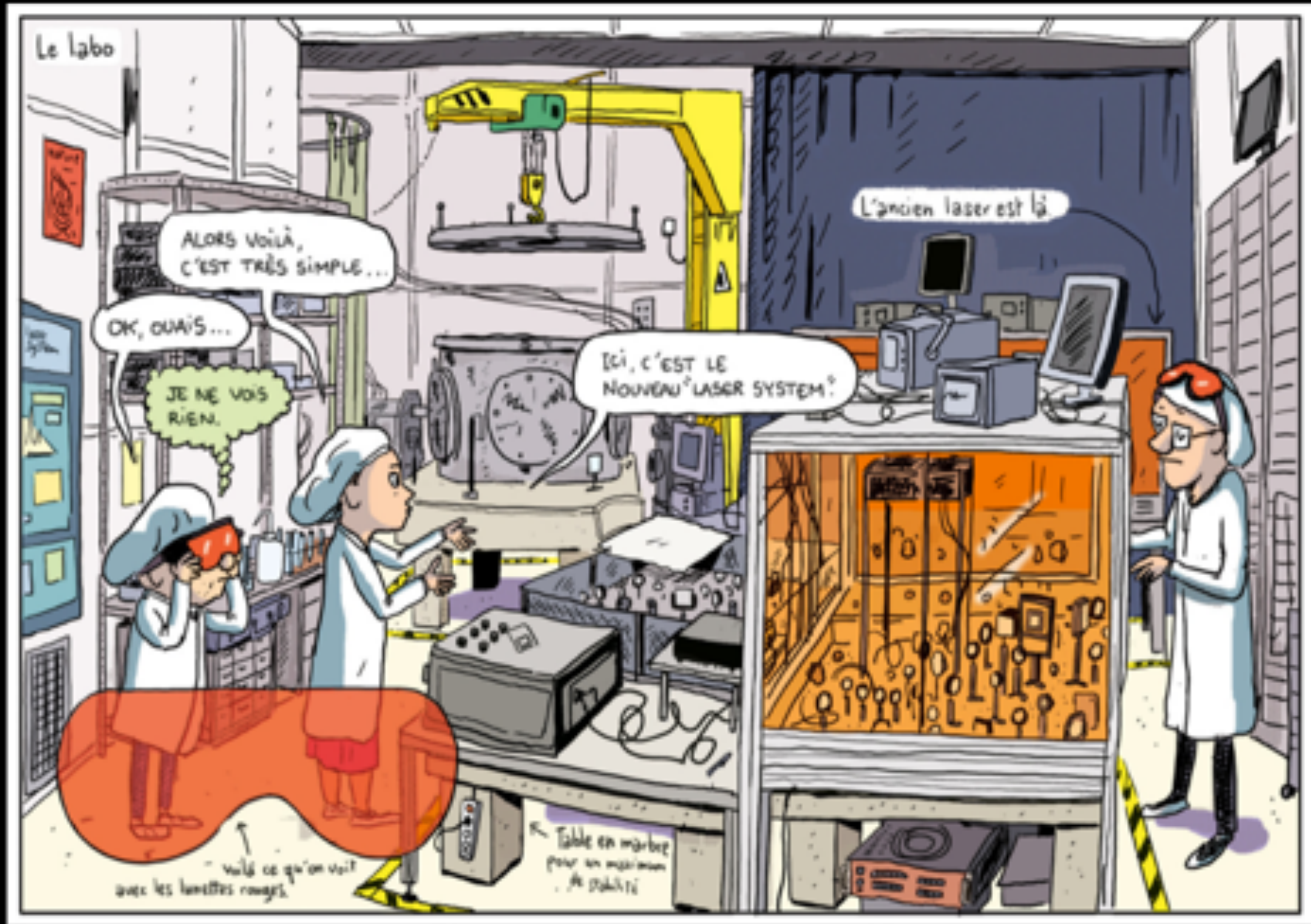


TÉCNICO LISBOA

ipfn
INSTITUTO DE PLASMAS E FUSÃO NUCLEAR

About myself

1992-1997

1996-2001

Claude Chenais
-Popovics &
Tito Mendonça

2001-2003

Philippe Zeitoun

2003-2013

2013-2018

Since 2016

About myself

European Physical Society
Plasma Physics Division

Member of Board, Chair of BPIF Section

EPS Plasma Physics Conferences

eli
eXtreme light infrastructure

ELI ISTAC

CileX Apollon

SAC & TAC

Laserlab Europe

Laserlab JRA LEPP

H2020-FET-VOXEL

VOXEL

TÉCNICO LISBOA

Gender Balance

Contents

1. Goal: Unveiling the dynamics of dense matter

2. High brightness coherent sources

- X-ray Free Electron Lasers
- High Harmonic Generation

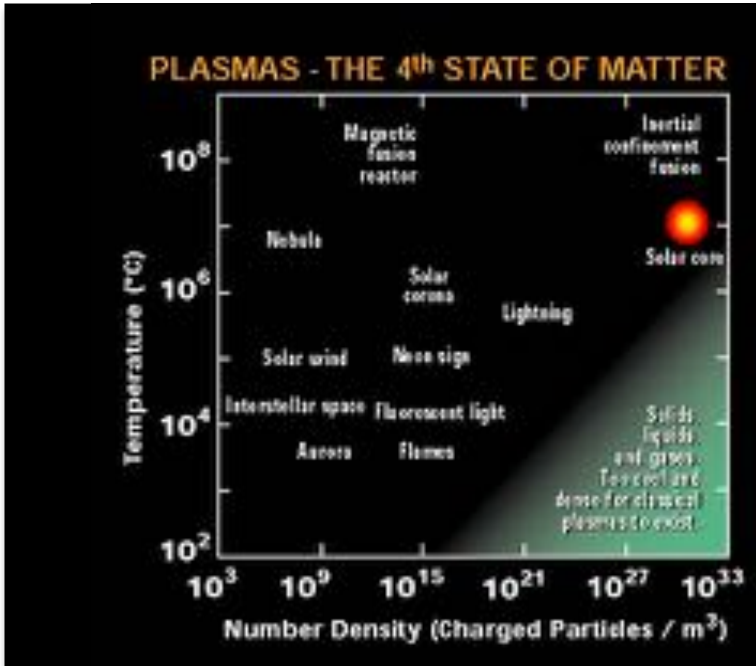
3. Advances in ultrafast imaging and dynamics

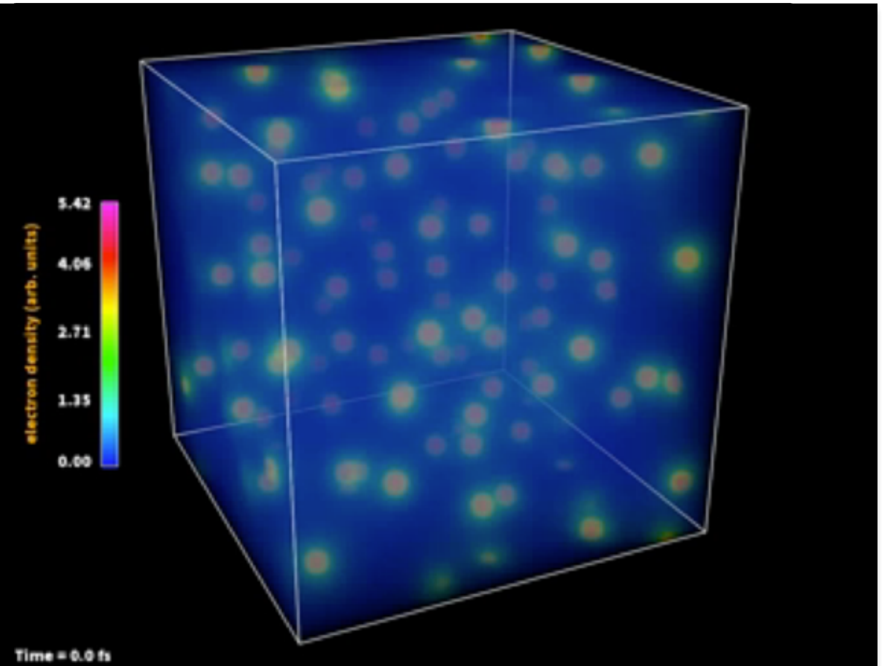
- High resolution imaging: Holography
- High resolution imaging: CDI
- Warm dense matter: Pump and probe

Betatron radiation > Félicie

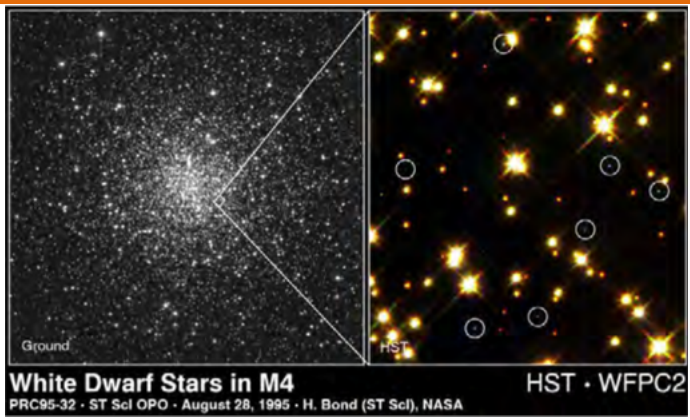
Plasma-based X-ray lasers > old me

21st century challenge: Capturing the dynamics of matter

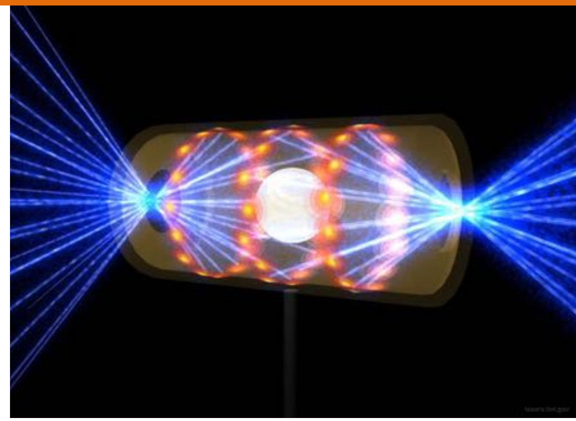




Warm Dense Matter , between cold solid and classical plasma, is difficult to model

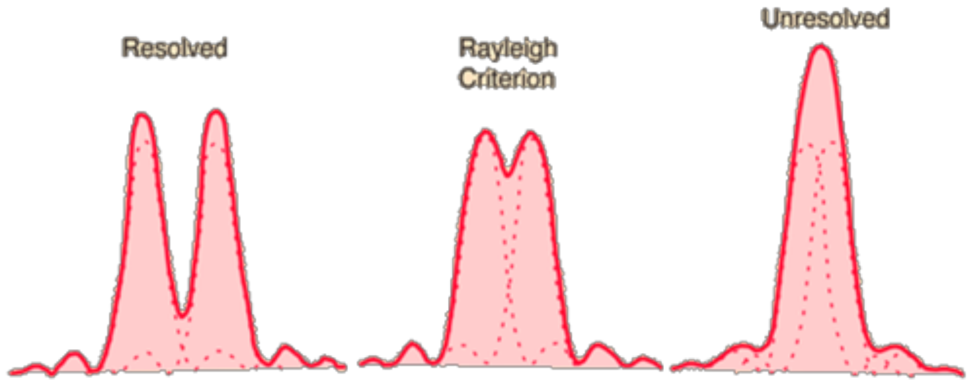


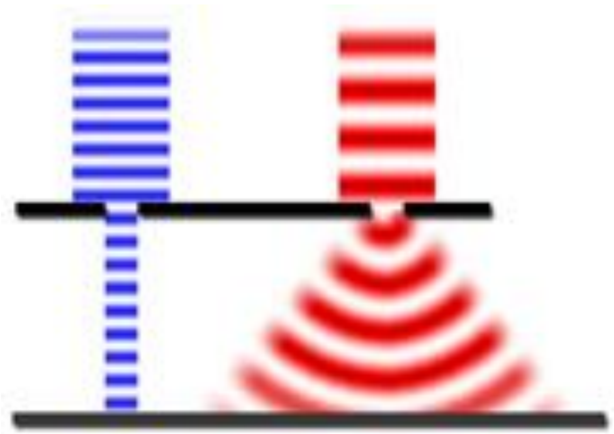
- Giant planets
- White dwarfs
- Inertial Fusion



Physical limit: why do we need X-rays (0)

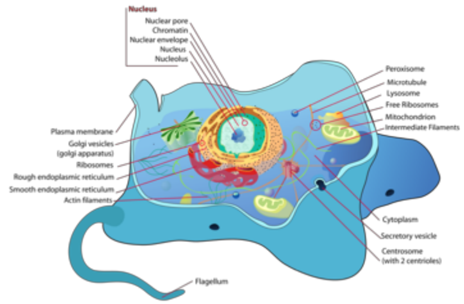
Physical limit: why do we need X-rays (1)



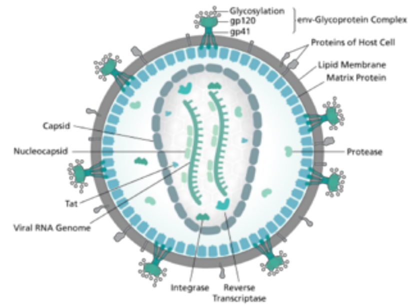


$$d = \frac{\lambda}{2n\sin\theta} = \frac{\lambda}{2NA}$$

Abbe diffraction limit



Animal cell >1µm

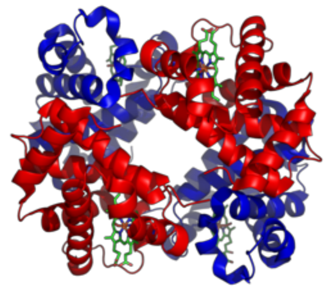


Aids virus ~120nm

Minimum resolvable feature size

For visible light diffraction limit: 200nm-400nm

Hemoglobin protein ~5nm

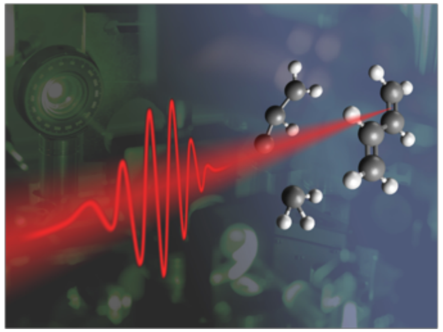


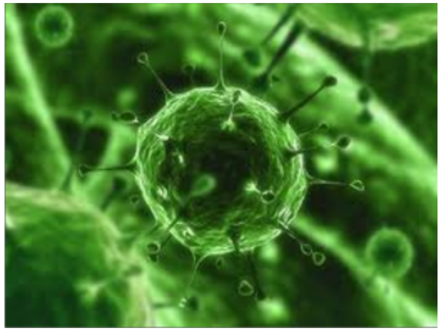
Physical limit: why do we need X-rays (2)

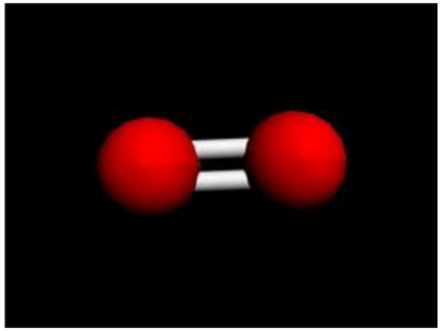
Timescales of laser pulses and related phenomena

1 μs	strobe light flash	10^{-6} s	0.3 km
1 ns	molecular fluorescence	10^{-9} s	0.3 m
1 ps	world's fastest transistor	10^{-12} s	0.3 mm
1 fs	world's fastest laser	10^{-15} s	0.3 μm
1 as	shortest measurable time	10^{-18} s	0.3 nm

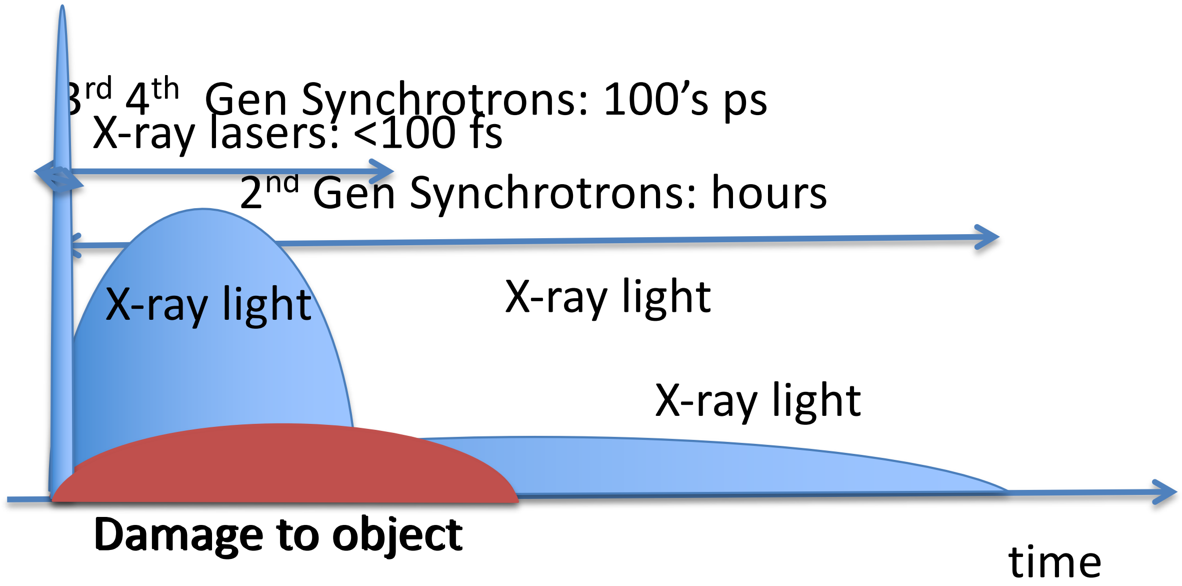
(age of the Universe ≈ 0.43×10^{18} s)



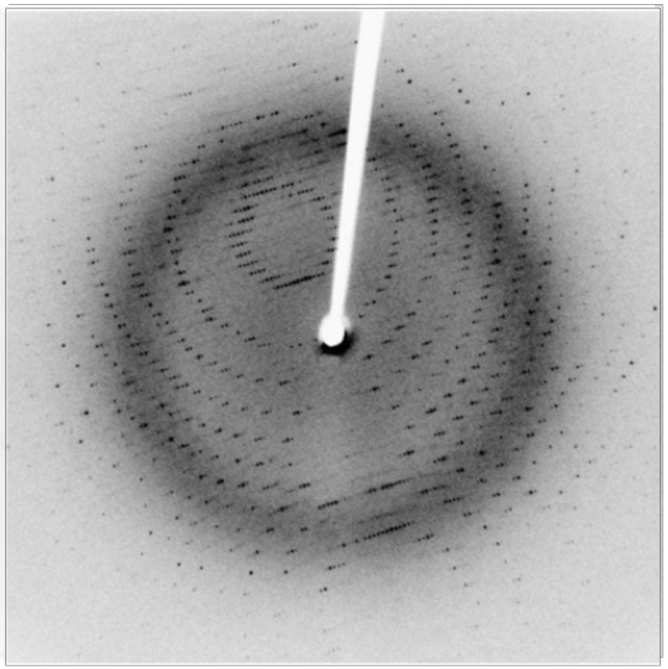




Physical limit: why do we need **coherent** X-rays (3)

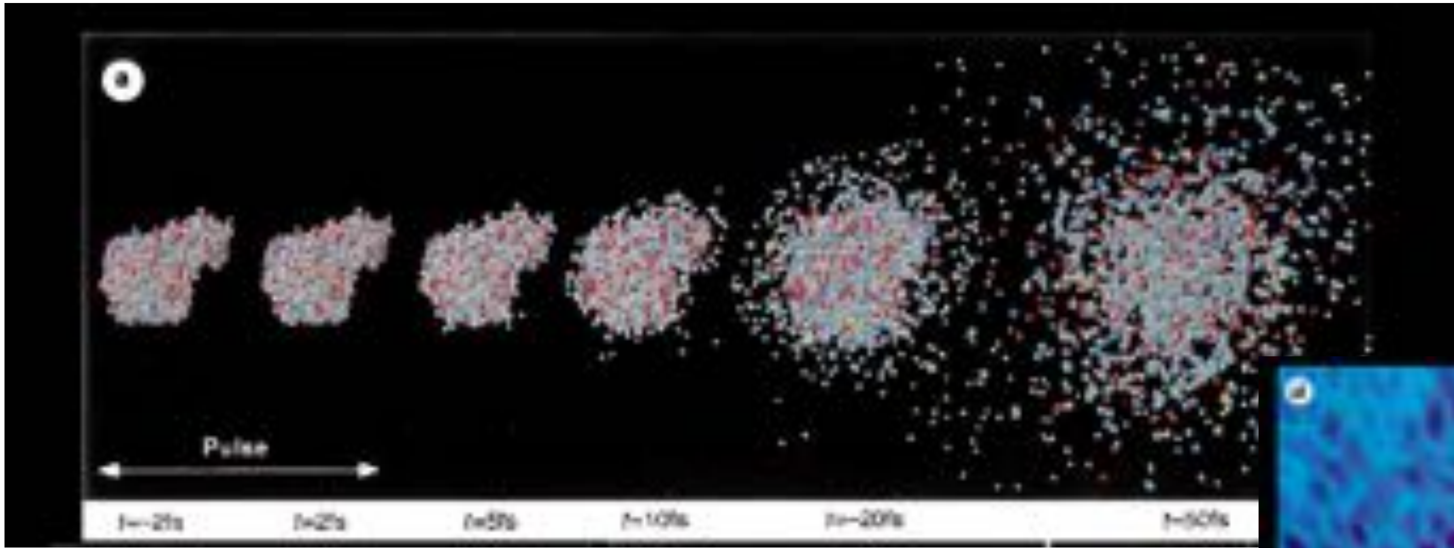


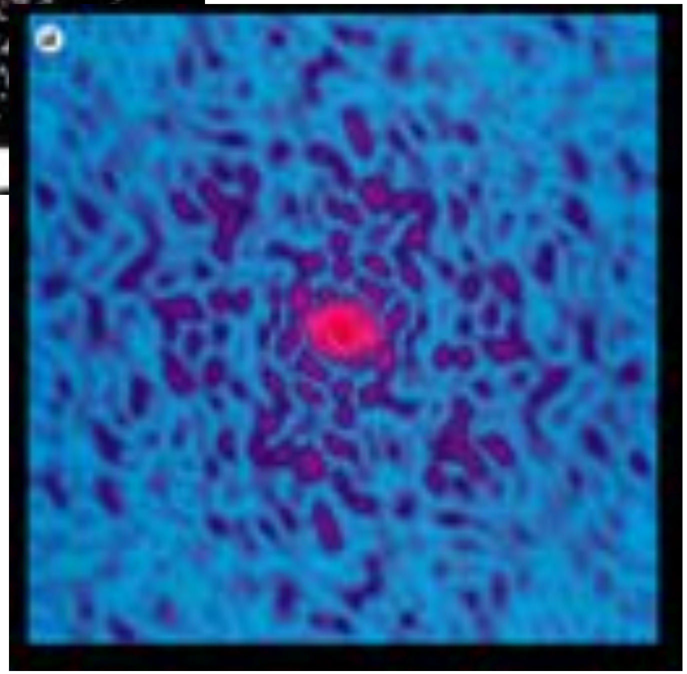
10^{12} X-ray photons are needed to take this picture

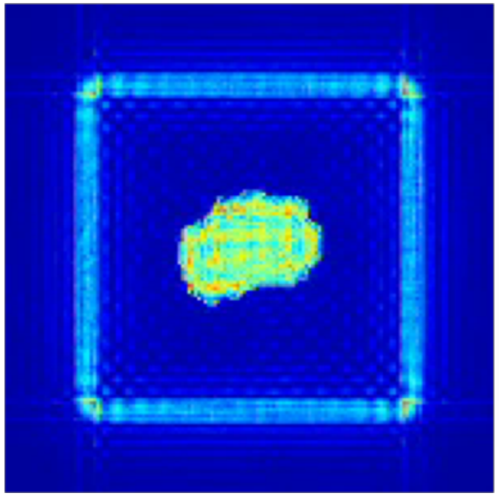


A revolution in structural biology

Neutze, Nature 406, 752 (2000)



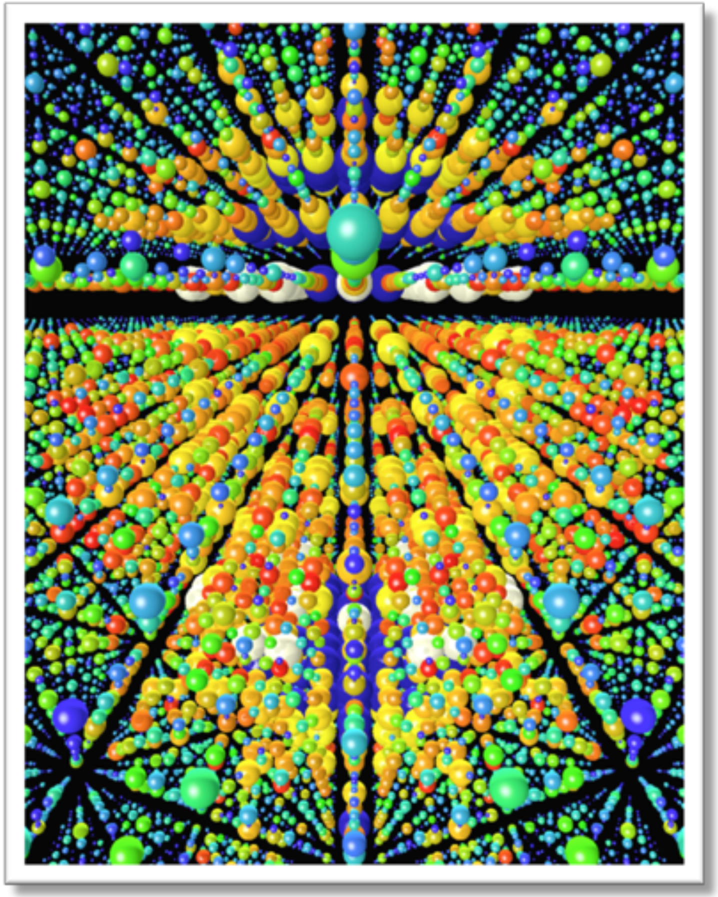




Hajdu, Nature Physics 2008

A revolution in structural biology

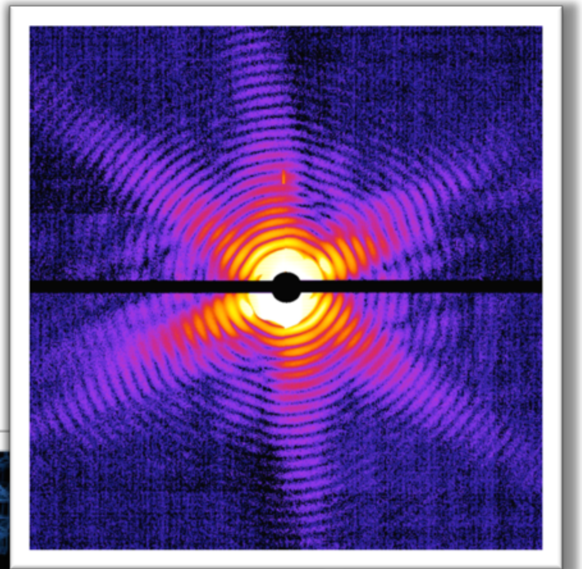
Siebert et al, Nature, February 2011

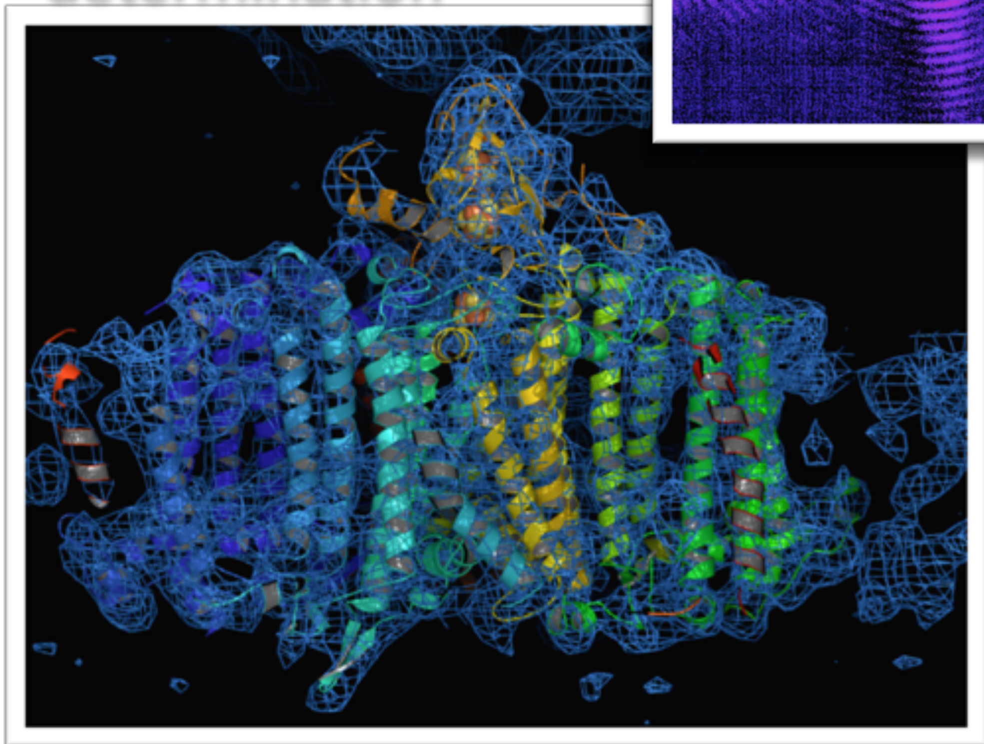


Single-shot Mimivirus

et al, Nature, February 2011

Single-crystal nanocrystal structure determination

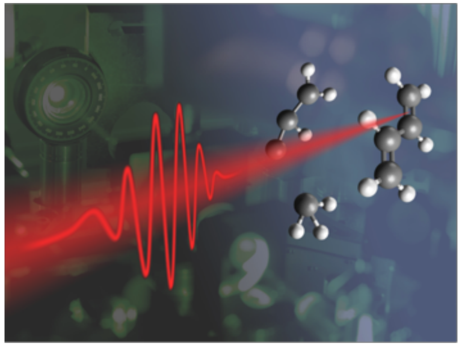




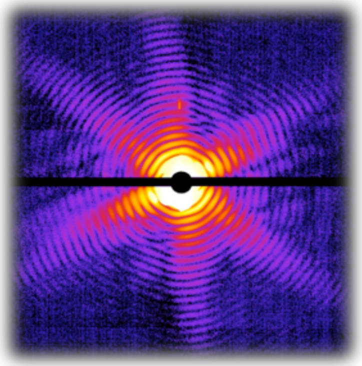
The ideal X-ray source

Hard wavelength

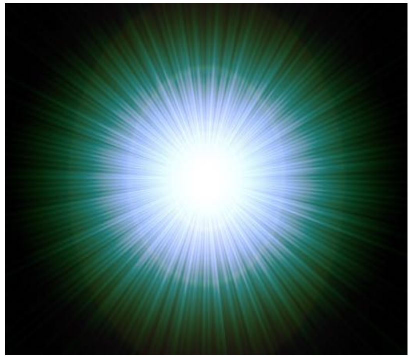
Ultra-short



Coherent

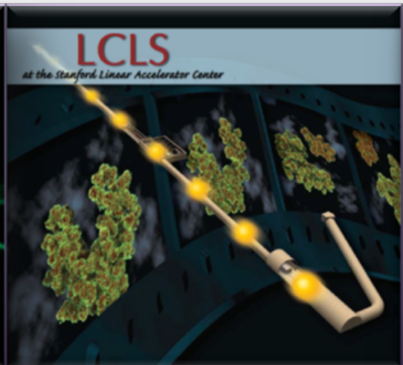


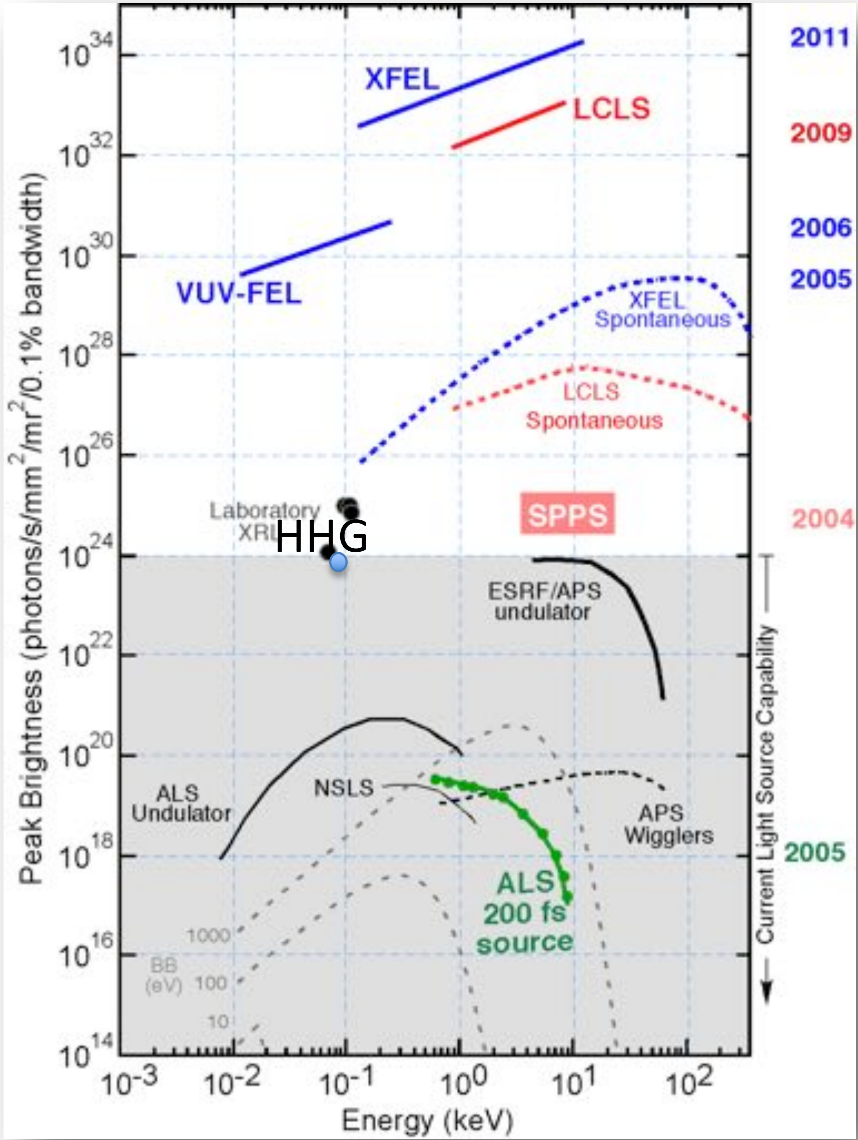
Bright



The 21st century has seen the birth of X-ray Free Electron Lasers

- FLASH, XUV (DESY, Germany): 2003
- LCLS (SLAC, USA): 2009
- FERMI(ELETTRA, Italy): 2011
- SACLA (Japan): 2012
- XFEL (DESY): 2017





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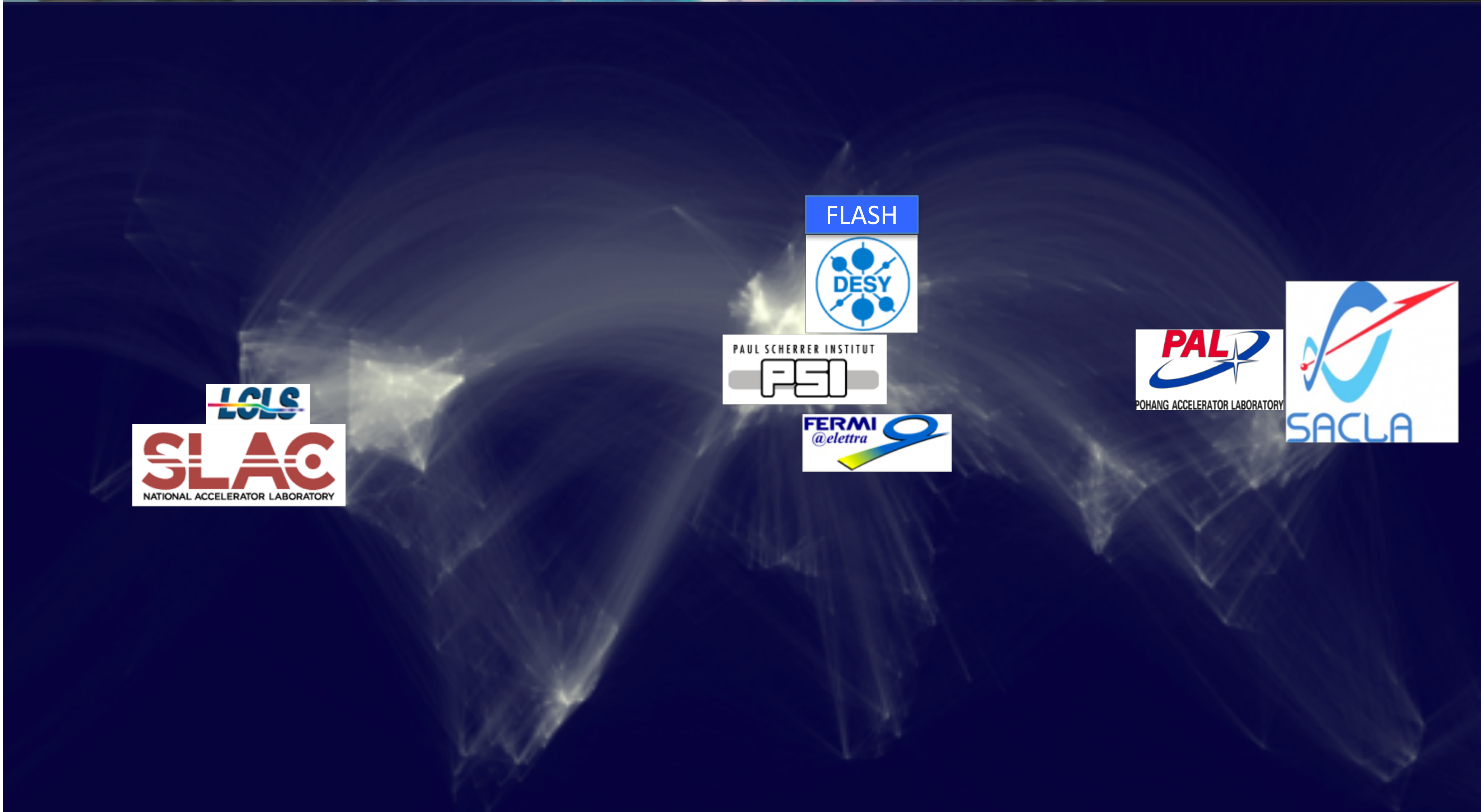
Experiments performed in large scale facilities

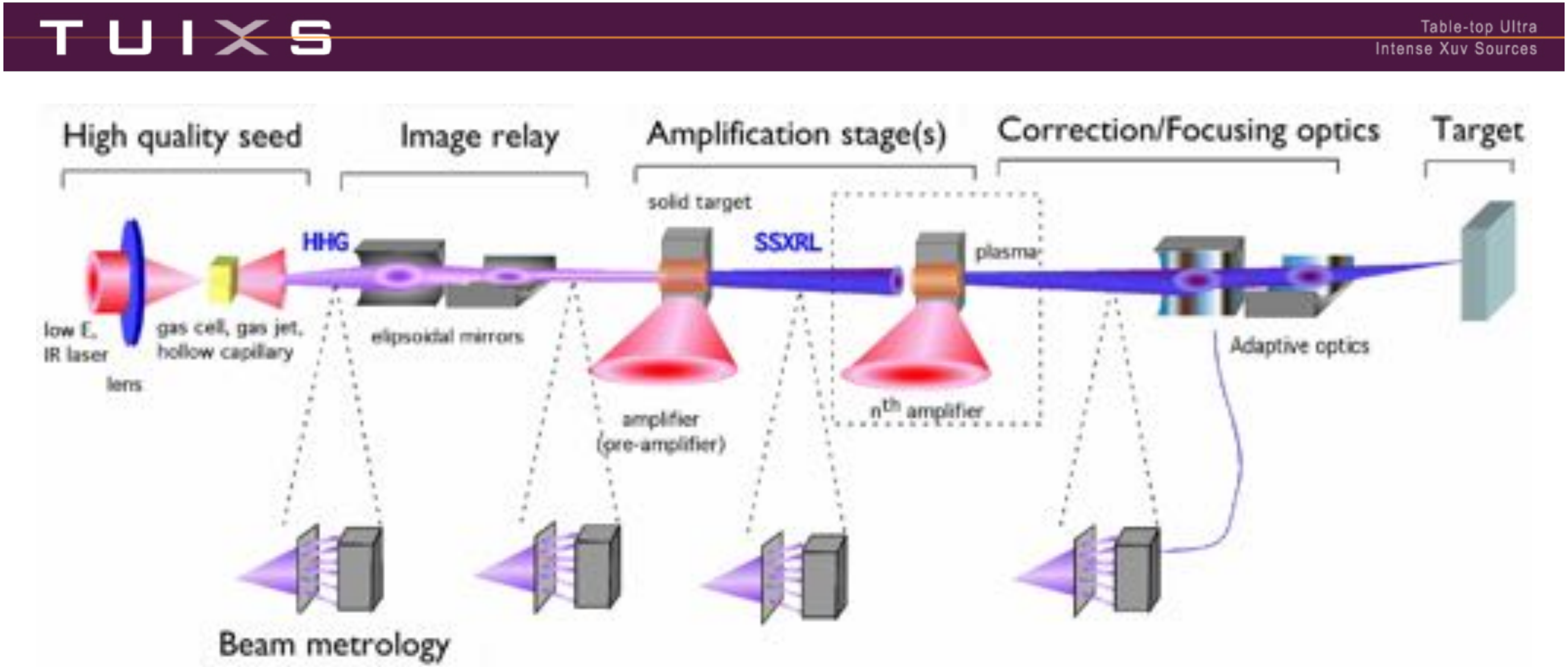


Map of scientific collaborations from 2005 to 2009
Computed by Olivier H. Beauchesne @ Science-Metrix, Inc.

Our team has been working on development of brighter X-ray lasers

We proposed using HHG to seed an XRL, overcoming noise

Zeitoun et al, Nature 2004 : first demo of seeded X-ray laser
E Oliva, M Fajardo et al, Nature Photonics 2012: proposal for CPA with plasma amplifier
Zeitoun, Fajardo & Lambert, Nature Photonics 2010: seeded FELs

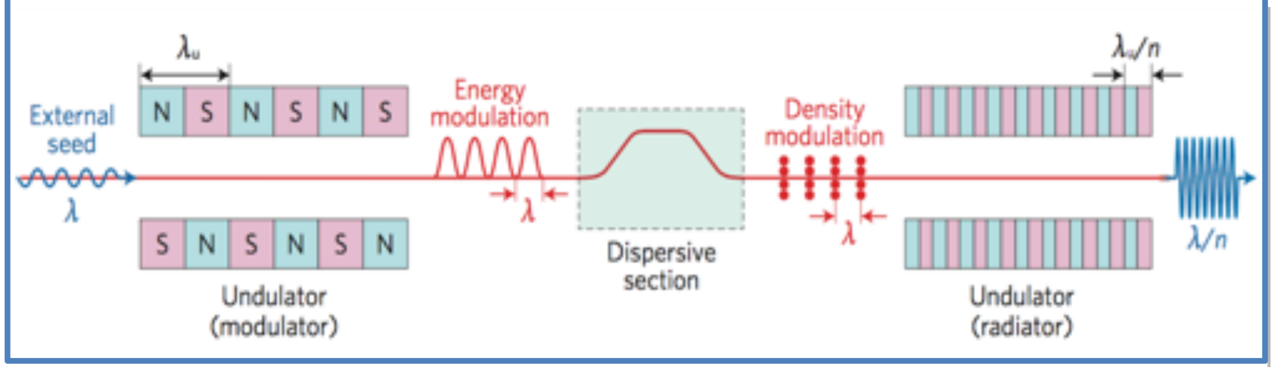


FERMI: a seeded Free electron laser

Basics

- Bunch of electrons accelerated
- Modulation in energy along the bunch
- Energy modulation is translated into electron density modulation
- Forming of micro bunching and coherent emission in undulator

Seeded FEL



Seeded FEL pulse duration

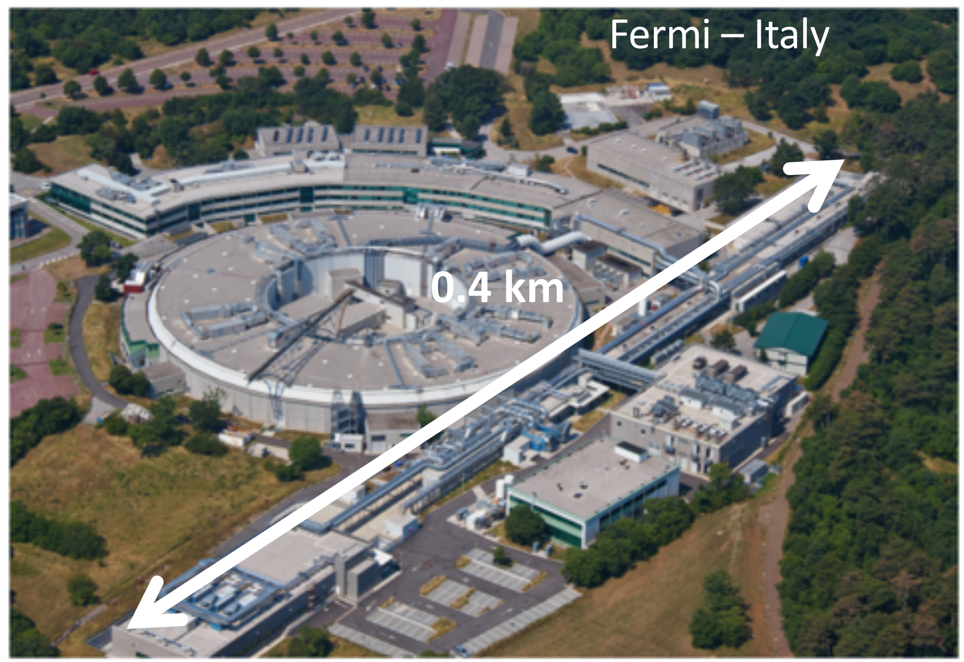
In standard seeded FEL operation the FEL pulse duration and seed pulse duration are correlated by

$$\Delta t_{FEL} = n^{-1/3} \Delta t_{seed}$$

Using a chirped seed increases the FEL bandwidth.

$$\Delta t_{FEL}^{CPA} = n^{-2/3} \Delta t_{seed}^{FT}$$

- XUV compressor for achieving a FT limited FEL pulse
- **Implantation of chirped-pulse amplification at an FEL**
- Experiment to demonstrate the two different regimes of operating an FEL with XUV compressor



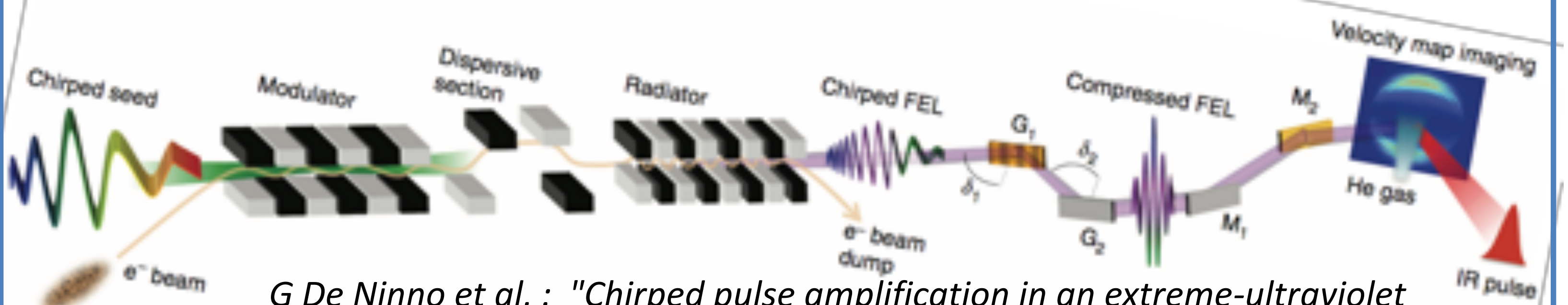
Free electron laser - Results

Goals

-Higher peak power and temporal resolution

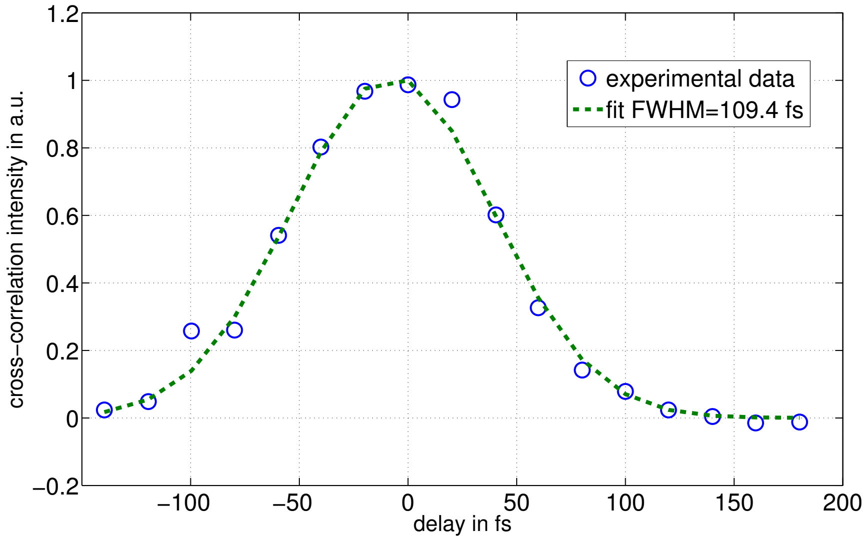
- Shorten FEL pulse duration

Experimental setup



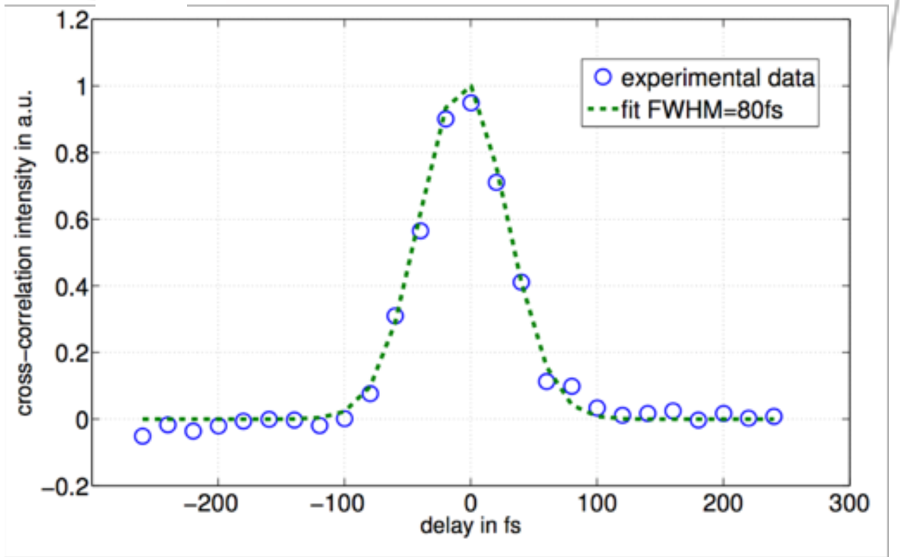
G De Ninno et al, : "Chirped pulse amplification in an extreme-ultraviolet free-electron laser." Nature Communications 7 (2016).

No CPA, seed with 170 fs



$\Delta t_{FEL}^{theo} = 89\, fs$ $\Delta t_{FEL}^{VMI} = 91\, fs$

CPA – shortest pulse



$\Delta t_{FEL}^{theo} = 40\, fs$ $\Delta t_{FEL}^{VMI} = 49\, fs$

ARTICLE

Received 17 Sep 2013 | Accepted 4 Mar 2014 | Published 30 Apr 2014
DOI: 10.1038/ncomms4539

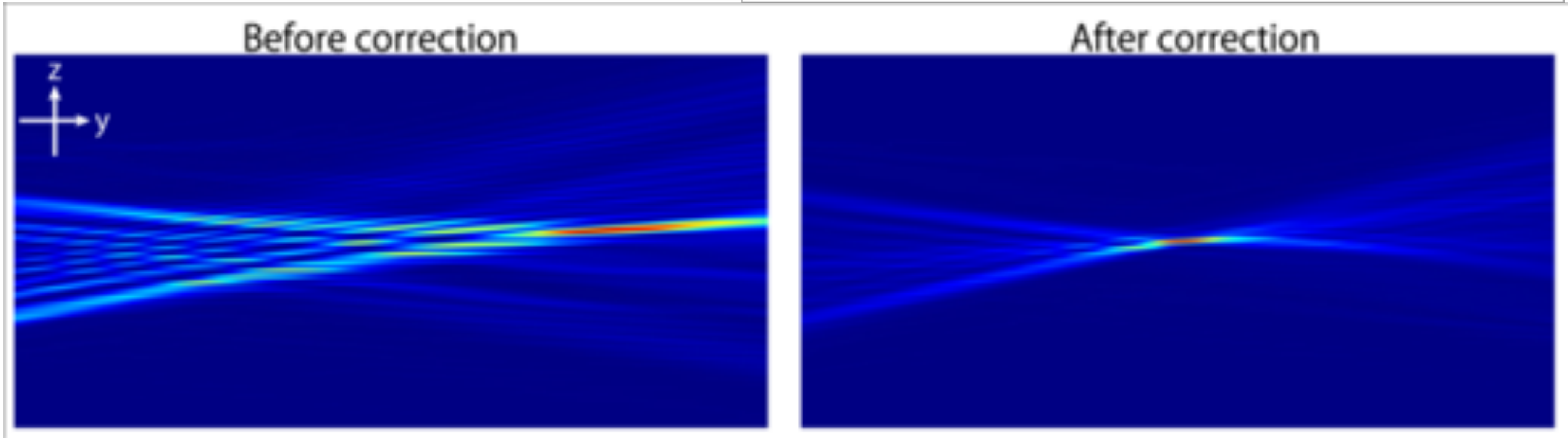
Generation of 10^{20} W cm^{-2} hard X-ray laser pulses with two-stage reflective focusing system

Hidekazu Mimura[1,*], Hirokatsu Yumoto[2,*], Satoshi Matsuyama[3,*], Takahisa Koyama[2], Kensuke Tono[2], Yuichi Inubushi[4], Tadashi Togashi[2], Takahiro Sato[4], Jangwoo Kim[3], Ryosuke Fukui[3], Yasuhisa Sano[3], Makina Yabashi[4], Haruhiko Ohashi[2,4], Tetsuya Ishikawa[4] & Kazuto Yamauchi[3]

Nanofocusing of X-ray free-electron laser using wavefront-corrected multilayer focusing mirrors

S. Matsuyama, T. Inoue, J. Yamada, J. Kim, H. Yumoto, Y. Inubushi, T. Osaka, I. Inoue, T. Koyama, K. Tono, H. Ohashi, M. Yabashi, T. Ishikawa & K. Yamauchi

Scientific Reports **8**, Article number: 17440 (2018) | Download Citation



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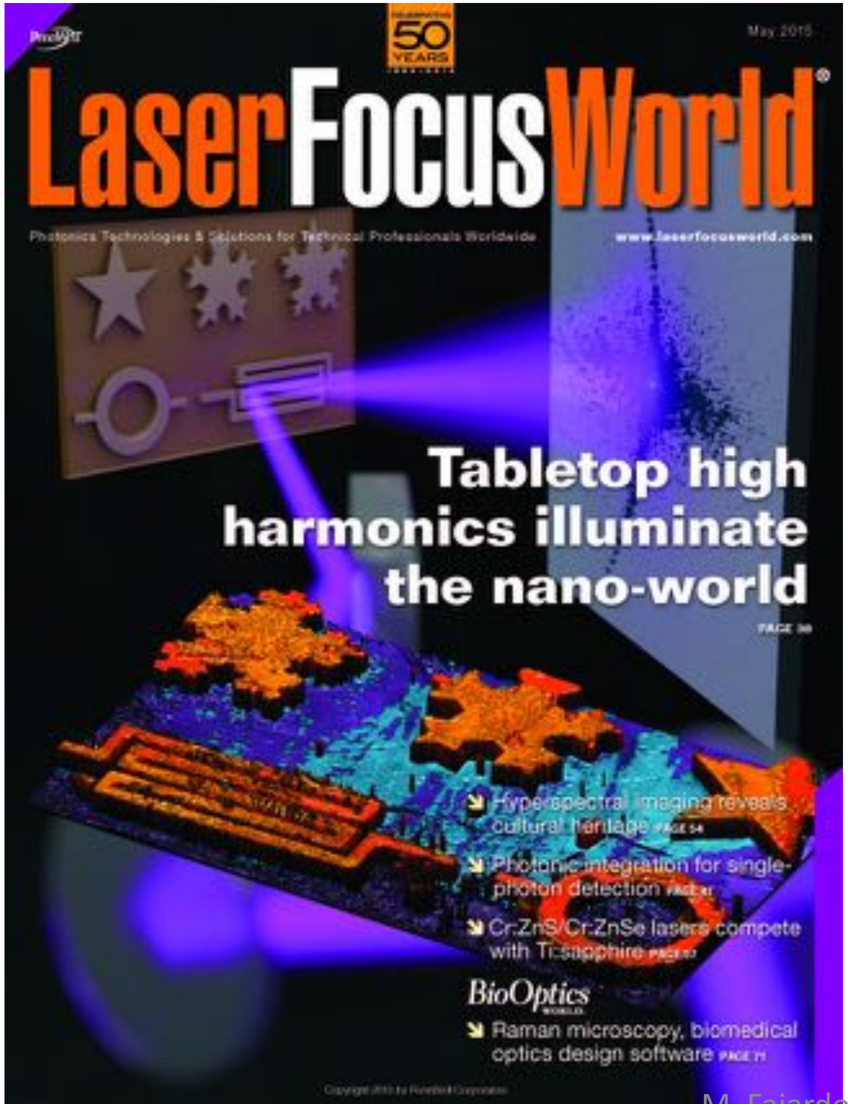
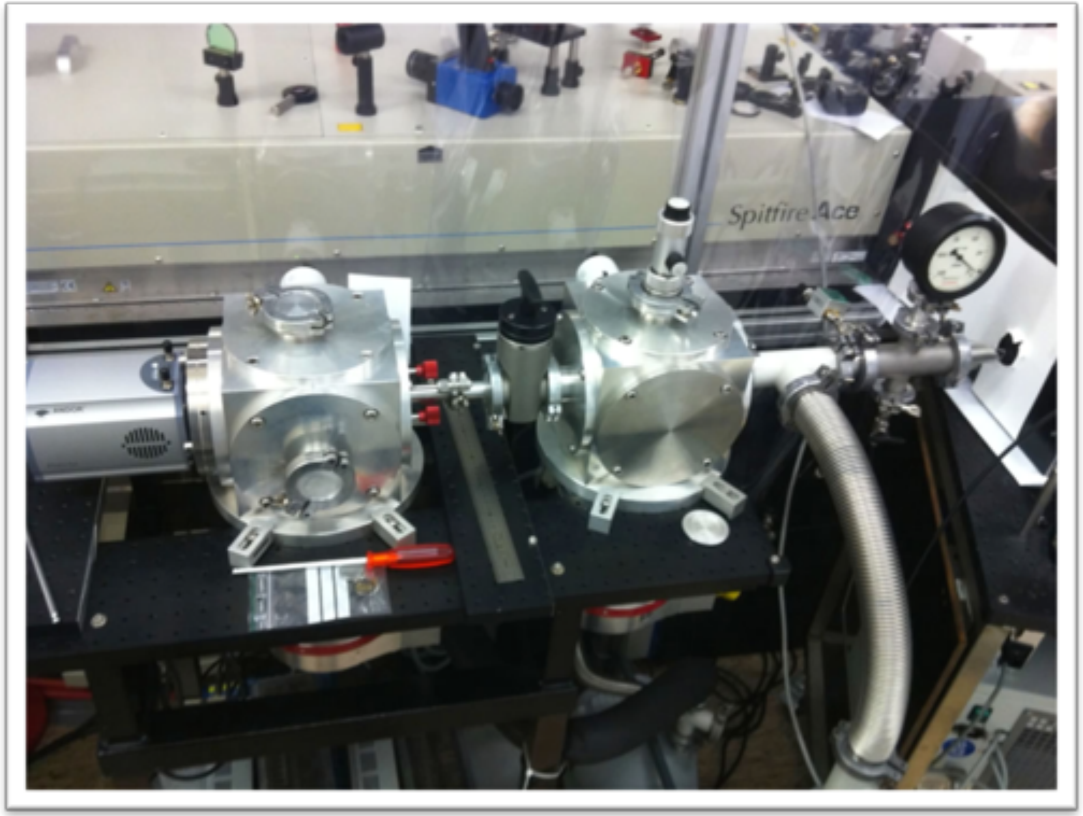
A tabletop source of bright coherent X-rays: High Harmonic Generation



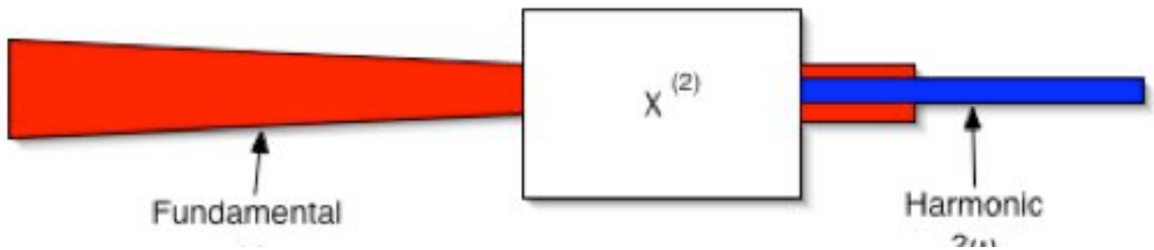


Perturbative Nonlinear Optics

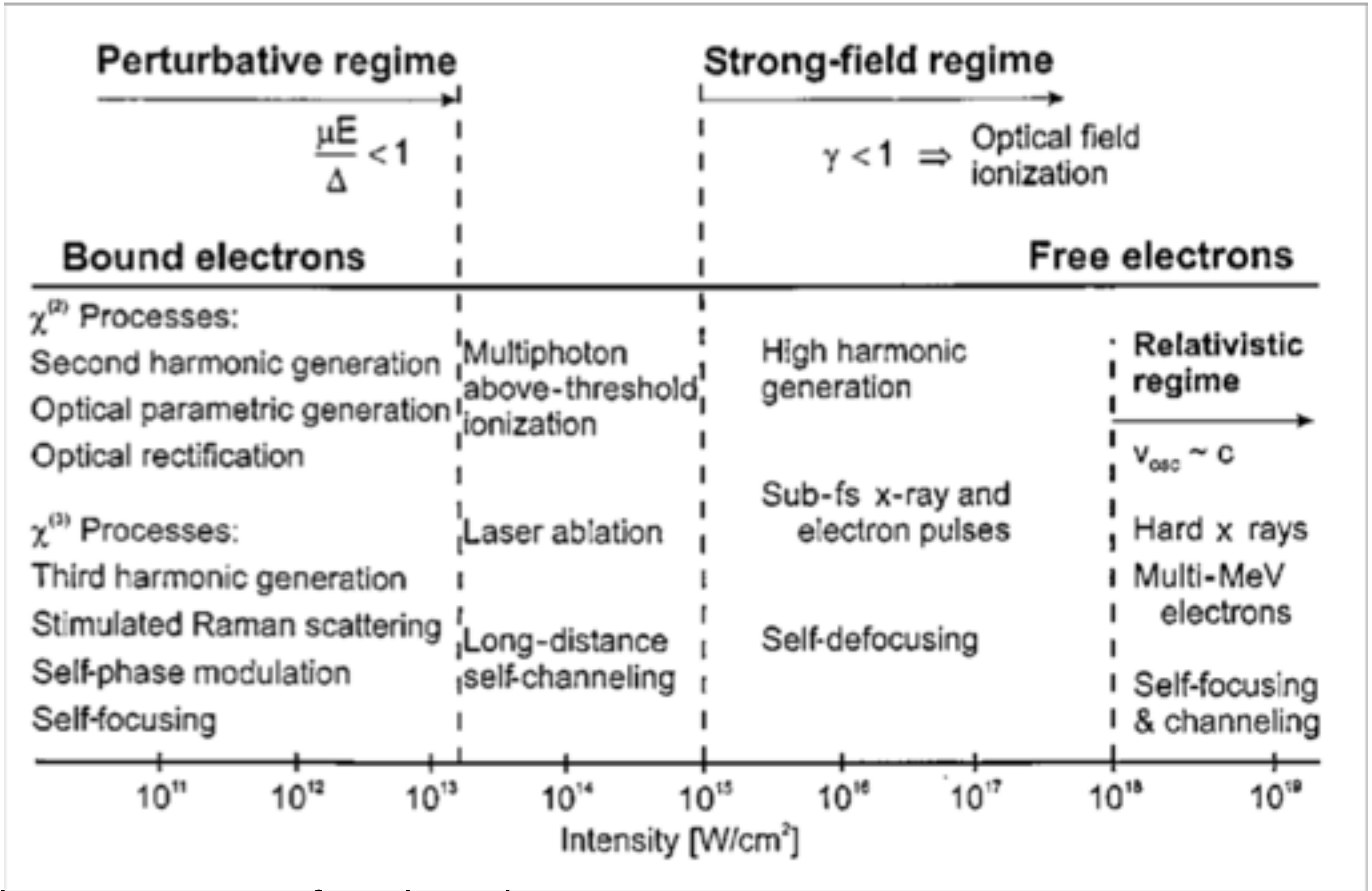
$$P = \chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + ...$$

•Accurately treated by treating the polarization as a power series in E.

•With sufficiently intense laser fields, the higher order terms give rise to Fourier components of the polarization at harmonics of the laser frequency, creating radiation at harmonics of the laser frequency.



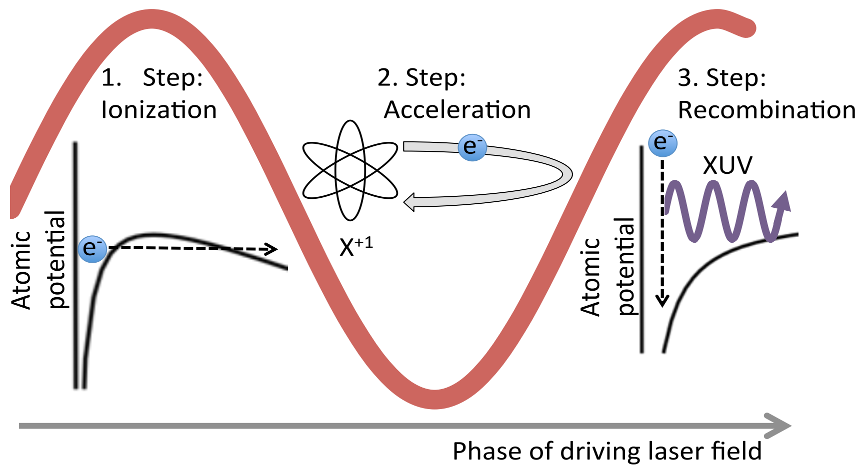
Regimes of nonlinear optics



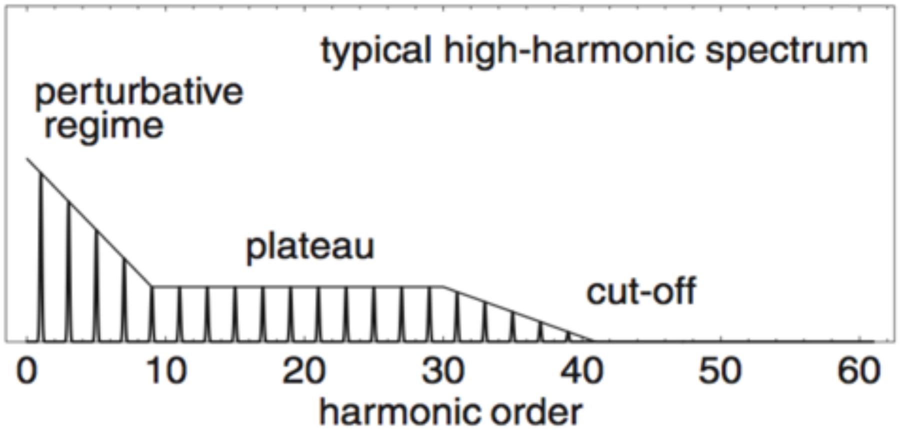
Brabec and Krausz, Review of Modern Physics 2000

High-Harmonic Generation

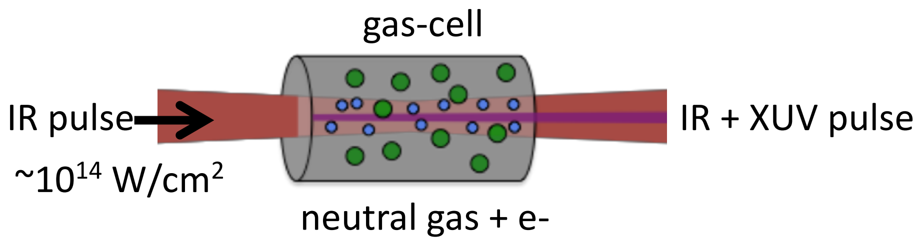
Atomic response / typical spectrum



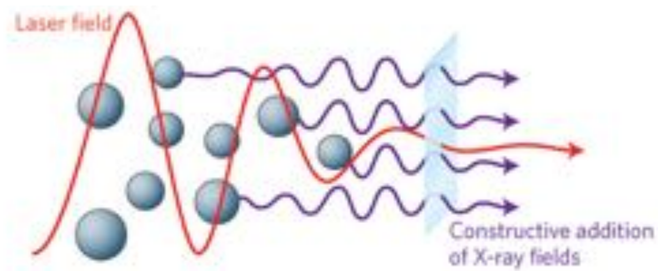
typical spectrum



Macroscopic effects



Phase-mismatch between IR driving field and XUV radiation field



"The attosecond nonlinear optics of bright coherent X-ray generation." *Nature Photonics* 4.12, 822-832 (2010)

Characteristics

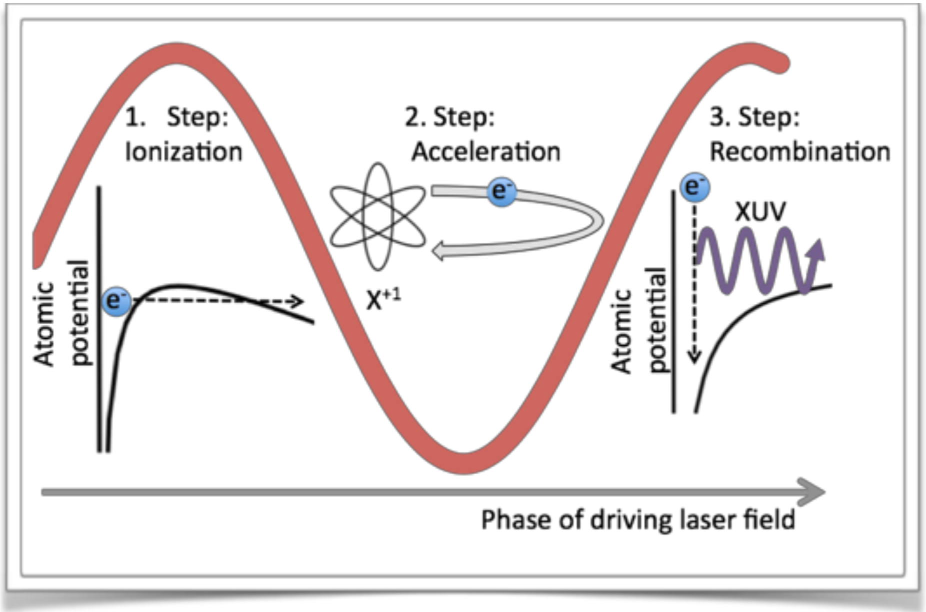
high spatial coherence, high brightness, ultra-short pulses duration, table-top, high-repetition rate

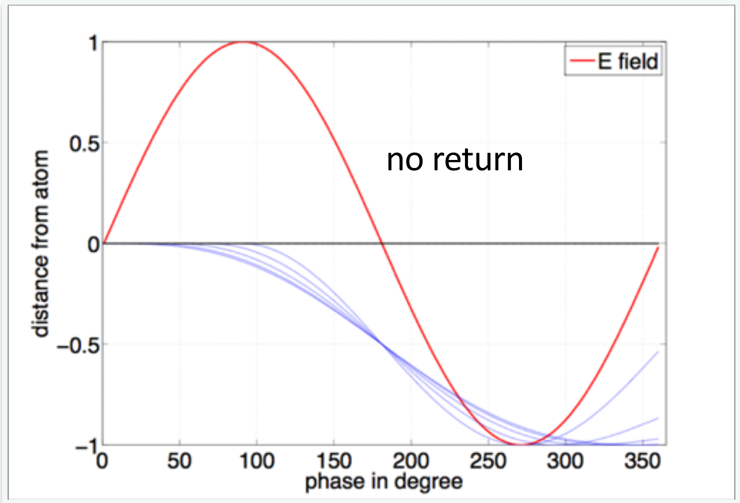
Anne L'Huillier, Philippe Balcou

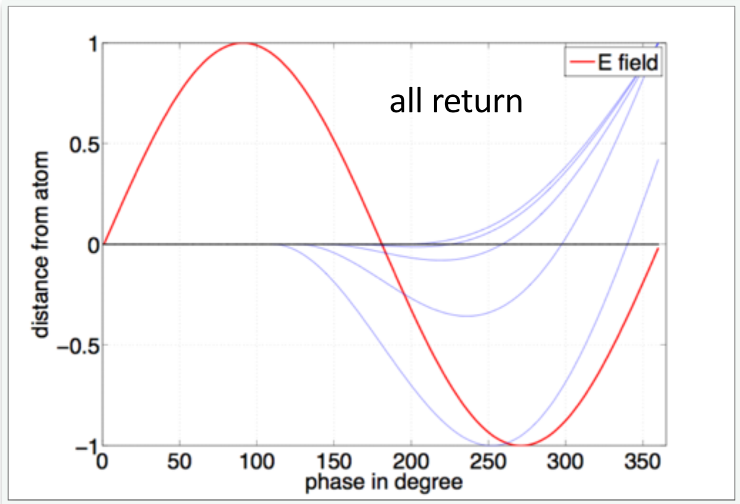
High-Harmonic Generation

single atom response

Semi-classical model: 3-step-model







$$F_L = m_e \cdot \ddot{x} = -e\left(E_0 \cdot \cos\left[\omega \cdot t + v \times B\right]\right.$$

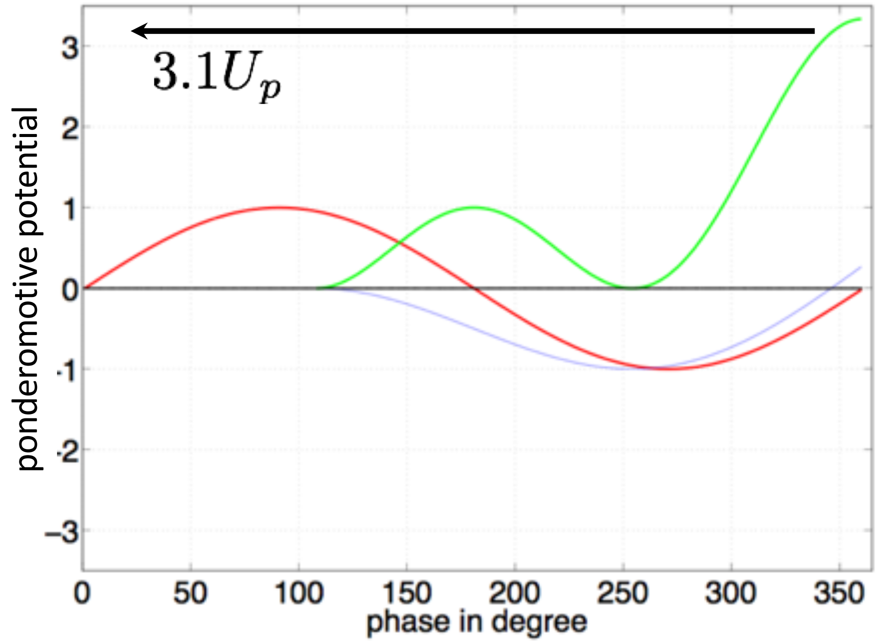
$$x = \frac{-e \cdot E_0}{\omega \cdot m_e} \cdot \left(\frac{\cos\left[\omega \cdot t_0\right]}{\omega} - \frac{\cos\left[\omega \cdot t\right]}{\omega} + \sin\left[\omega \cdot t_0\right] \cdot (t_0 - t)\right)$$

electron trajectories in blue

HHG

single atom response

Semi-classical model: 3-step-model



Cut-off law: $$\hbar\nu_{max} = E_{kin_{max}} + I_p = 3.1U_p + I_p$$

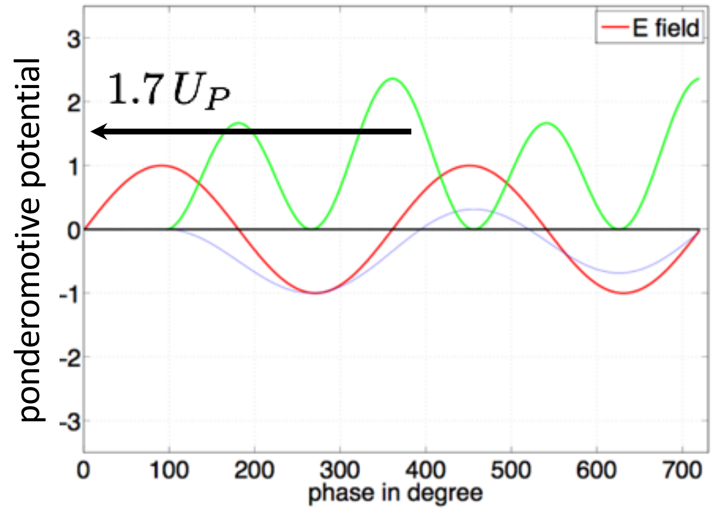
Can explain cut-off and scaling

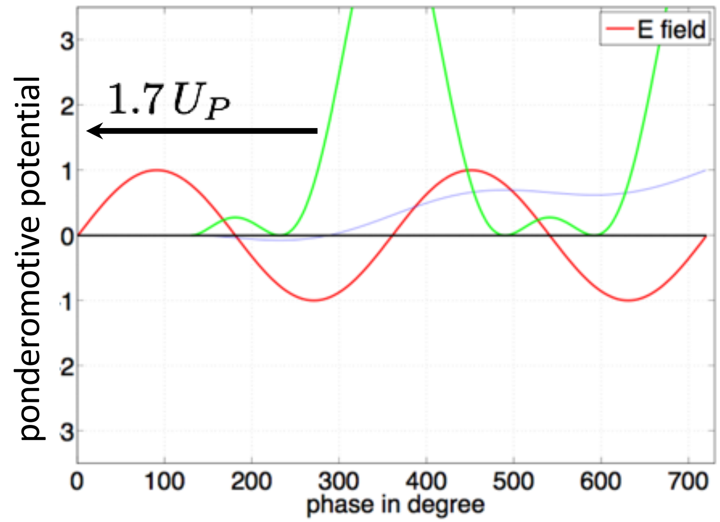
But not spectrum with discrete HH orders

electron trajectories in blue

ponderomotive potential in green

long/short trajectory





HHG

single atom response

Quantum model

Solve time-depended Schrödinger equation of an electron initially bound to an electron

$$i\frac{d}{dt}|\psi\rangle = H|\psi\rangle - E(t)x$$

With the Hamiltonian

$$H = -\frac{1}{2}\nabla + V(\vec{r}),$$

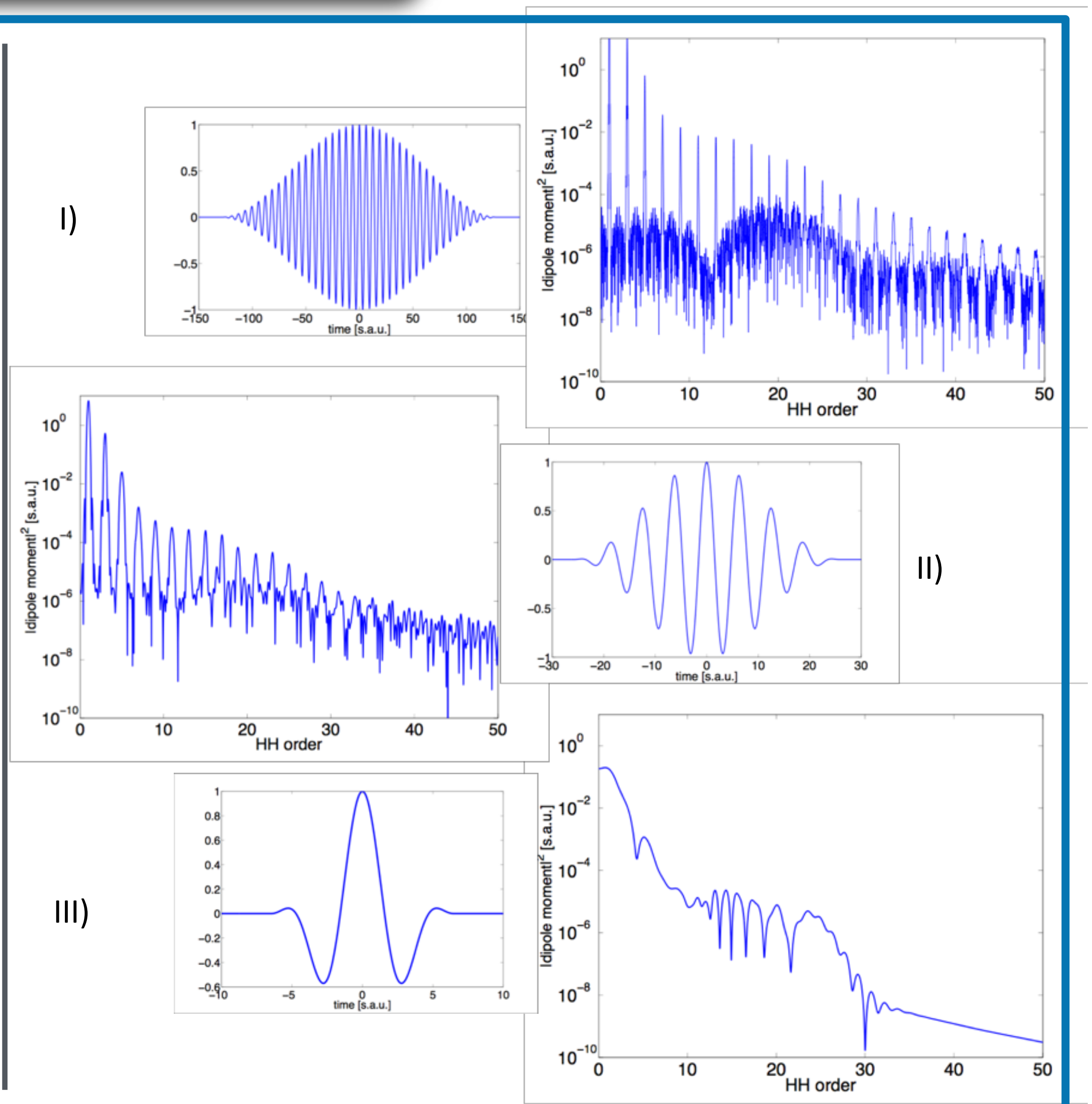
Wave-function is superposition between ground state and free electron

$$|\psi(t)\rangle = a(t)|0\rangle + |\varphi(t)\rangle$$

Ion and electron act as an dipole and dipole moment is

$$\vec{d}(t) = \langle\psi(t)|\,\vec{x}\,|\psi(t)\rangle$$

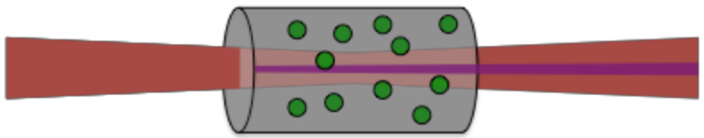
Source of radiation is dipole acceleration
FT of dipole acceleration is HHG spectrum



Phase-matching

sources of mismatch

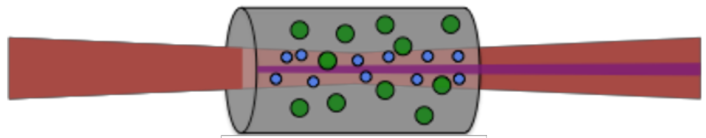
Dispersion of neutral gas



$$n(\lambda_0) \neq n(\lambda_q)$$

$$\Delta k_N = \frac{2\pi q}{\lambda_0}(n(\lambda_0) - n(\lambda_q))\frac{p}{p_{atm}}(1-\eta)$$

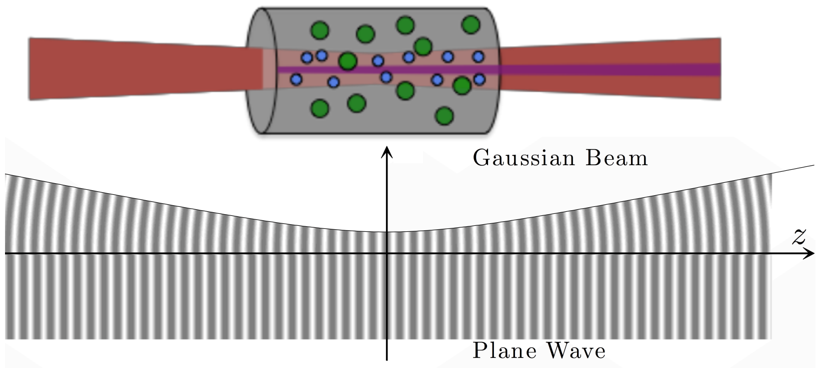
Dispersion of plasma



$$n_p = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$

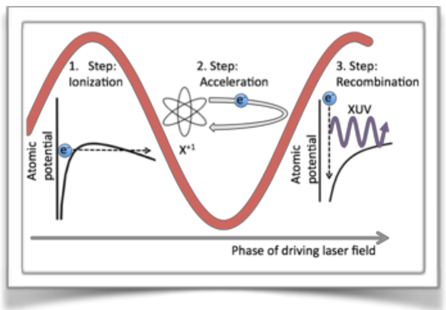
$$\Delta k_p = N_{atm}\frac{p}{p_{atm}}\eta\lambda_0 r_e(\frac{1-q^2}{q})$$

Gouy-phase



$$\Delta k_{gouy}(z) = q\frac{\pi\lambda_0\omega_0^2}{\pi^2\omega_0^4 + \lambda_0^2 z^2}$$

Atomic phase



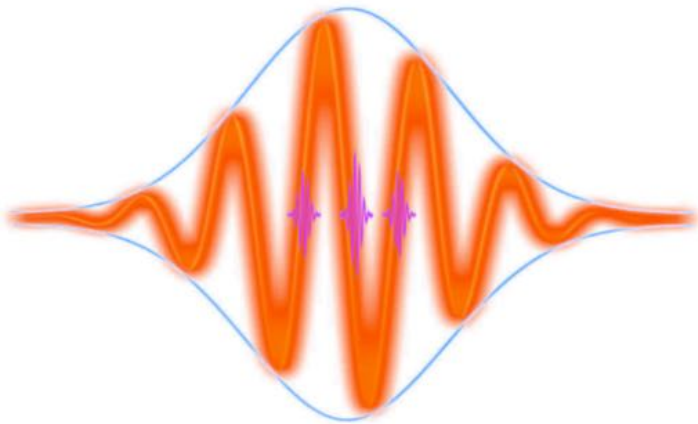
$$I(z) = \frac{I_0}{1 + \left(\frac{2z}{z_r}\right)^2}$$

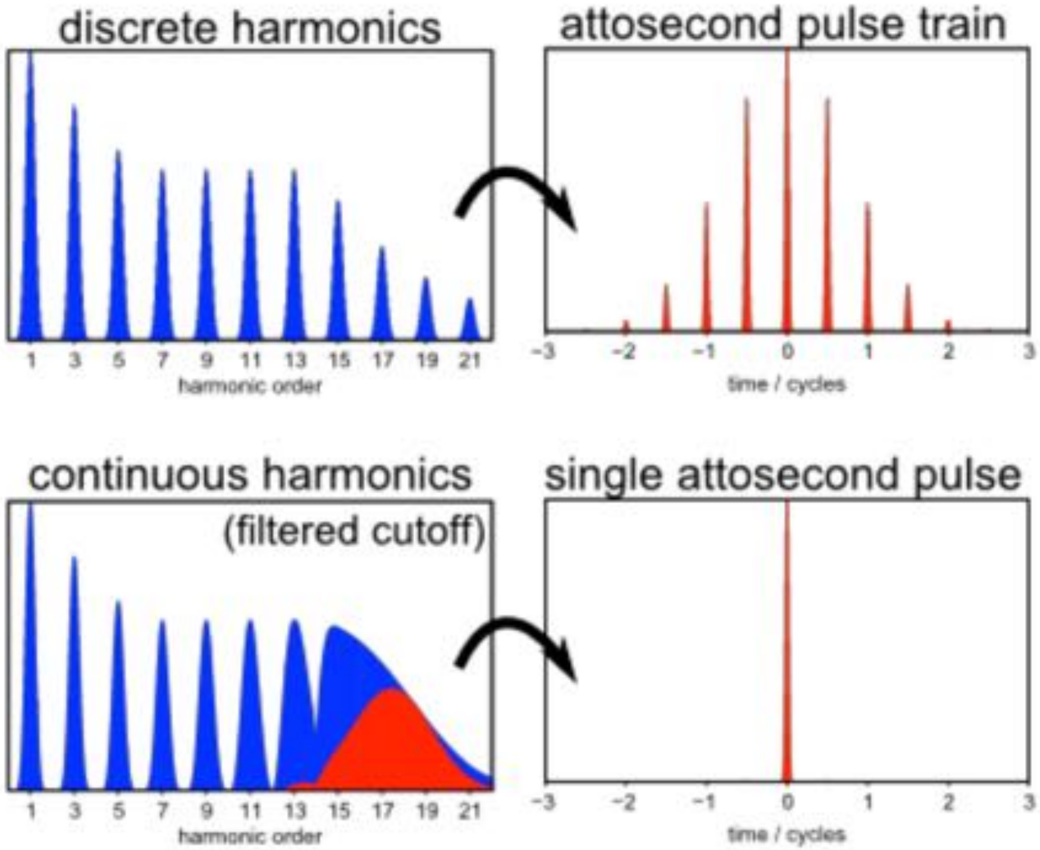
initial phase of HHs depends on intensity

$$\Delta k_{at}(z) = \alpha_q \frac{8 I_0 z}{z_r^2\left(1 + \frac{4z^2}{z_r^2}\right)^2}$$

Attosecond (10^{-18}s) Pulses

Very Short Pulse

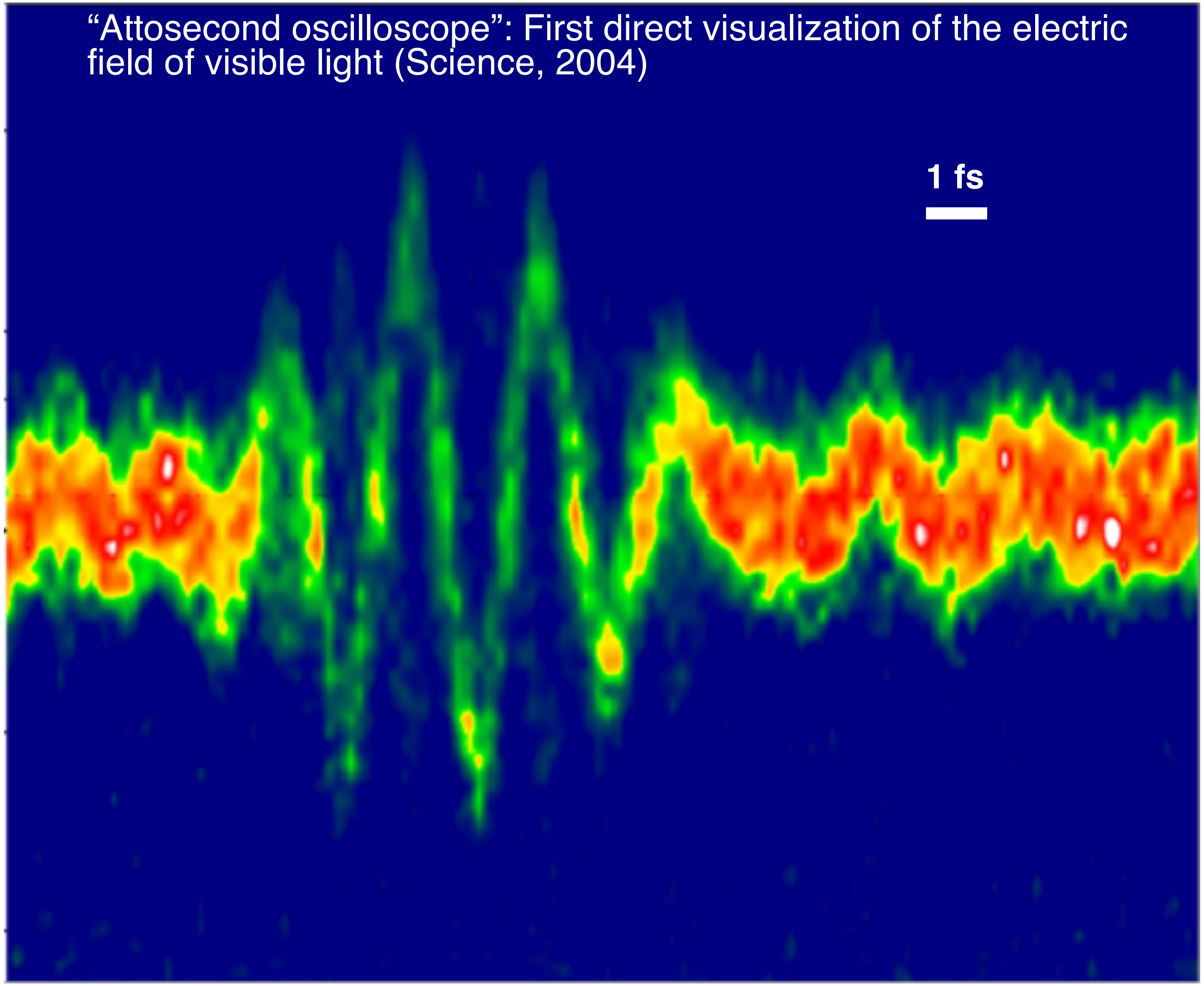




[K. Zhao et al, OL, 2012]

Shortest Pulse measured is ~ 67 attoseconds

Few-cycle laser pulses are only a few optical periods (~μm) long



Current records

Shortest pulse duration: 67 as

Krausz group: (few fs laser)

Shortest wavelength: 7Å (1.6 keV)

Murnane group: (3.9 μm laser)

Highest photon count*:

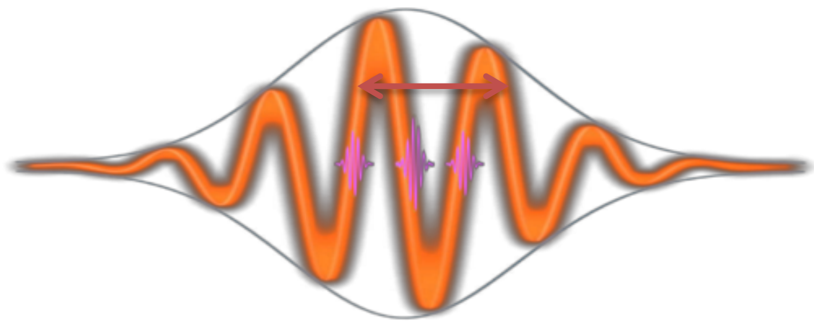
1μJ at 45eV

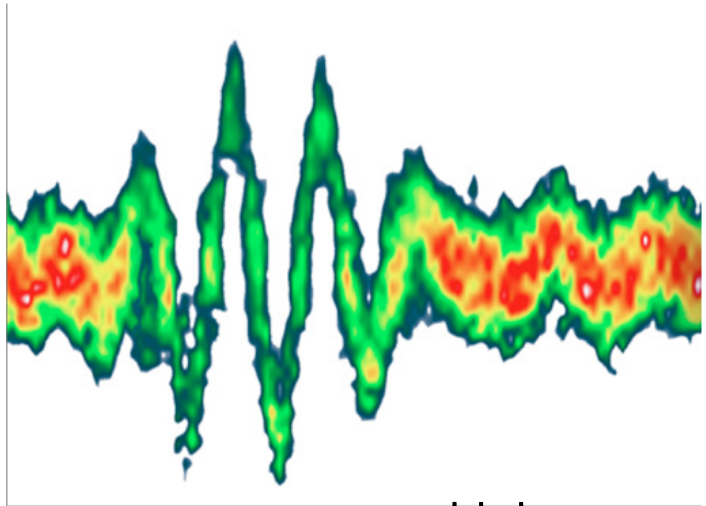
Kim group: (w/2w)

1μJ at 100eV

Krausz group: (f=18m, 80mJ, 5fs)

!!150 μJ at FORTH - Charalambidis

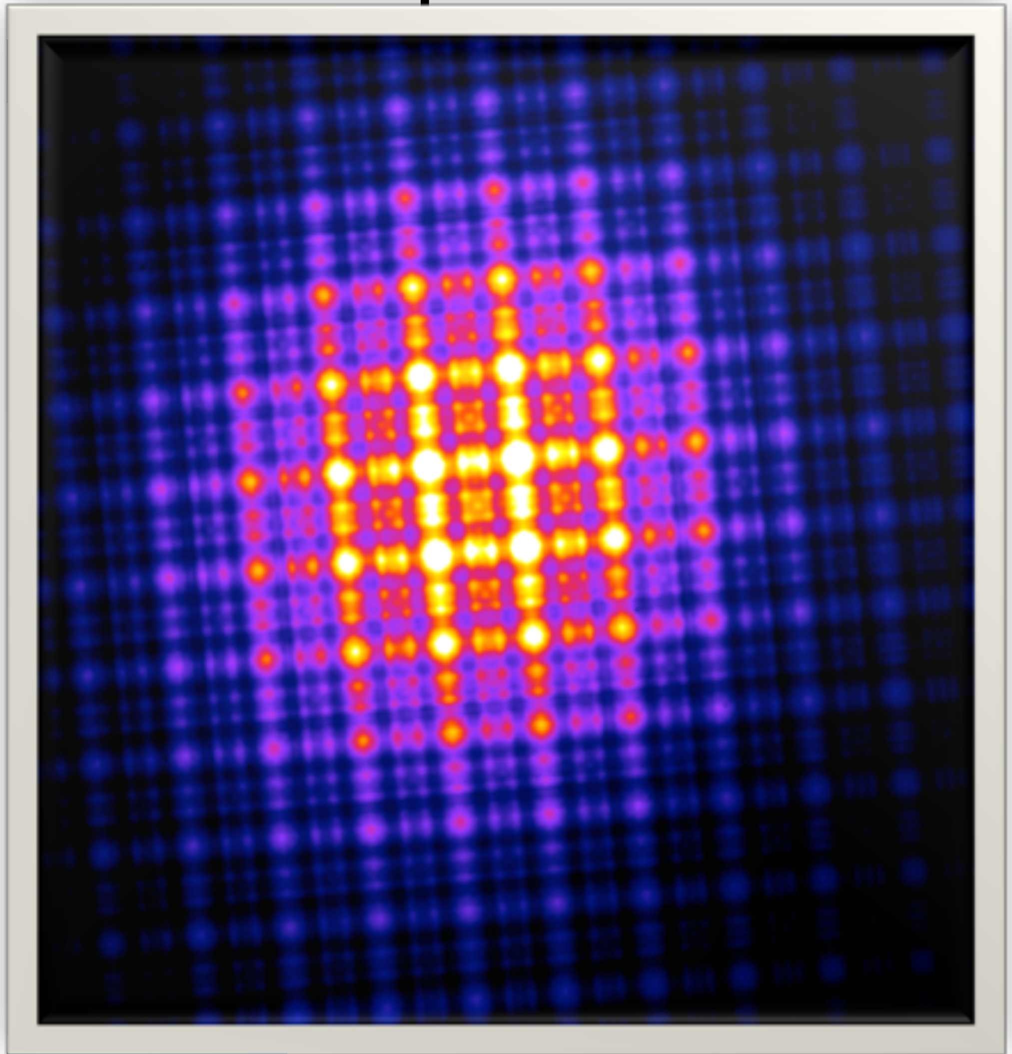




www.attoworld.de

**That's 10^9 photons/pulse, compared to 3 mJ XFEL at 10^{12} photons/pulse*

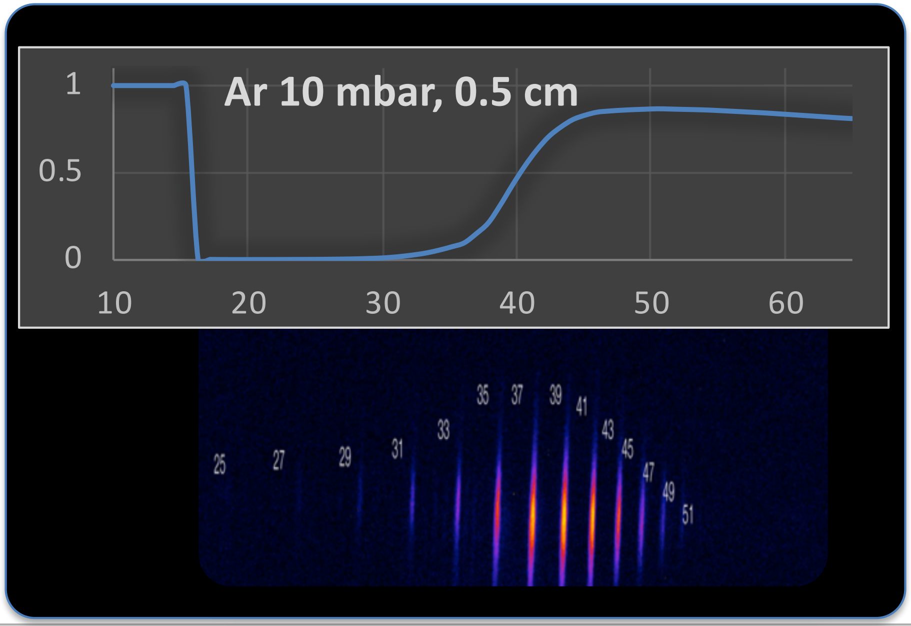
High Harmonic Generation: A tabletop source

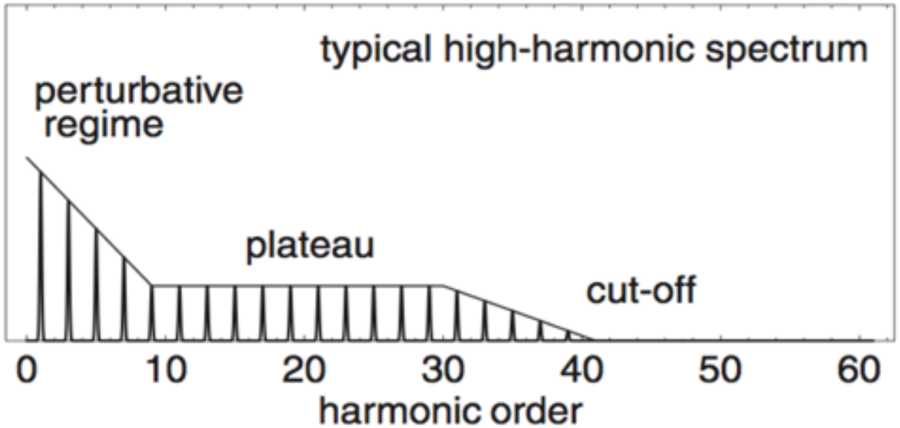


Characteristics

high spatial coherence, high brightness, ultra-short pulses duration, table-top, high-repetition rate

Atomic response / typical spectrum





The VOXEL Station at IST

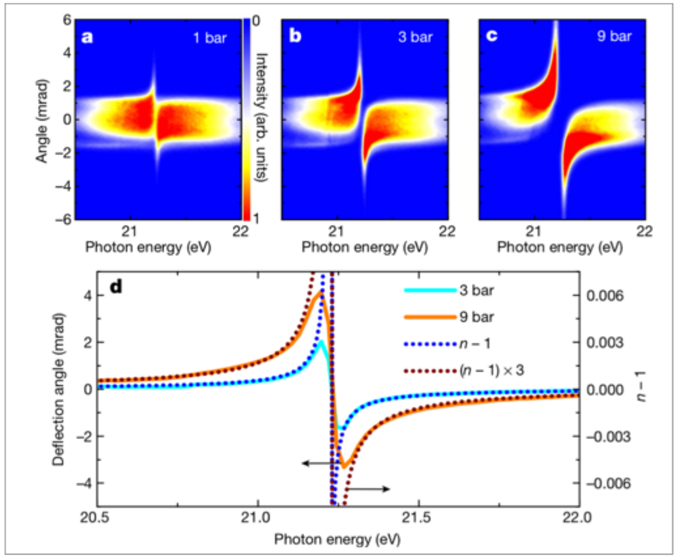
November 2016

December 2016

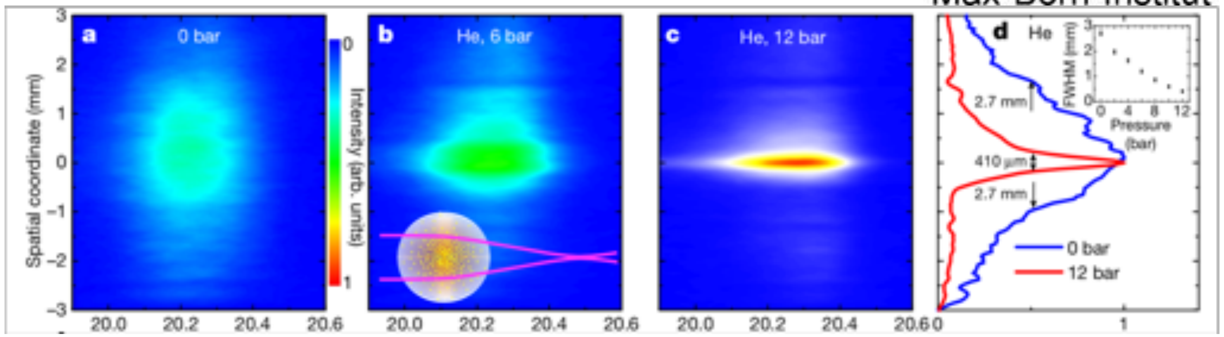

First Light
24 April 2017

Manipulating Harmonic Properties

Novel focusing optics with gas density



Extreme-ultraviolet refractive optics
L. Drescher et al, Nature (Dec 2018)

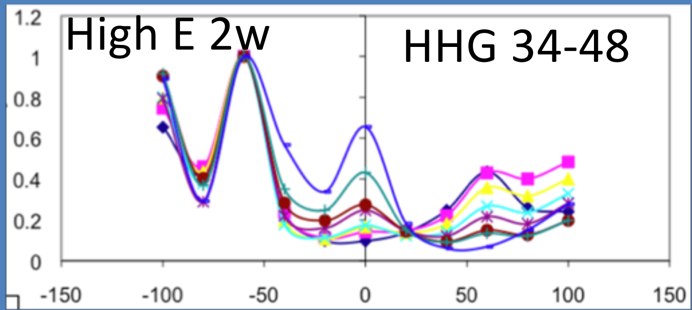


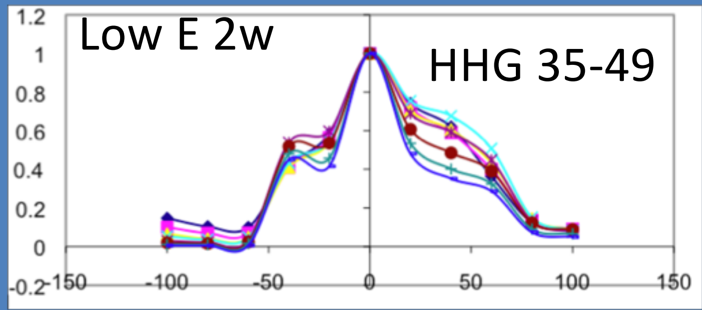
We have been pursuing XUV adaptive optics for a long time

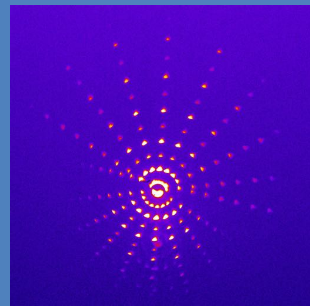
G Lambert, New Journal Physics 2009: two colour fields

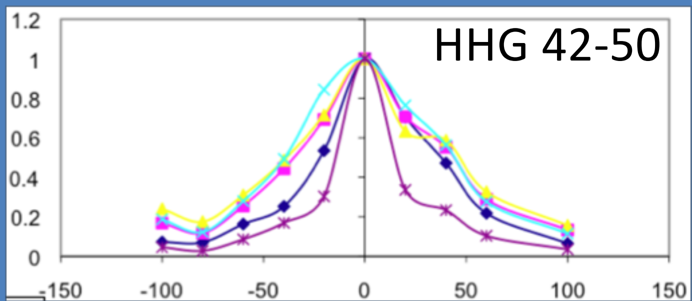
G Lambert, EPL, 89 (2010) 24001: wavefront measurements

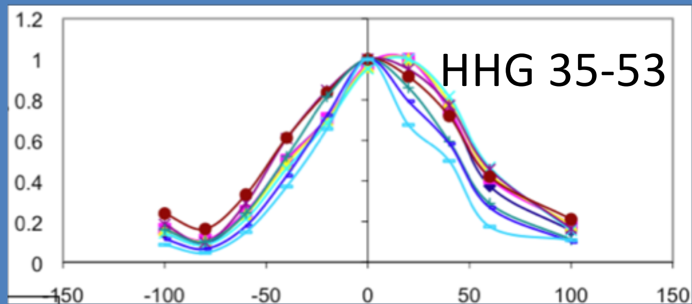
2 color generation: polarization does not follow the simplistic δ^3 model

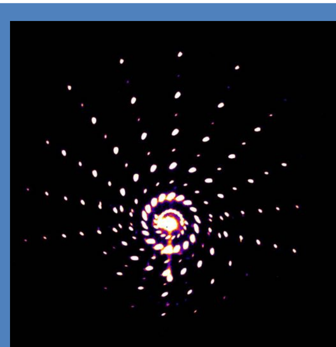




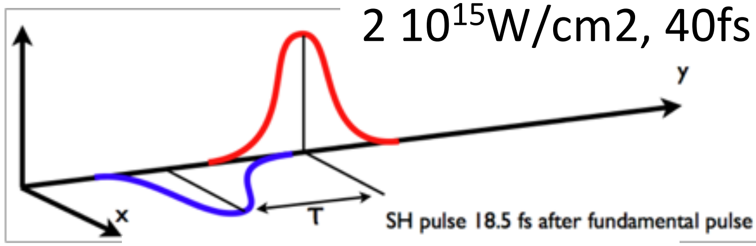




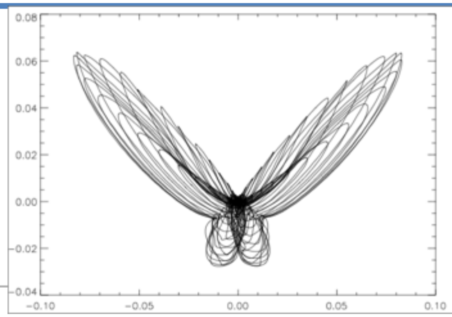


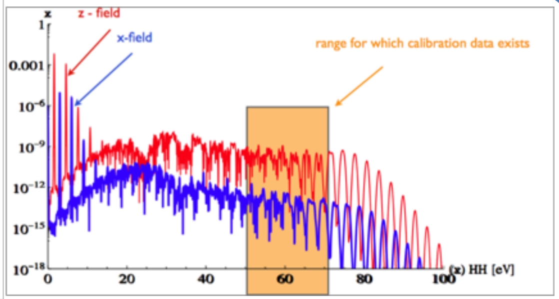


2 10^{15}W/cm2, 40fs



10^{12}-5 10^{14}W/cm2, 40fs

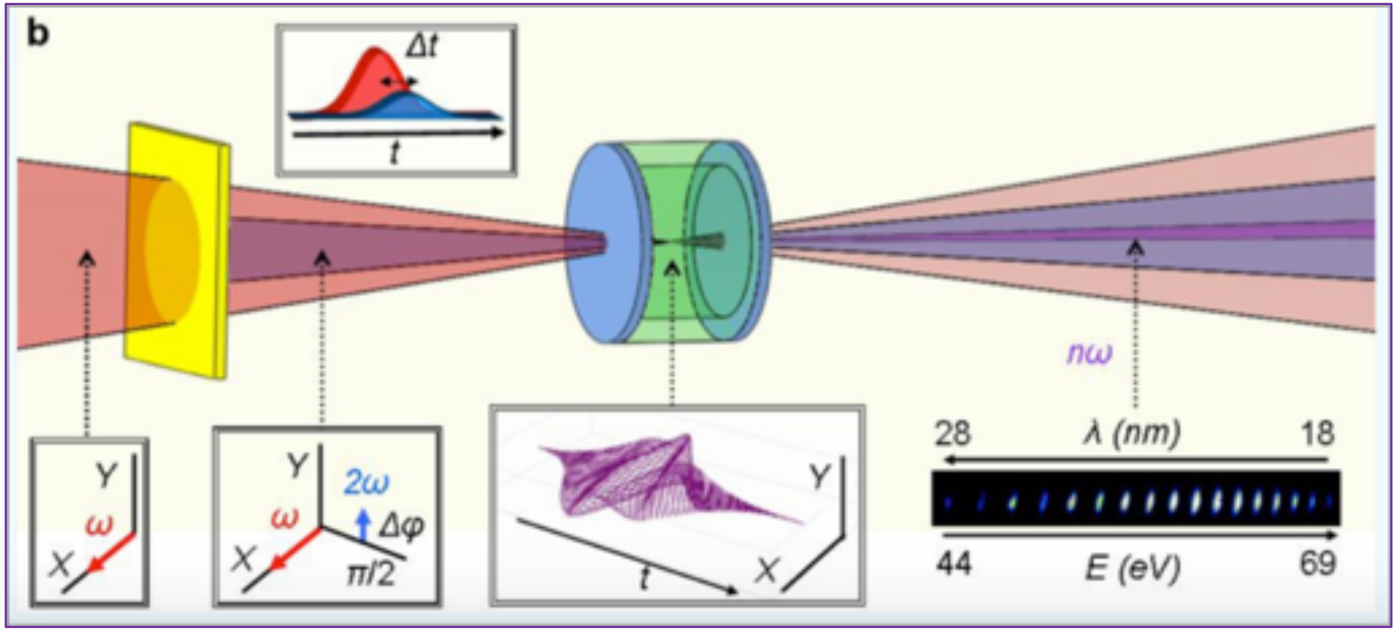




Simulations by J. Biegert, ICFO

Control over Harmonic Properties

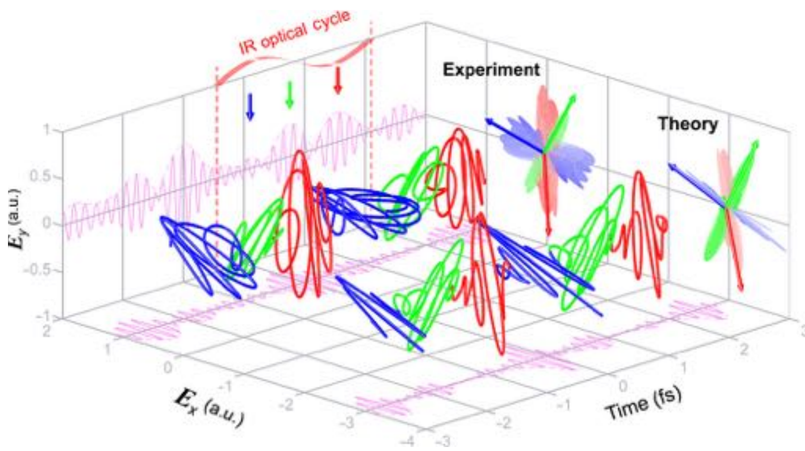
In collaboration with LOA: generation of HHG with circular polarization



Control over polarization and ellipticity

G. Lambert et al, Nature Communications 2015

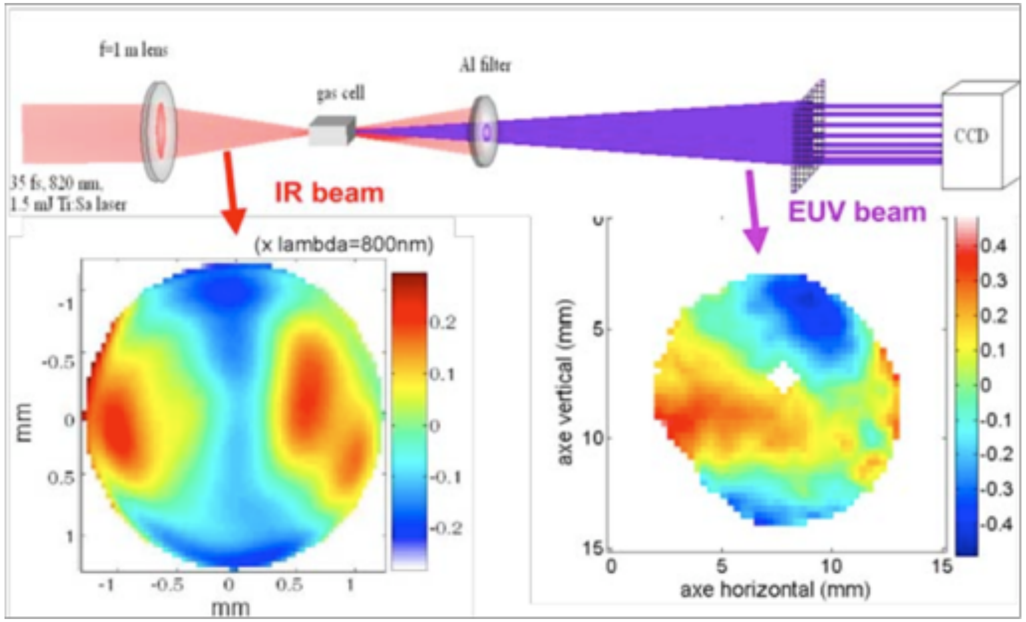
O. Kfir, et al, Generation of bright phase-matched circularly-polarized extreme ultraviolet high harmonics, *Nature Photonics* 9, 99–105 (2015)



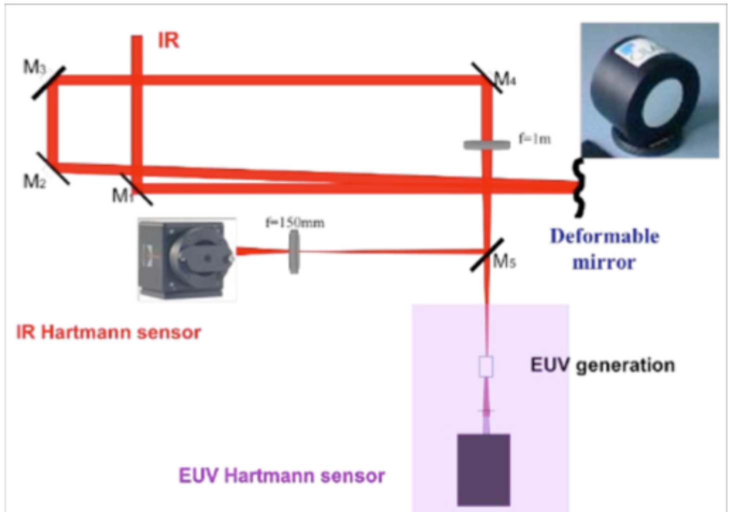
Cong Chen et al. Sci Adv 2016;2:e1501333

01 MAY 2015 VOL 348, ISSUE 6234

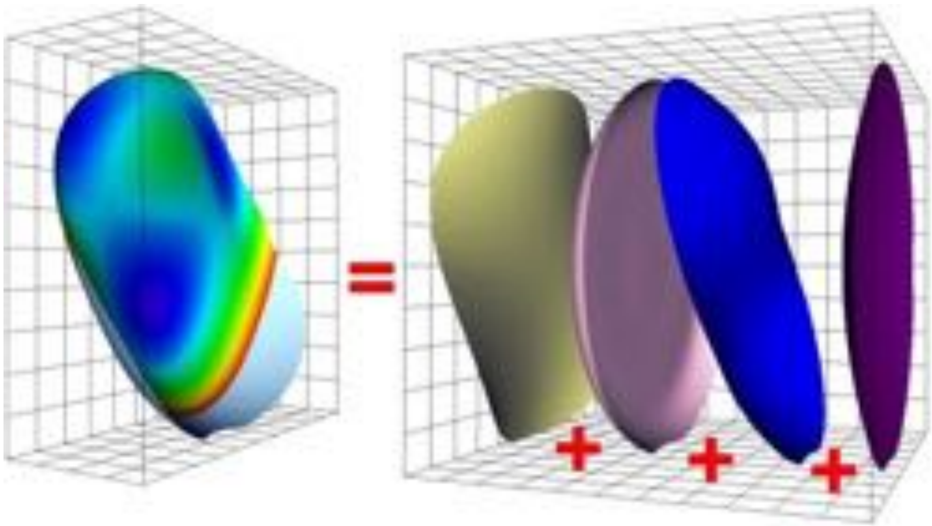
This wavefront sensor has been used routinely to improve the WF of HHG

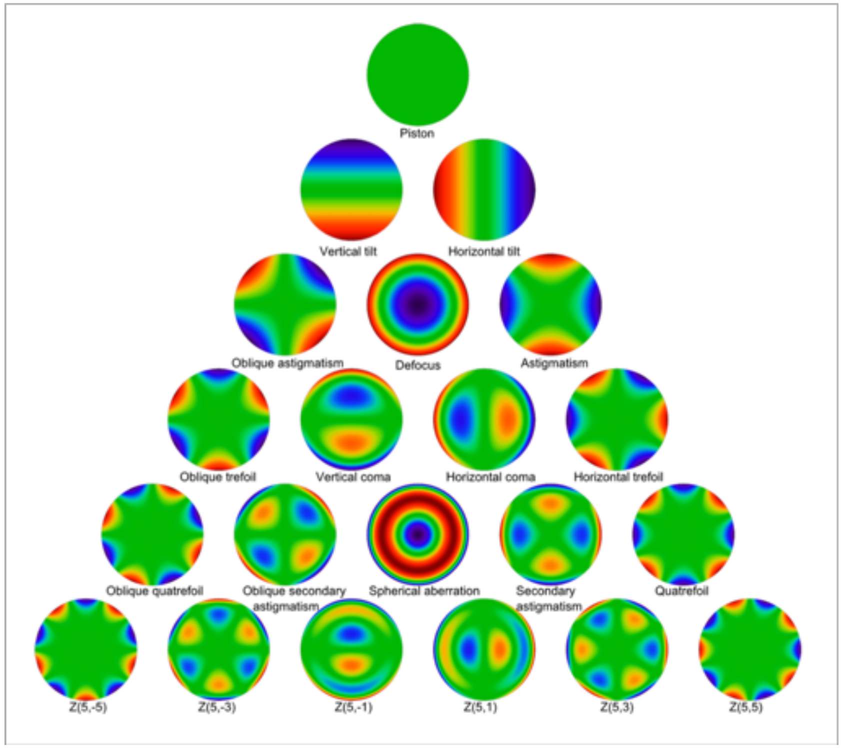


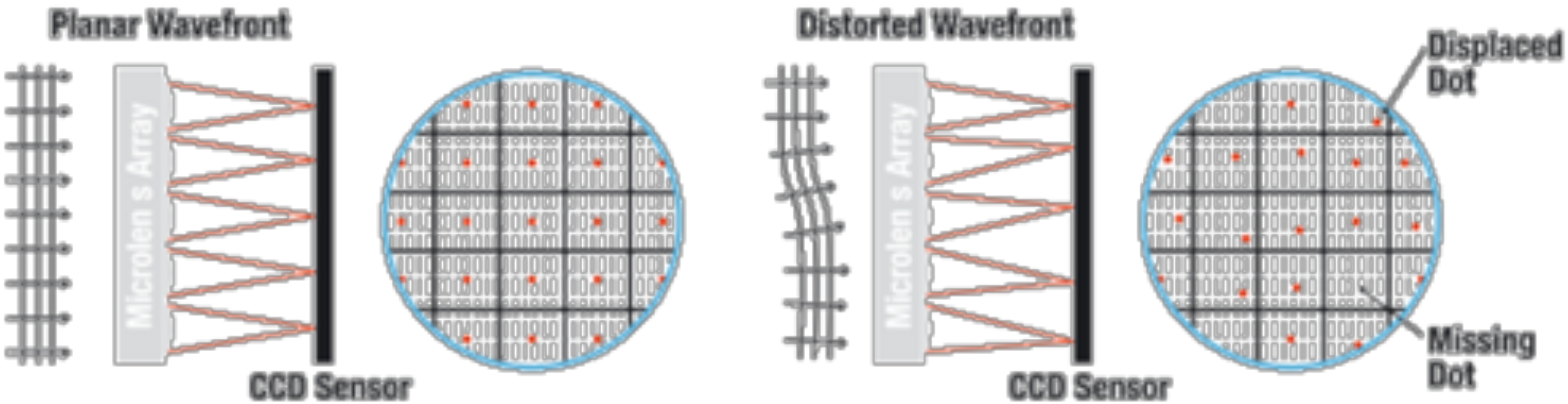
Using closed-loop correction, we achieved diffraction limited harmonics (<λ/14 rms)



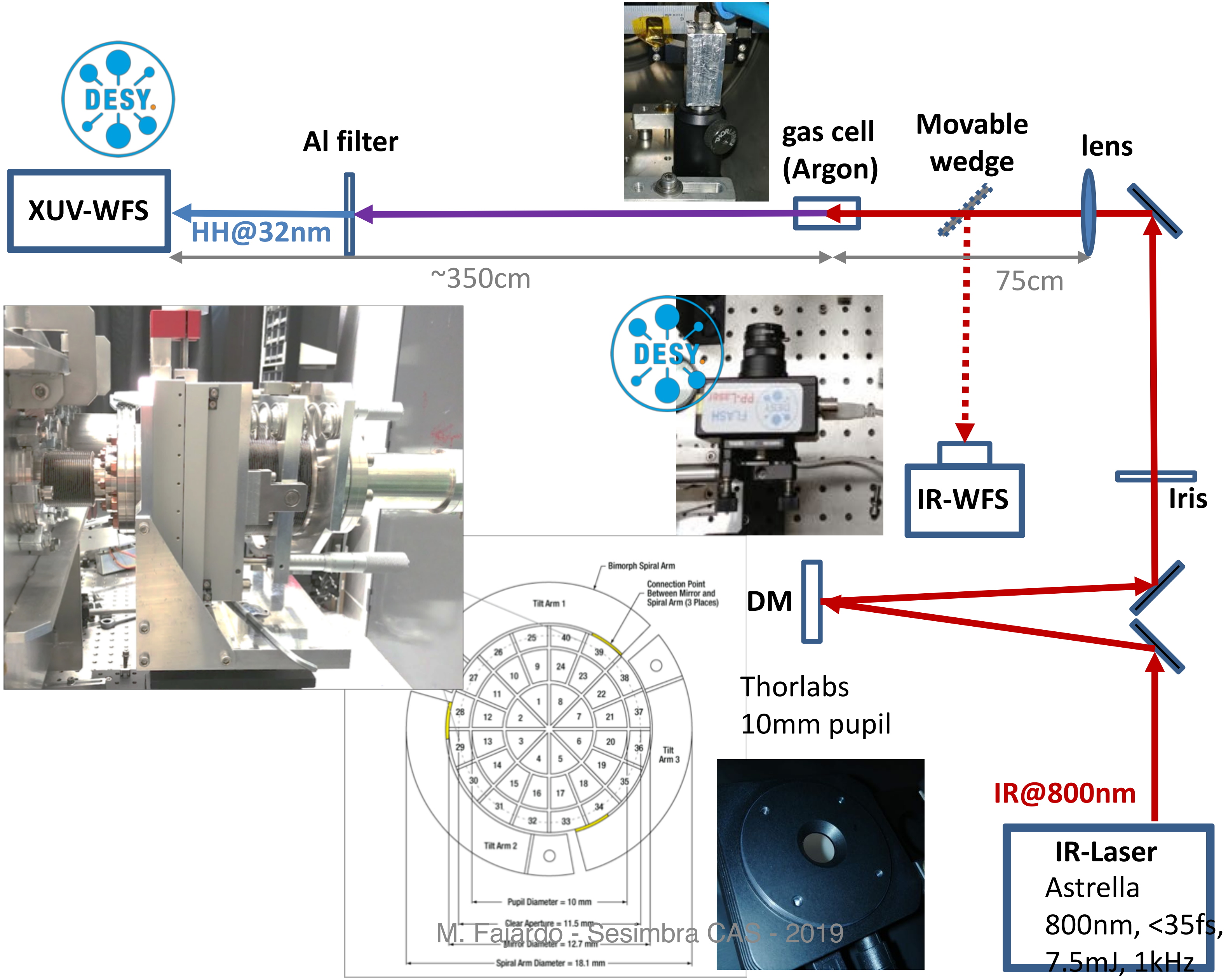
Wavefront aberrations



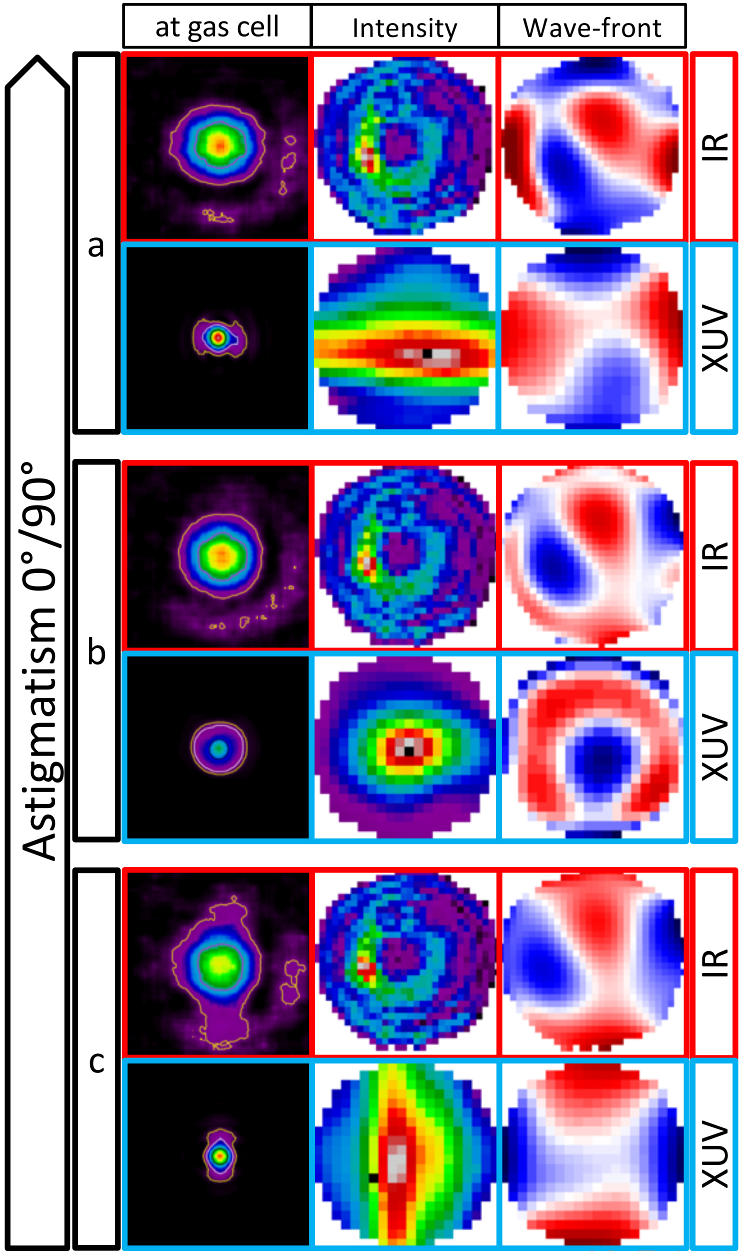


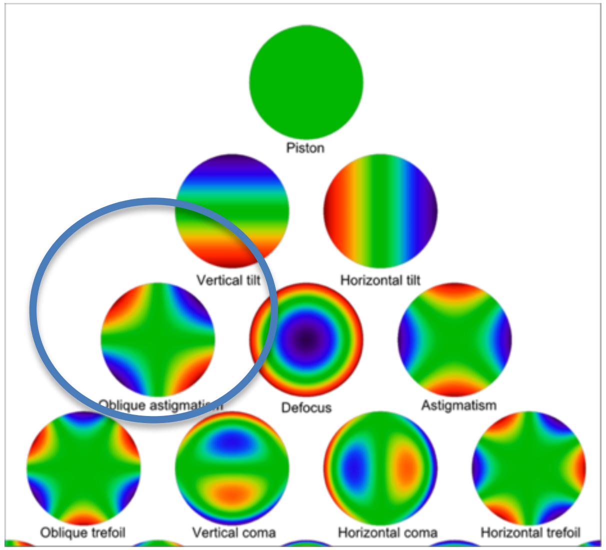


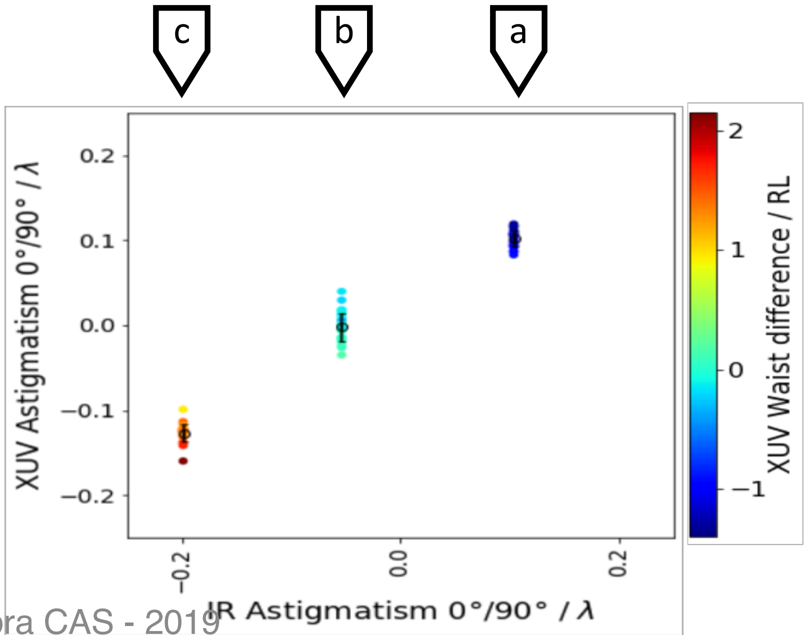
VOXEL station experiment July 2018



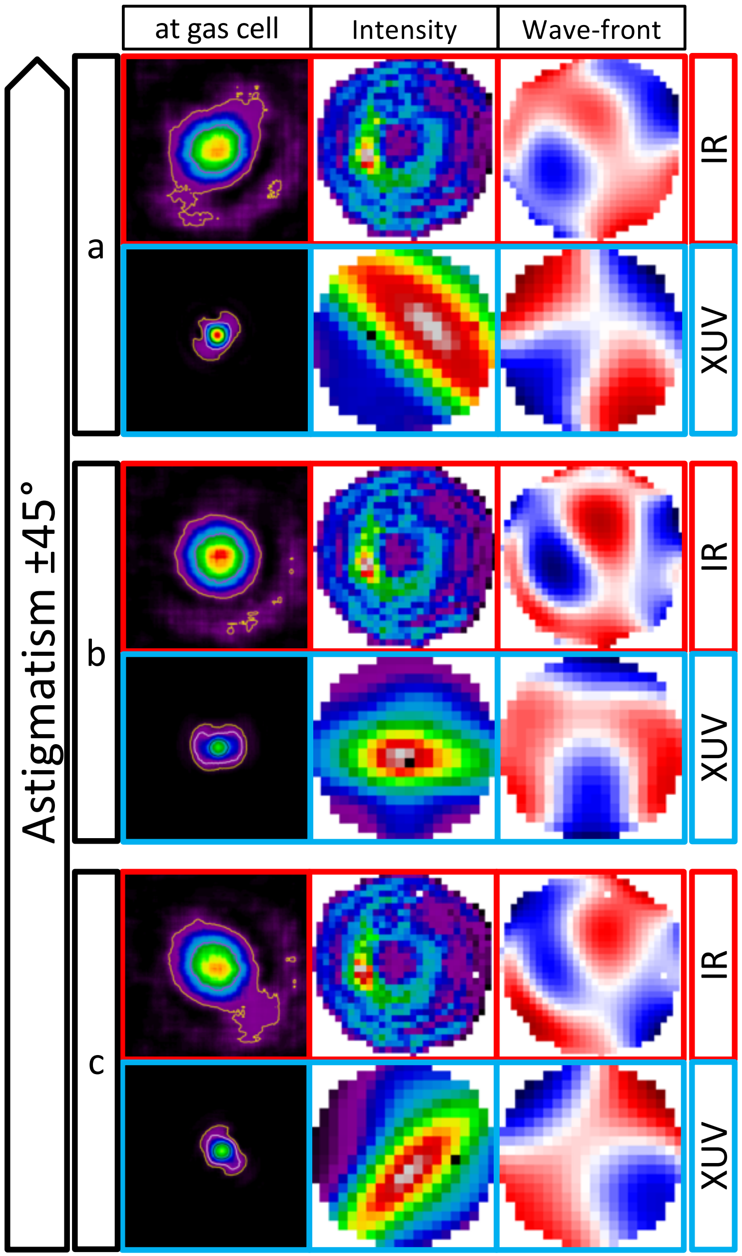
Wavefront aberrations

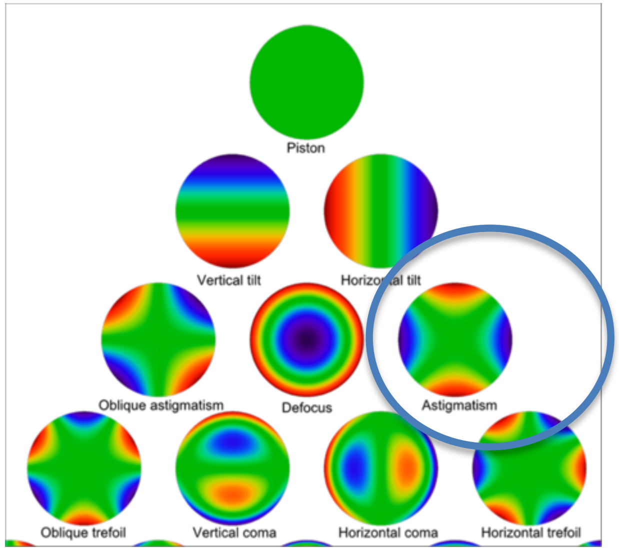


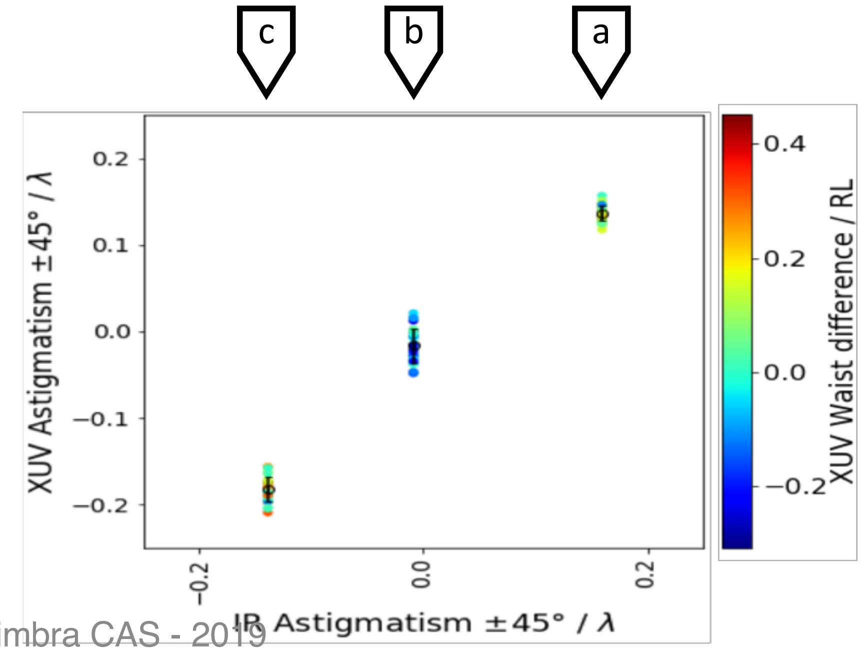




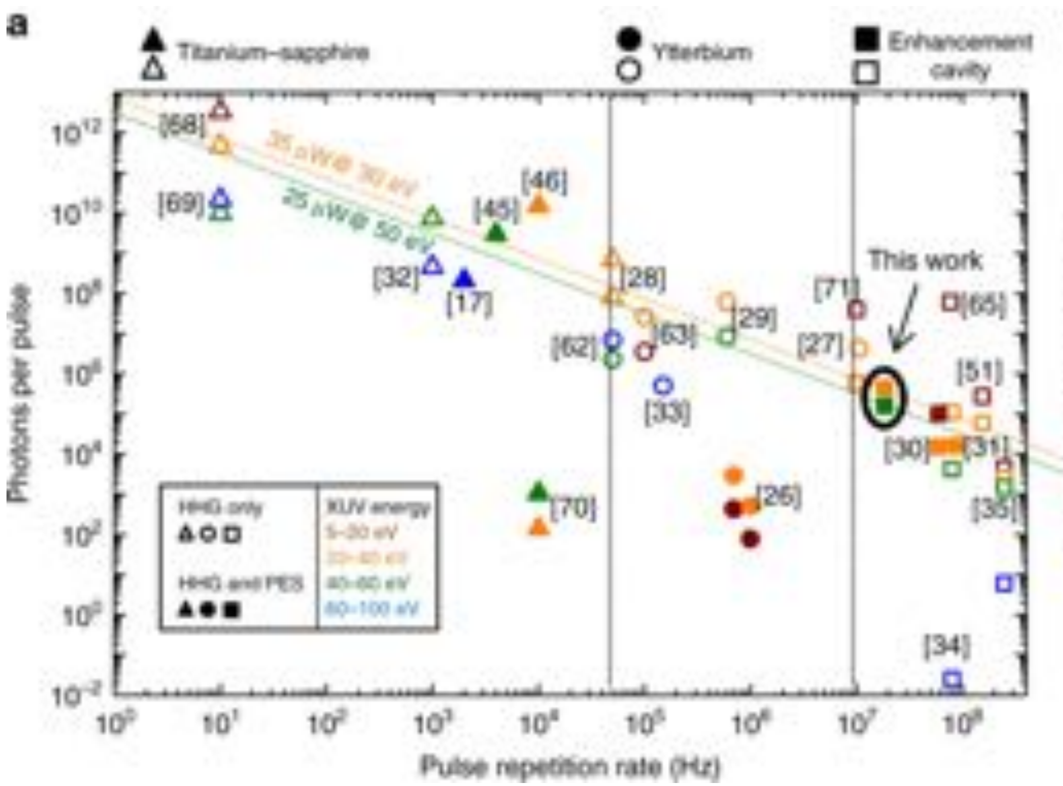
Wavefront aberrations







The future is bright for HHG



Saule et al, Nature Communications 2019

[High-flux ultrafast extreme-ultraviolet photoemission spectroscopy at 18.4 MHz pulse repetition rate]

OAM is being explored as well (see work by Fabien Queré's group)

Contents

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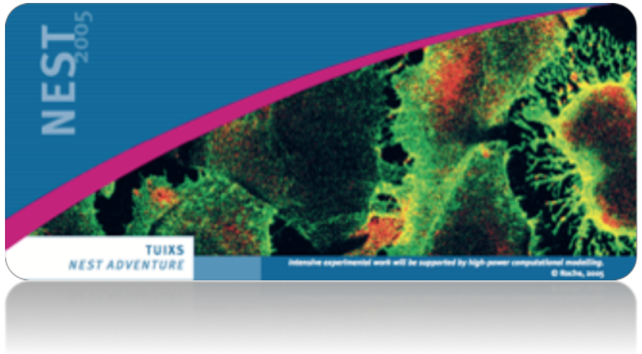
- High resolution imaging: CDI
- Warm dense matter: Pump and probe

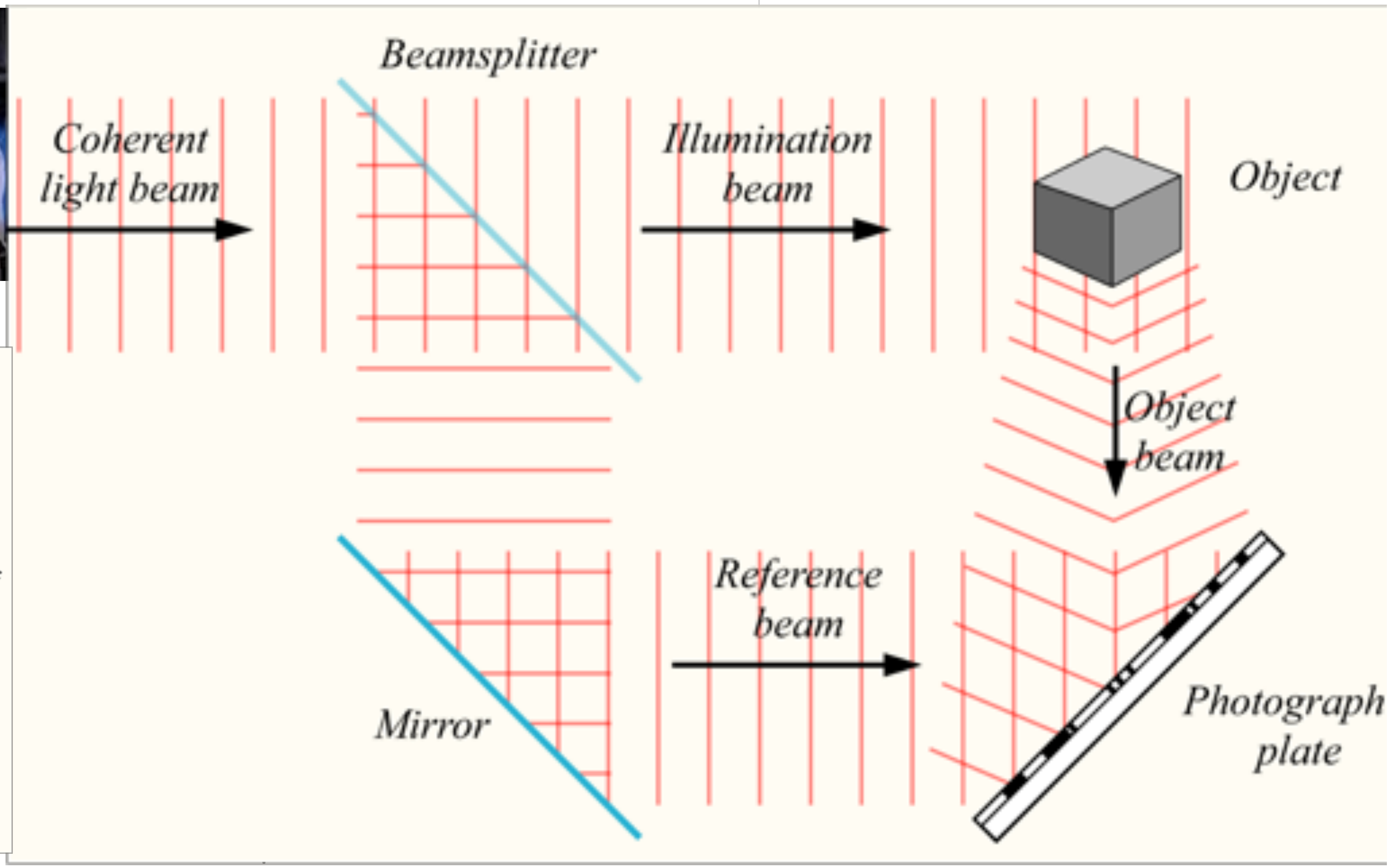
Gabor Holography (in-line)

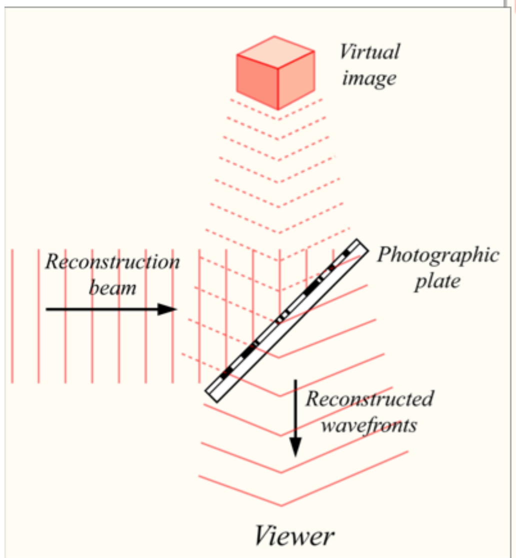


$$|U_{\mathrm{O}} + U_{\mathrm{R}}|^2 = U_{\mathrm{O}} U_{\mathrm{R}}^* + |U_{\mathrm{R}}|^2 + |U_{\mathrm{O}}|^2 + U_{\mathrm{O}}^* U_{\mathrm{R}}$$

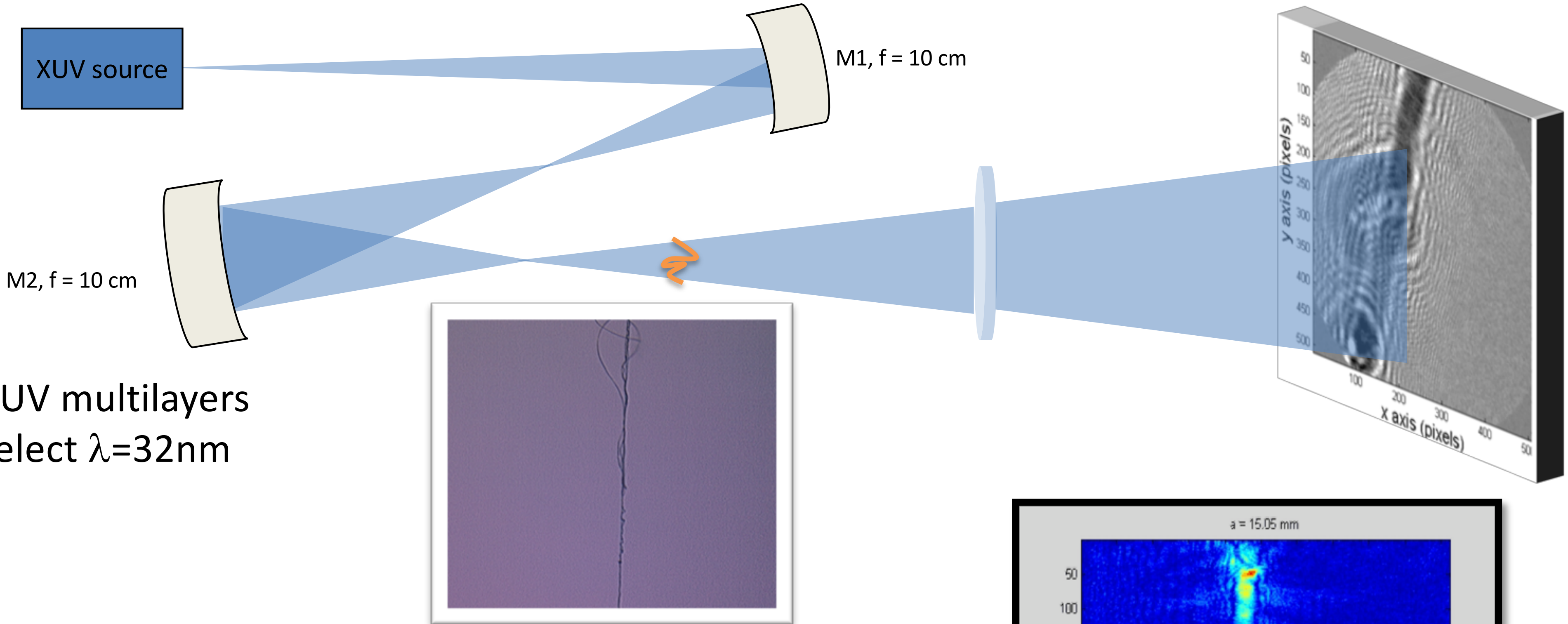
$$T = kU_{\mathrm{O}} U_{\mathrm{R}}^* + k|U_{\mathrm{R}}|^2 + k|U_{\mathrm{O}}|^2 + kU_{\mathrm{O}}^* U_{\mathrm{R}}$$

$$U_H = TU_{\mathrm{R}} = kU_{\mathrm{O}}|U_{\mathrm{R}}|^2 + k|U_{\mathrm{R}}|^2 U_{\mathrm{R}} + k|U_{\mathrm{O}}|^2 U_{\mathrm{R}} + kU_{\mathrm{O}}^* U_{\mathrm{R}}^2$$

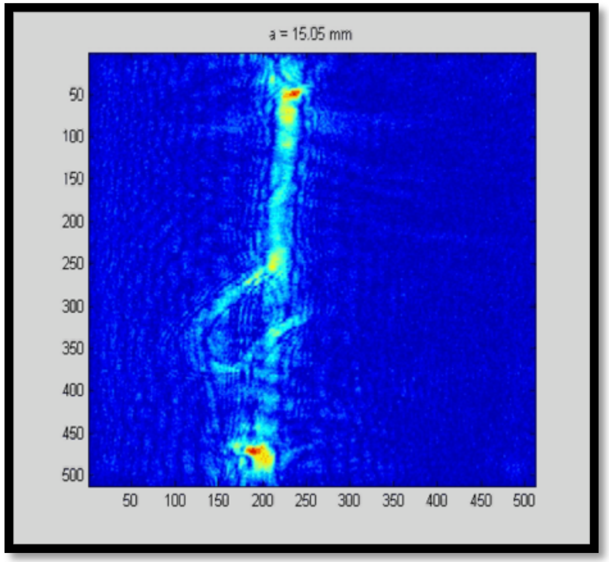




We did 3D "microscopy" in the XUV



XUV multilayers
select λ=32nm

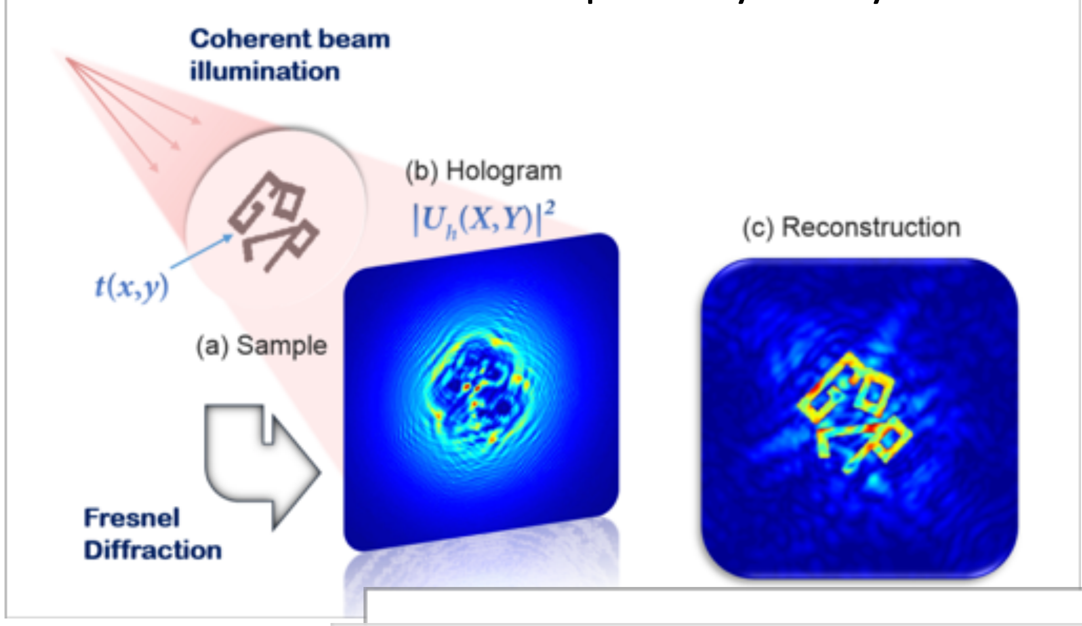


Gabor inline digital holography

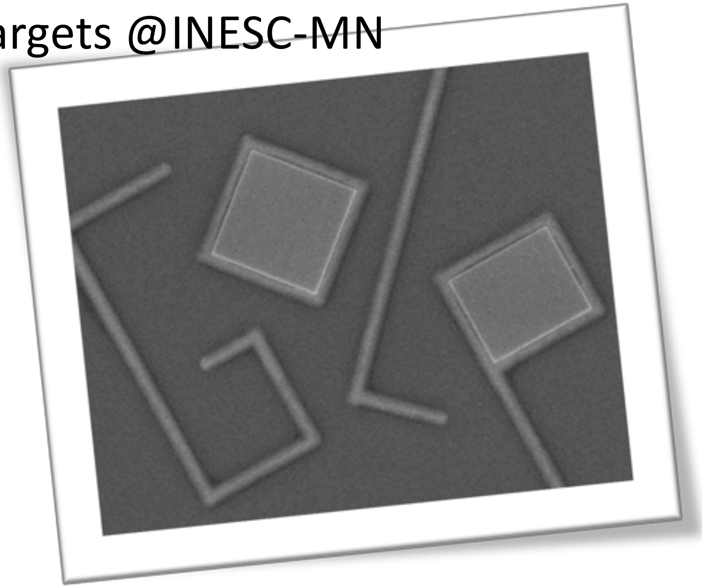
Achieved resolution: 800 nm in 2D, 140x magnification
Depth of field: limited by Numerical Aperture: >100µm
A. S. Morlens et al, Opt. Letters 2006

Aberrations at the source degrade the image

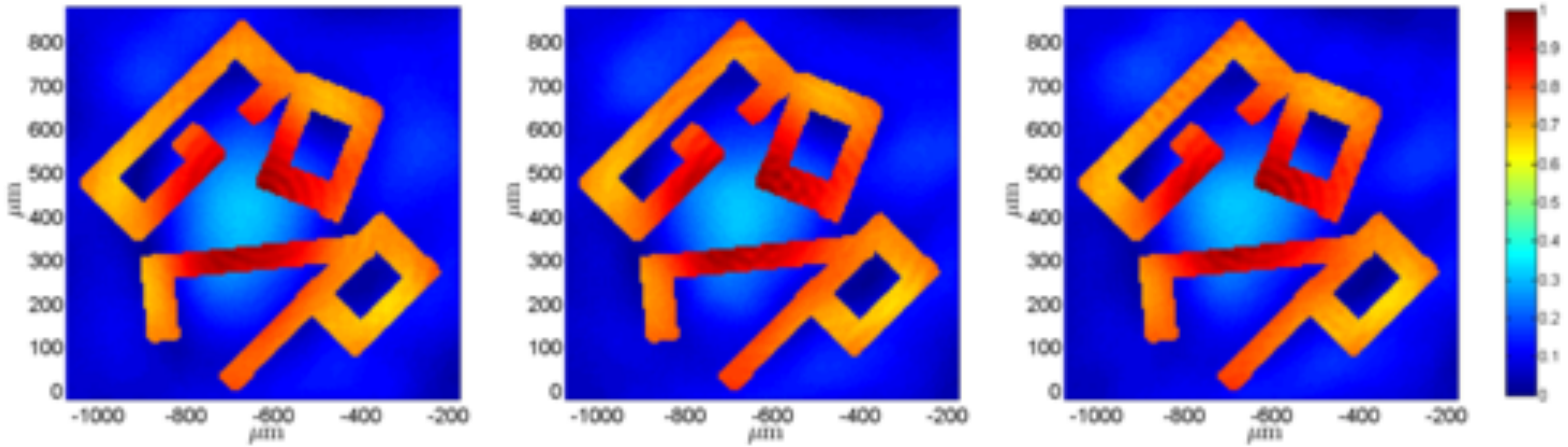
Cleaning up reconstruction
Inspired by T Latychevskaia



Targets @INESC-MN



J. Duarte, Masters thesis 2016

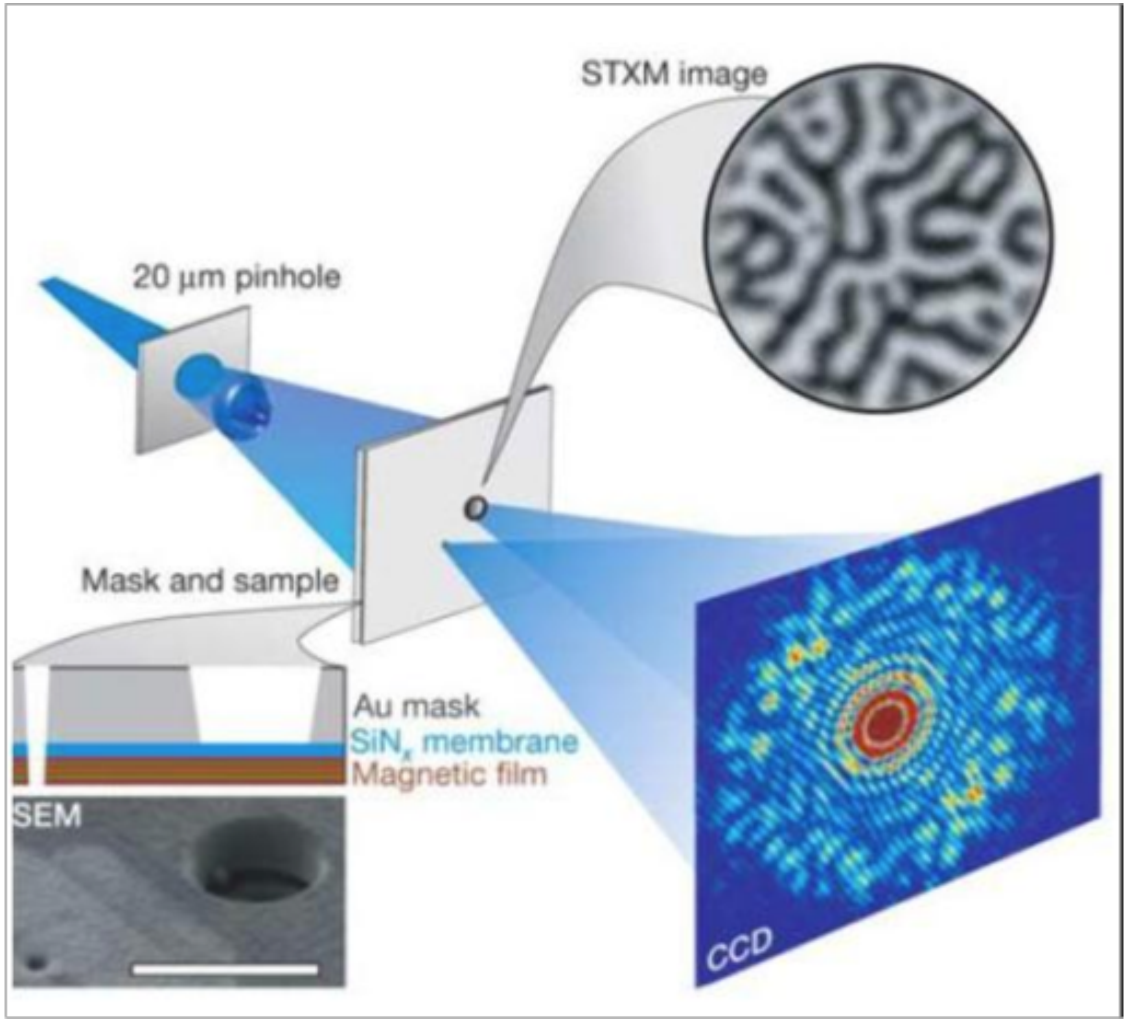


(a) Reconstruction of $Z = 20$ cm, with an astigmatism 0º of coefficient $C_2^2 = -5$.

(b) Reconstruction of $Z = 20$ cm, with an astigmatism 0º of coefficient $C_2^2 = 0.5$.

(c) Reconstruction of $Z = 20$ cm, with an astigmatism 0º of coefficient $C_2^2 = 2$.

Fourier Holography gives better resolution



Benefits: increased numerical aperture

$$d \sim \lambda/NA$$

Resolution limit ~ size of pinhole for reference wave

Drawbacks:

- No depth – it's 2D
- Balancing the two waves

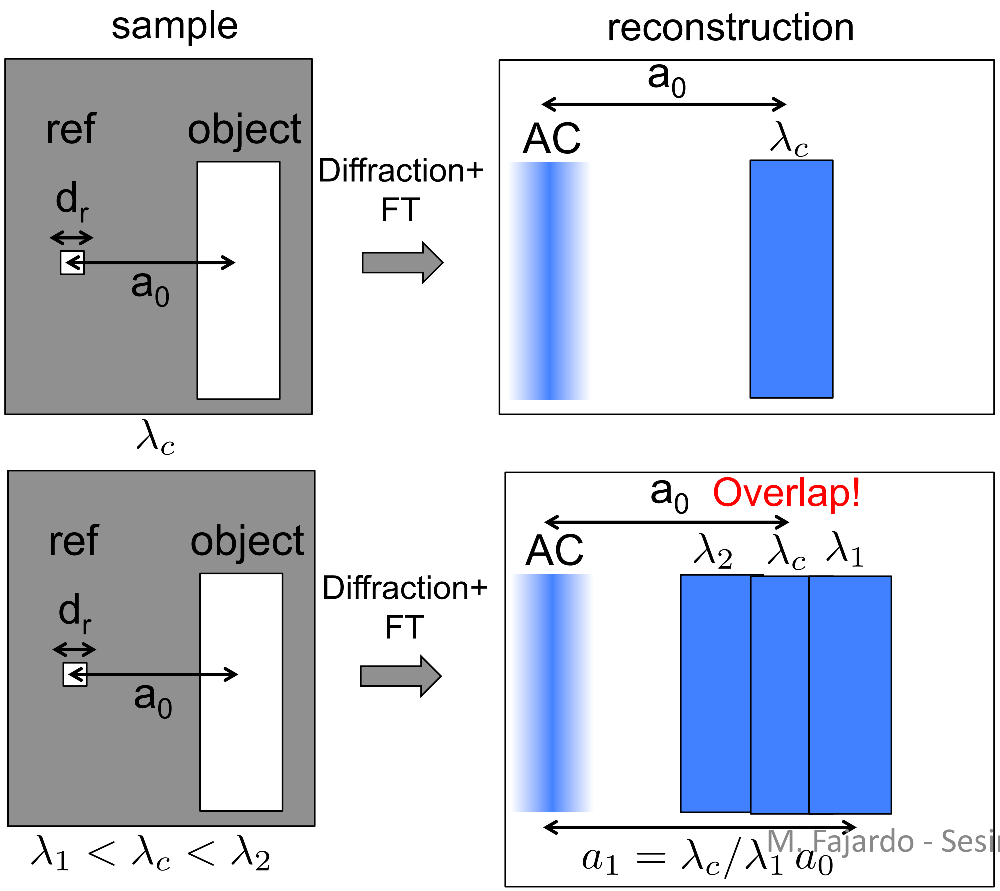
Applications: Holography

Multicolor / Attosecond holography

HHG pulses can produce several discrete HH orders or a continuous XUV spectrum with attosecond duration

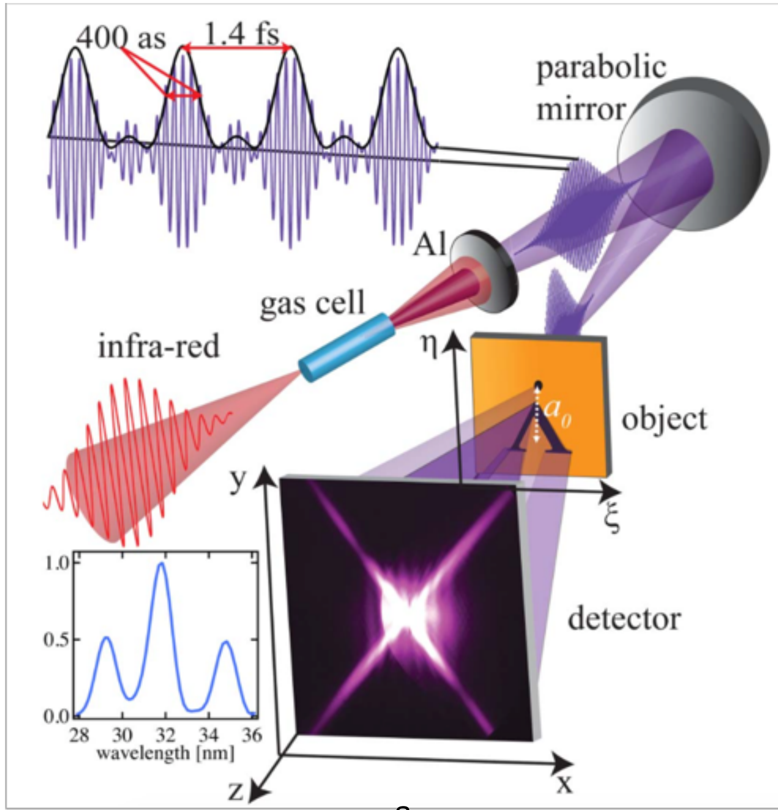
⇒ Ultra-fast dynamic processes can be imaged

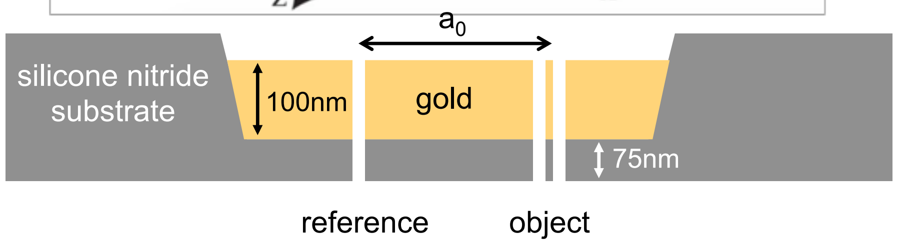
Broad bandwidth or several discrete wavelengths requires careful target design.



Goals / Experimental setup

- Demonstrating FTH with several discrete wavelengths



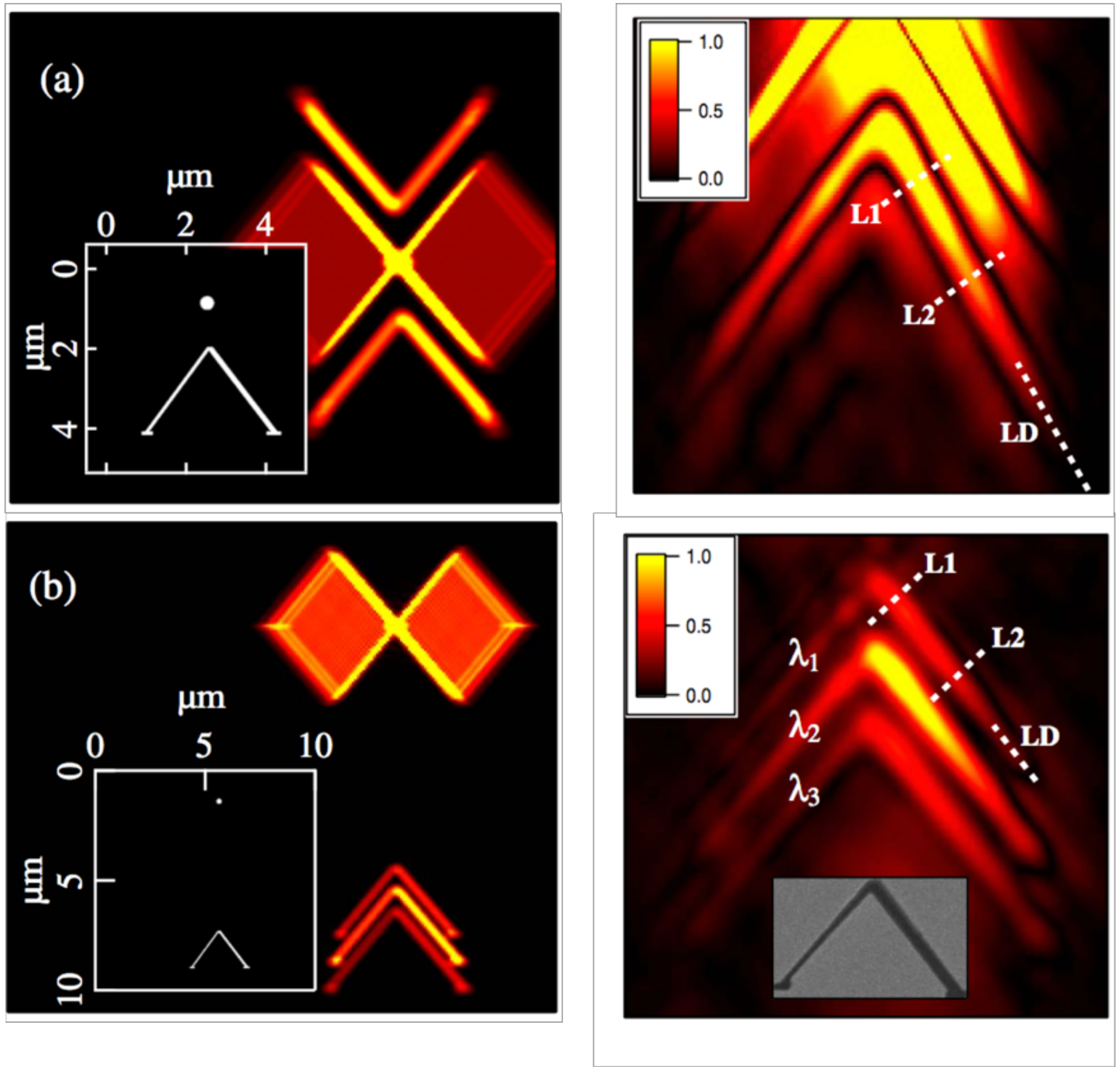


Applications: Holography - Results

simulation | experiment | resolution

Broadband/
Overlap
a_0~2 µm

Discrete/
Separate
a_0~6 µm



L1: 130 nm
L2: 130 nm
LD: 660nm

If spectrum was continuous:
~5 nm bandwidth @ 32 nm
correspond to 250 as

L1: 100 nm
L2: 100 nm
LD: 190 nm

Nano-metric spatial resolution spectrally resolved!

Published: Fourier transform holography with high harmonic spectra for attosecond imaging applications." Optics Letters 40.13, 3205-3208 (2015)

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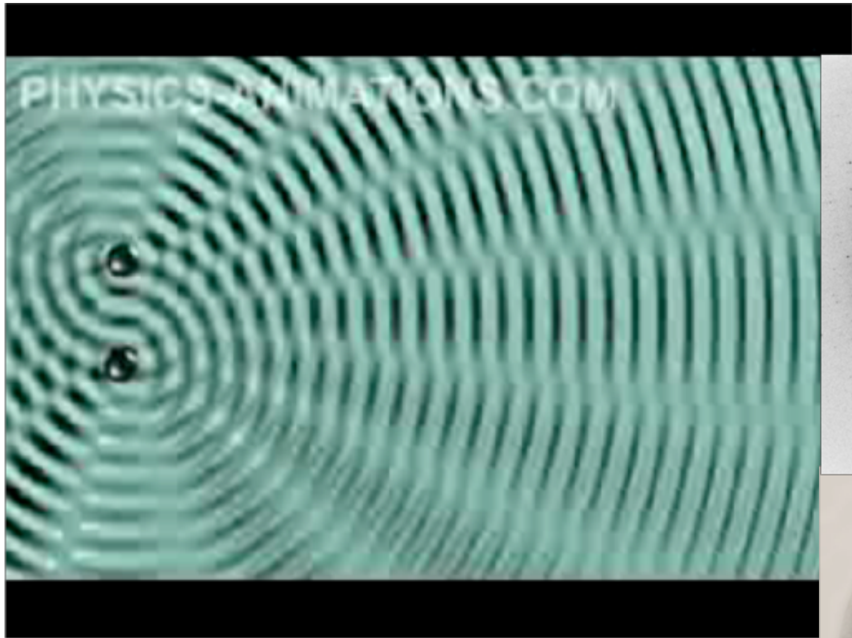
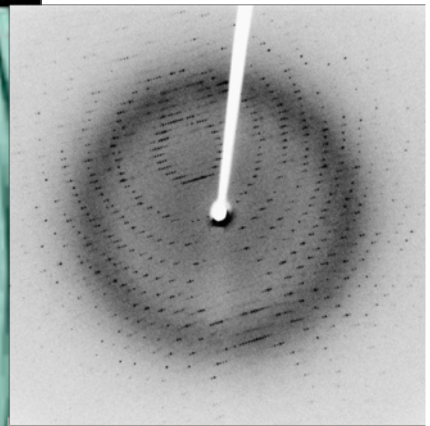
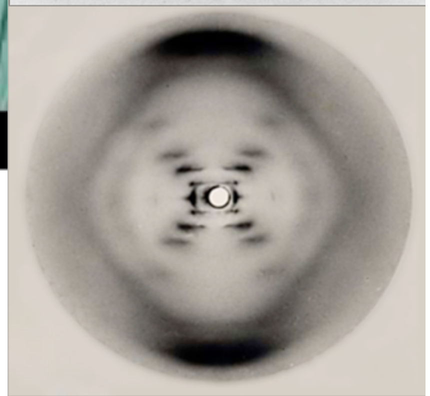
Lenslens imaging 1: Crystallography

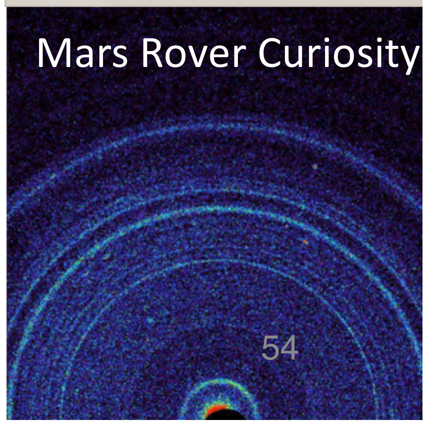
X-ray crystallography uses the known relationship between the far-field and the object

A plane wave incident on an object is scattered.
Scattered waves interfere



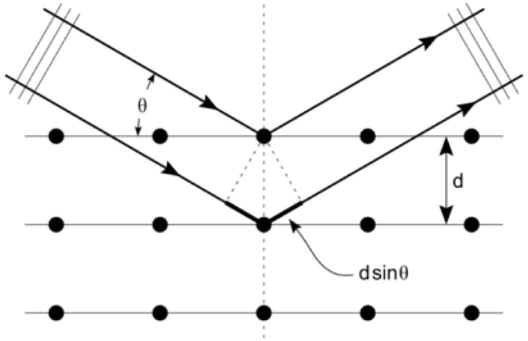






$$F(\mathbf{k}) = \int_{-\infty}^{\infty} f(\mathbf{x}) \exp(2\pi i \mathbf{k} \cdot \mathbf{x}) d\mathbf{x}$$

28 Nobel prizes using this technique



Bragg peaks

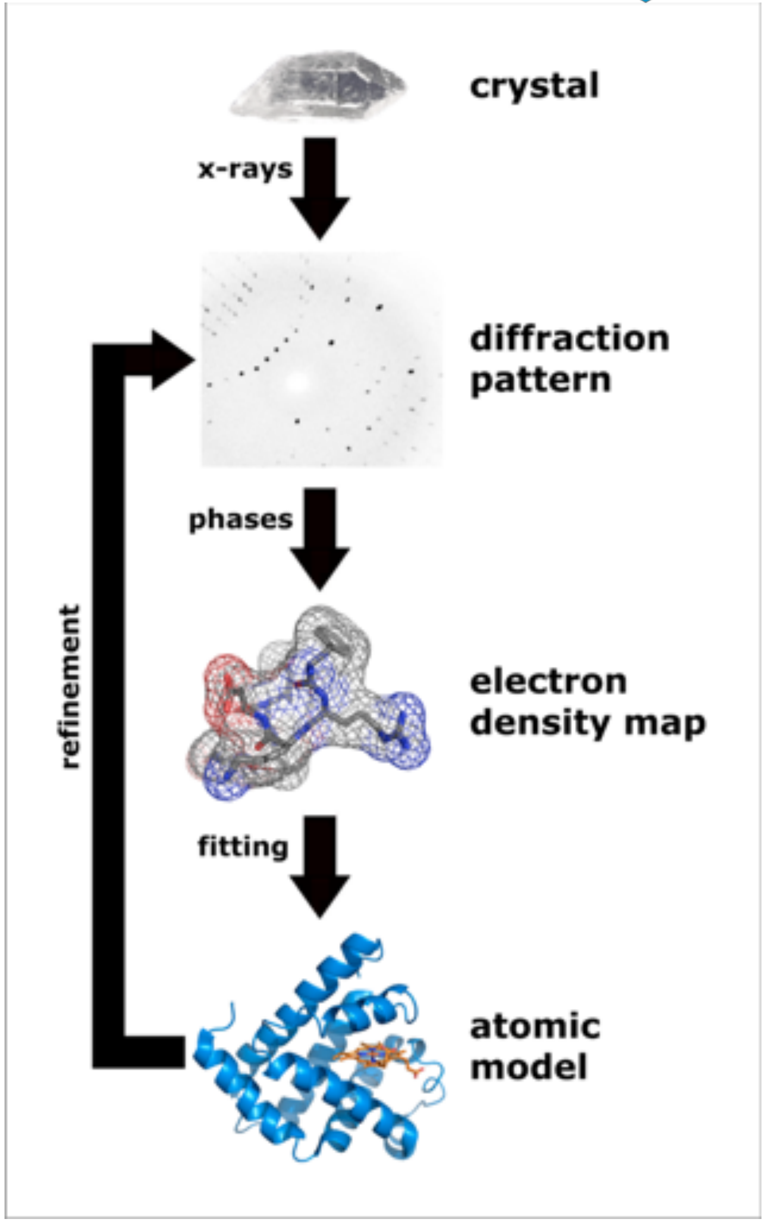
Lenslens imaging 2: Coherent Diffraction Imaging

The Fourier Transform encodes the object

But one can only measure the Intensity: the phase is lost

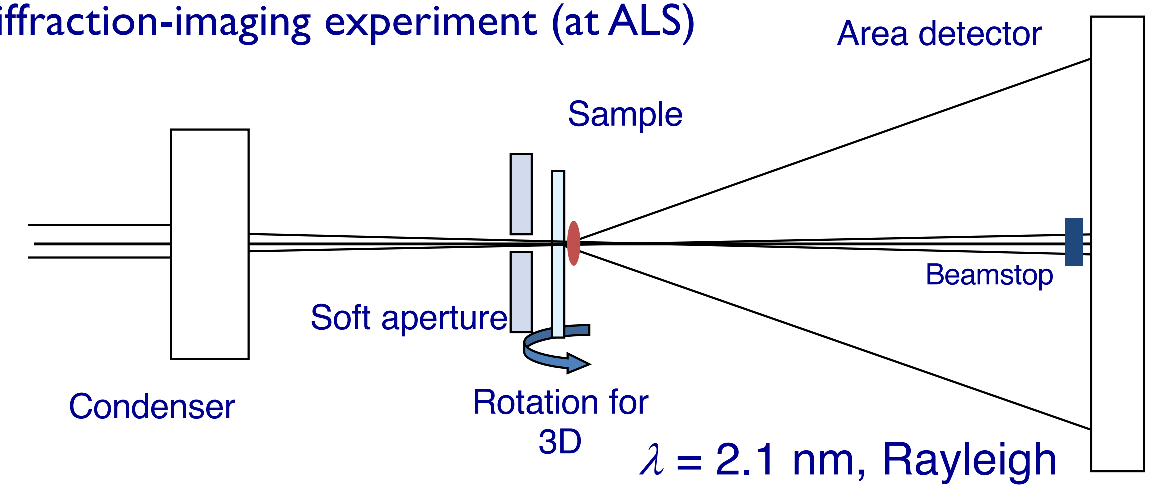
Solution: a Phase Guessing algorithm

Review: Coherent lensless X-ray imaging
Henry N. Chapman
& Keith A. Nugent
Nature Photonics 4, 833–839 (2010)



Lenslens imaging 2: Coherent Diffraction Imaging

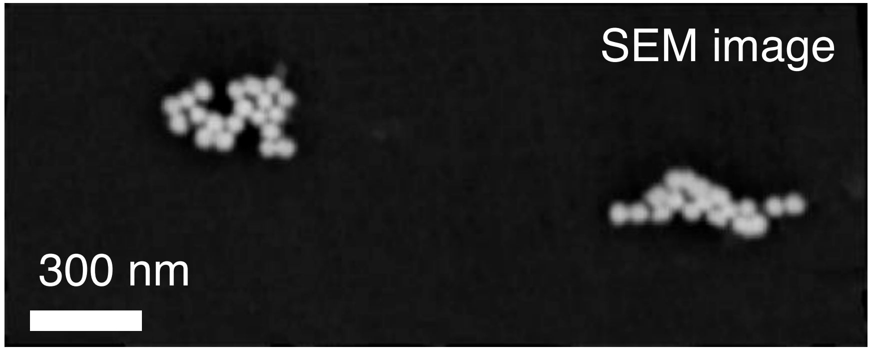
Diffraction-imaging experiment (at ALS)

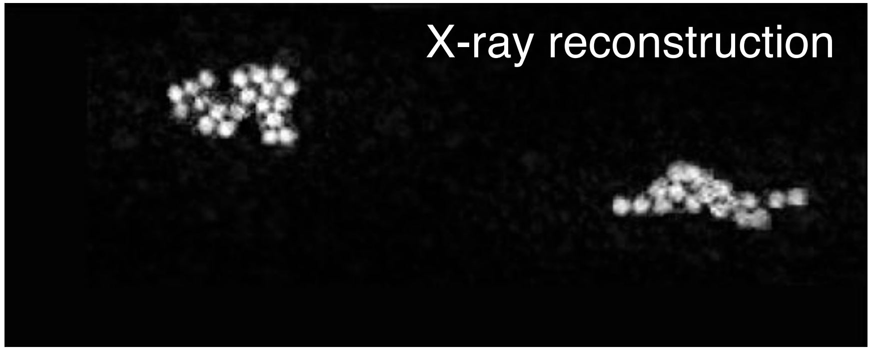


λ = 2.1 nm, Rayleigh resolution = 10 nm

X-ray diffraction pattern

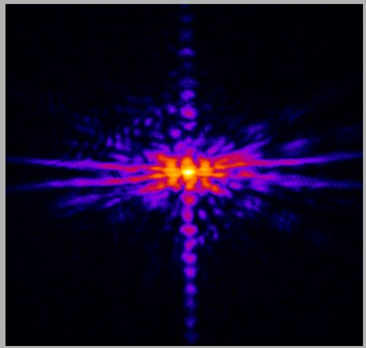
J. Miao's group in the US demonstrated Coherent Diffraction Imaging with non-periodic samples in 2004





Sample: 50 nm gold spheres

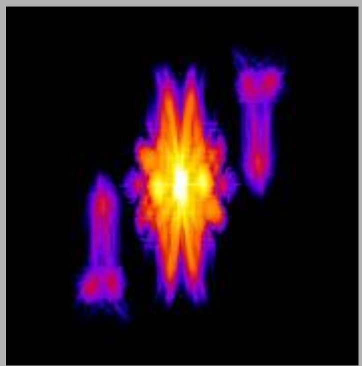
Reconstruction: Full wave



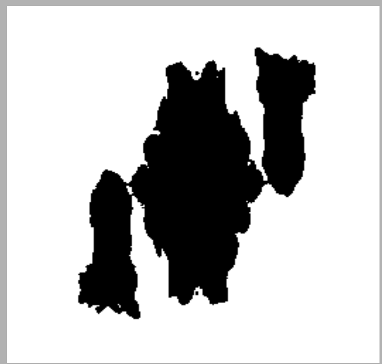
Fourier amplitudes constraints

The square of the Fourier transform is equal to the measured intensities

TF



Support



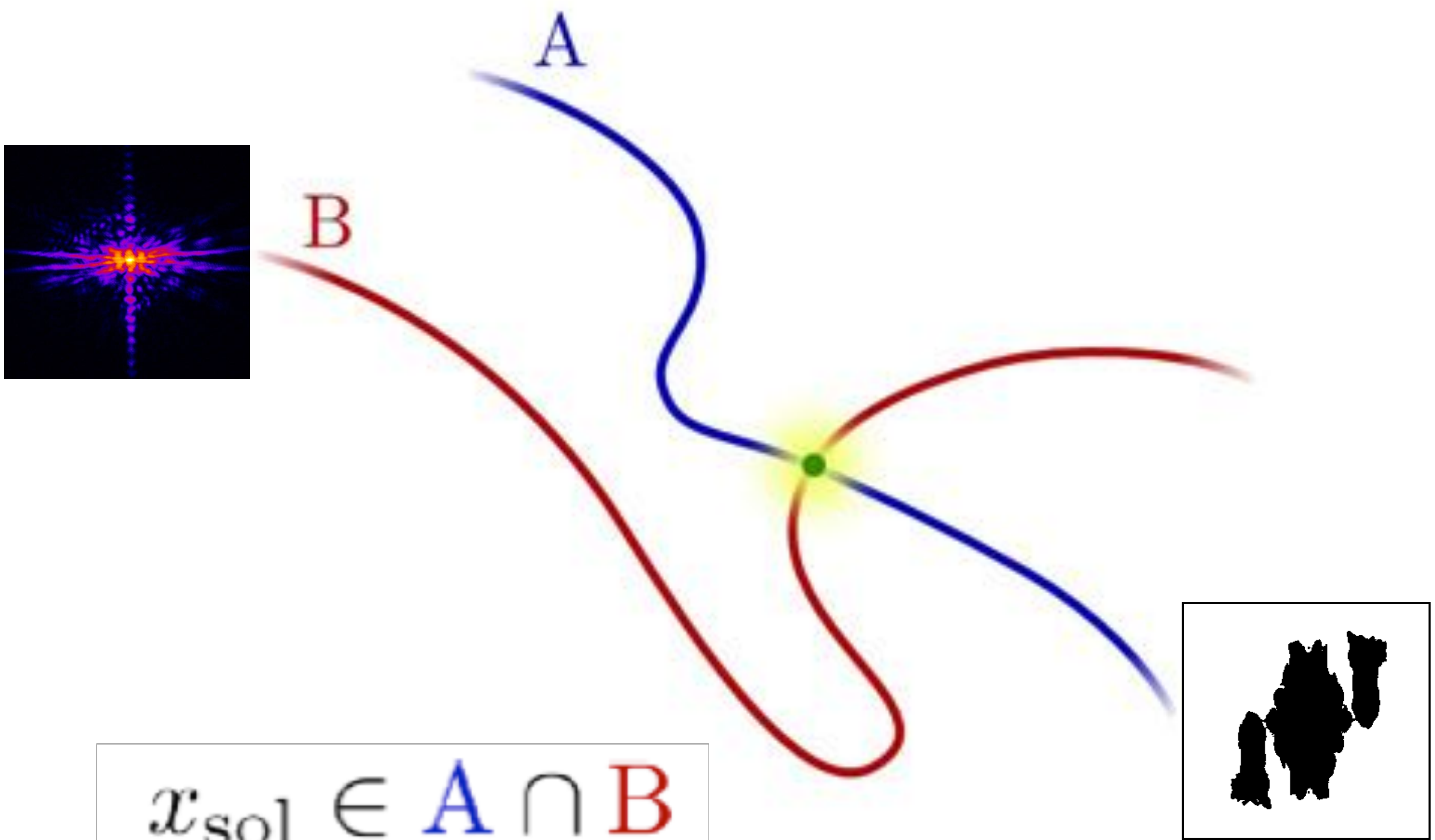
Support constraints

The reconstructed image is inside a support defined by the autocorrelation function of the object

Formalism

The solution

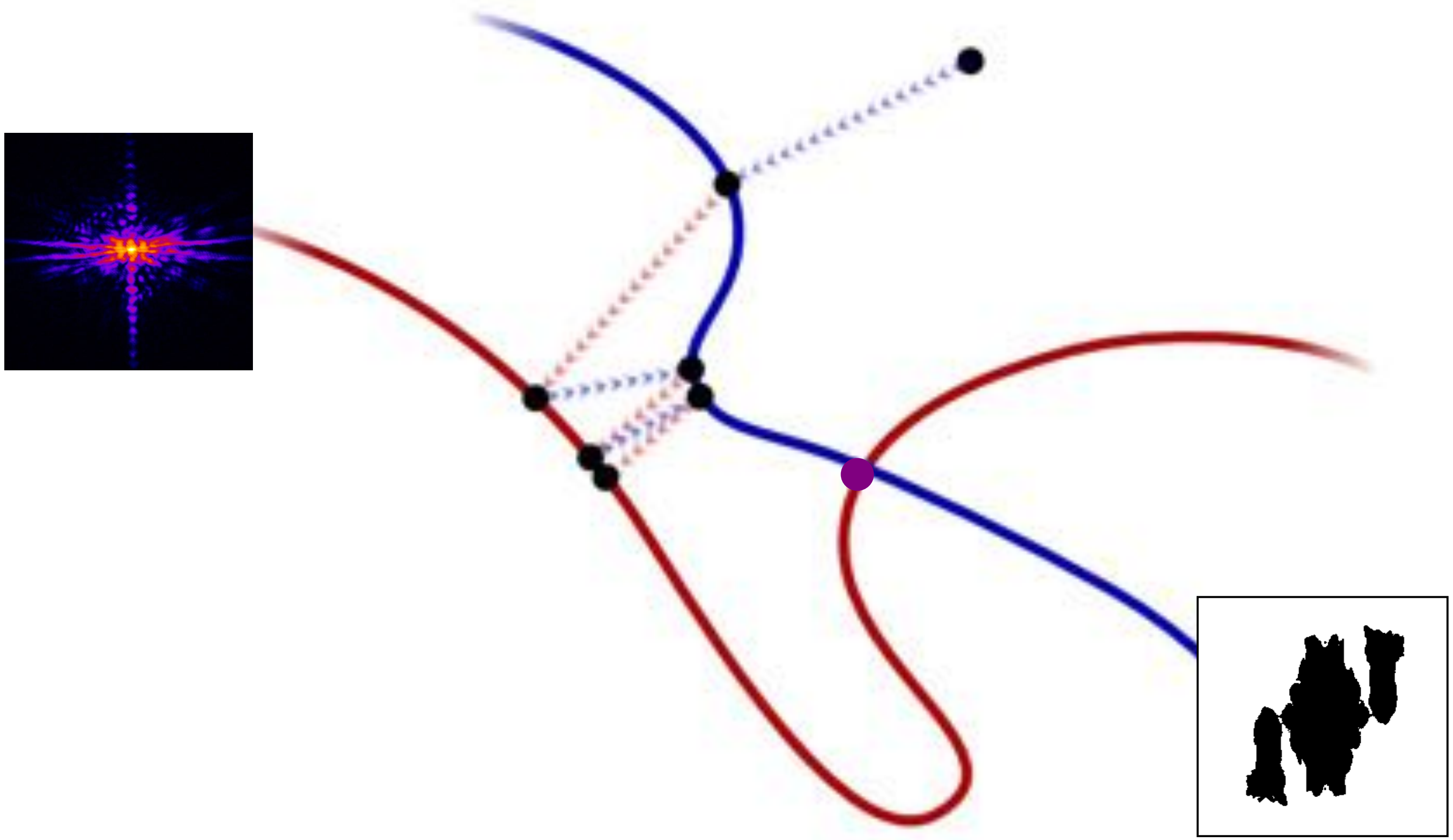
The solution is at the intersection of two constraints spaces



$$x_{\mathrm{sol}} \in A \cap B$$

Formalism

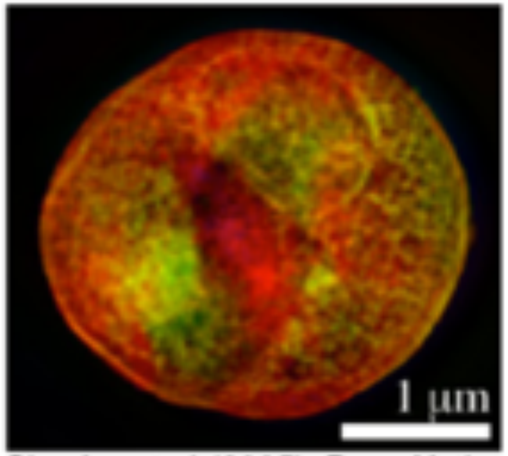
Iterative algorithm



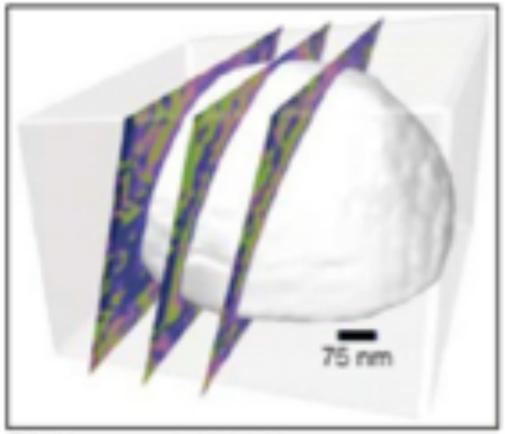
Recent demonstrations

Miao *et al.* (1999). Nature, **400**, 342–344.

Chapman *et al.* (2006). J. Opt. Soc. Am. A, **23**, 1179–1200.

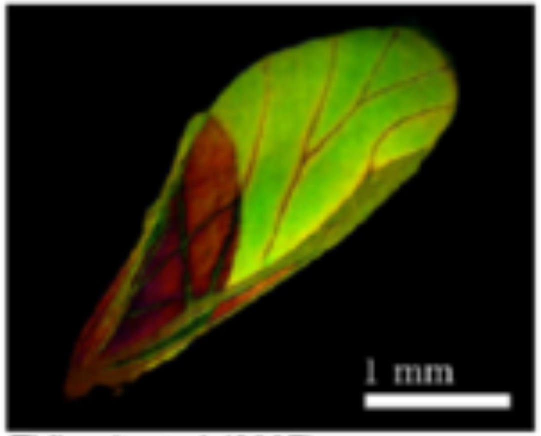


Shapiro *et al.* (2005). Proc. Natl. Acad. Sci.USA , **102**, 15343–15346.



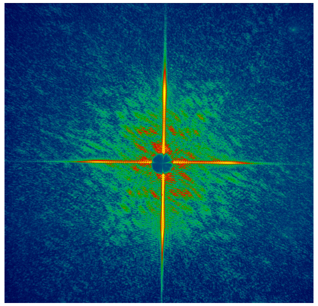
Pfeifer *et al.* (2006). Nature, **442**, 63–66.

Chapman *et al.* (2006). Nature Physics, **2**, 839–843.



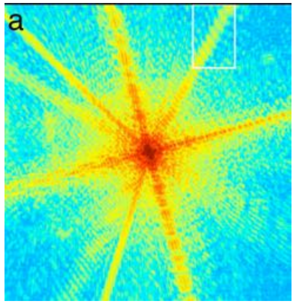
Thibault *et al.* (2007). Am. J. Phys., **75**, 827–832.

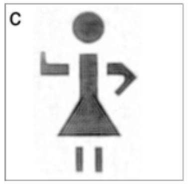
Coherent diffractive imaging with ultrafast coherent soft X-ray sources



Soft X-ray Free Electron Laser

Chapman et al., Nature Phys. 2006



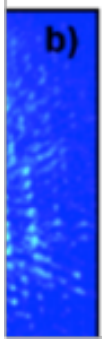


Soft X-ray High harmonic source

Sandberg et al., PRL 2007, PNAS 2008

$\Rightarrow$ **Hour acquisition time:100000 shots!**

REVIEW LETTERS — week ending 31 AUGUST 2007

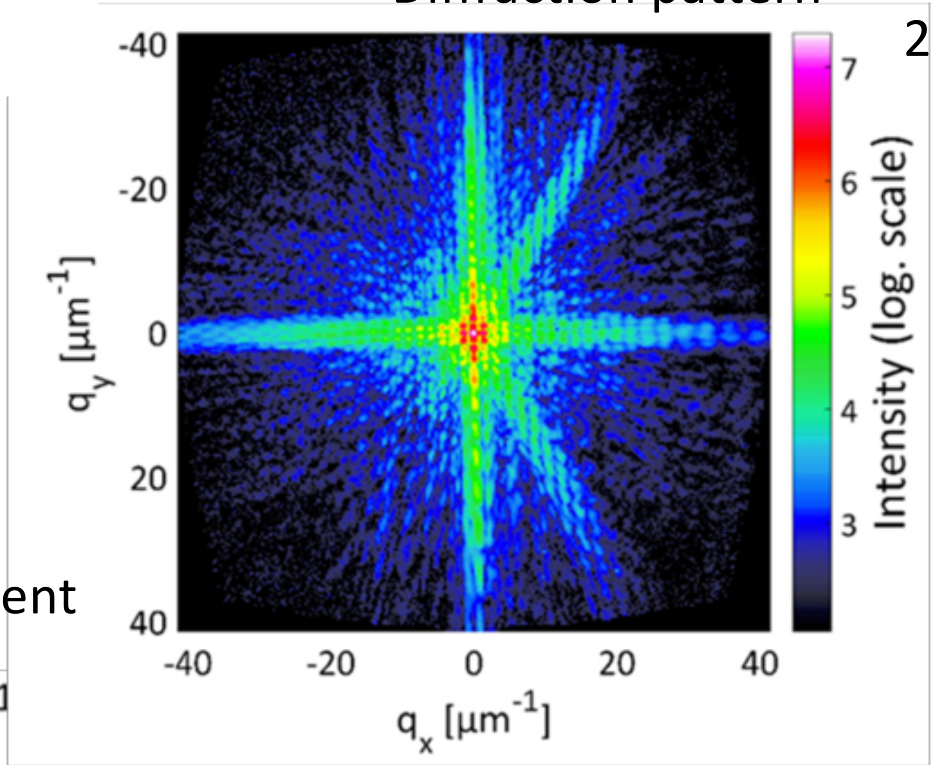


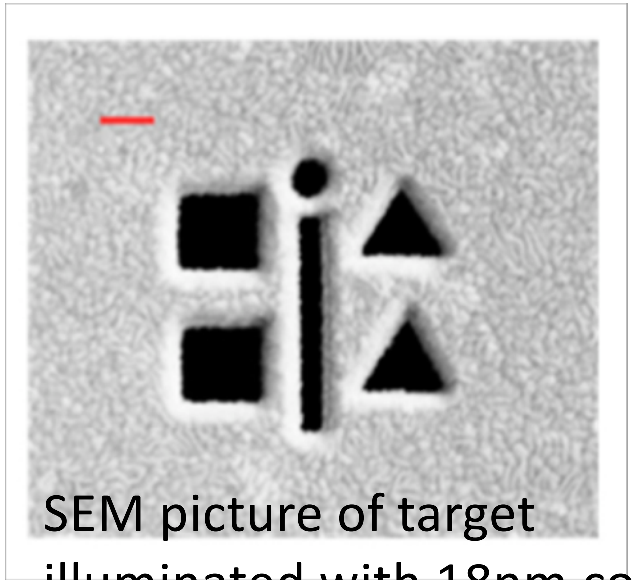
order that can result in narrower bandwidths at shorter wavelengths have recently been demonstrated [23–25]. Such improvements will extend the ultimate resolution to tens of nm. As the laser repetition rates are increased from 3 kHz to tens of kHz, the soft-x-ray flux will be simultaneously increased, and acquisition time will be dramatically reduced from hours to minutes. Also, as computing

Coherent diffraction imaging

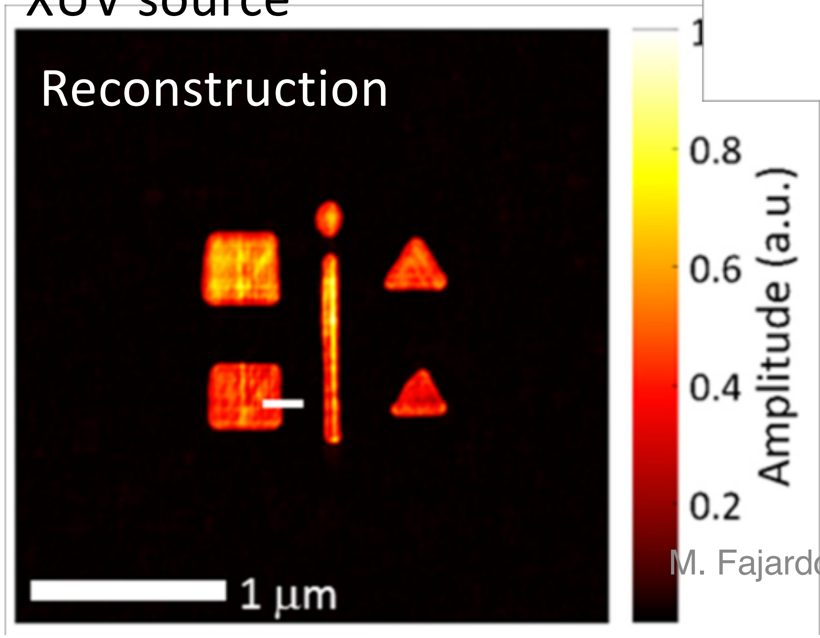
15min integration / 2.7×10^7 shots

Diffraction pattern





SEM picture of target illuminated with 18nm coherent XUV source

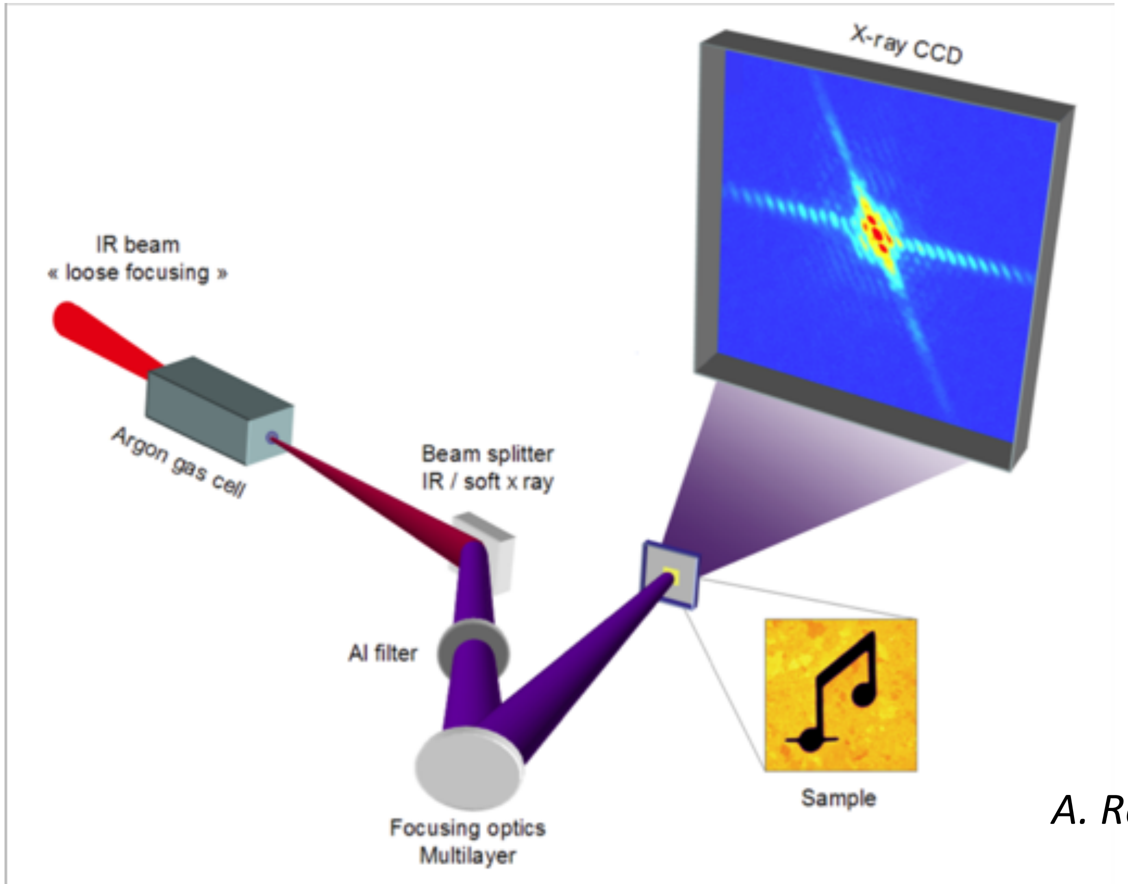


GK Tadesse et al., Opt. Express, 2016

Sub-wavelength spatial resolution: 15 nm
Diffraction limit: 12nm

We have used HHG to make single-shot diffraction imaging

Coherent diffraction in the XUV achieved 62 nm, 20 fs resolution

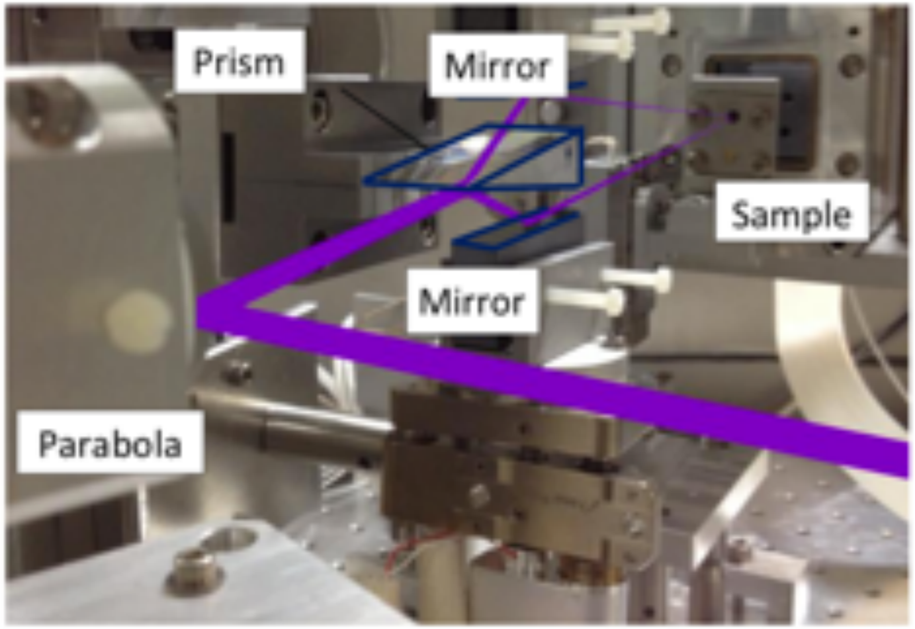


Laser energy: 35 mJ
5.5 m focal length lens
10 cm, 2 mbar argon gas cell

0:6 µJ in XUV
500 µrad divergence,
92% coherence.

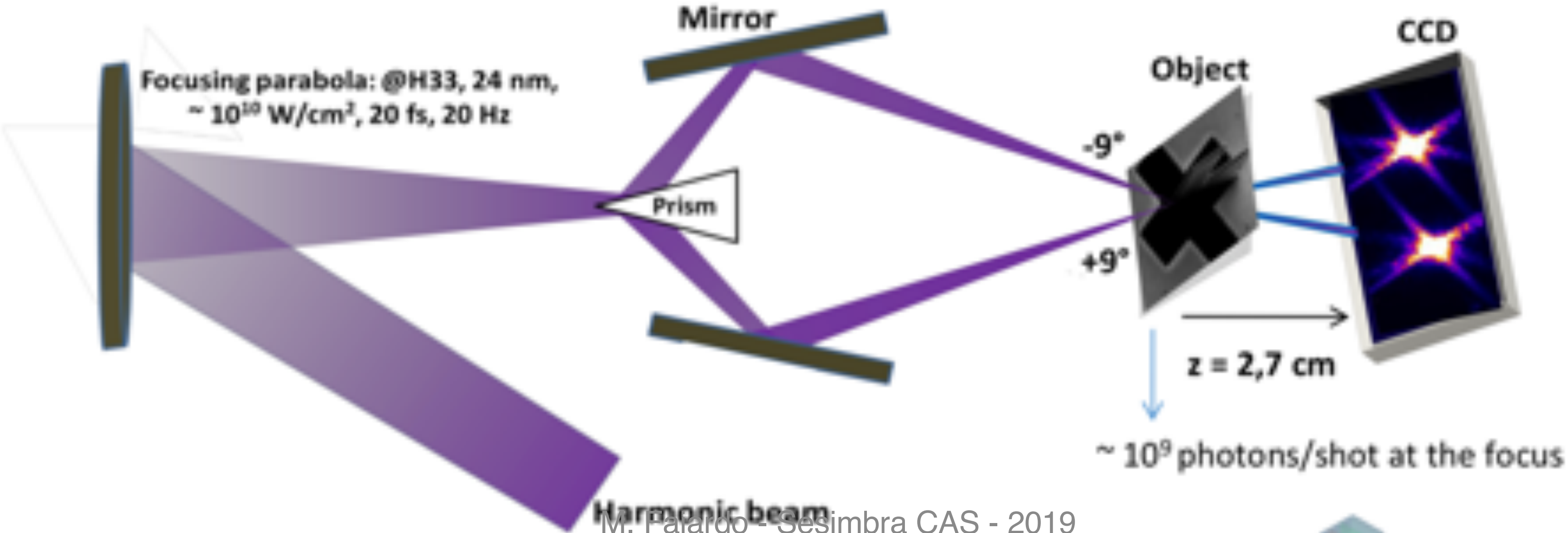
A. Ravasio et al, Phys. Rev. Letters 2009

Experimental Setup @ CEA- Saclay

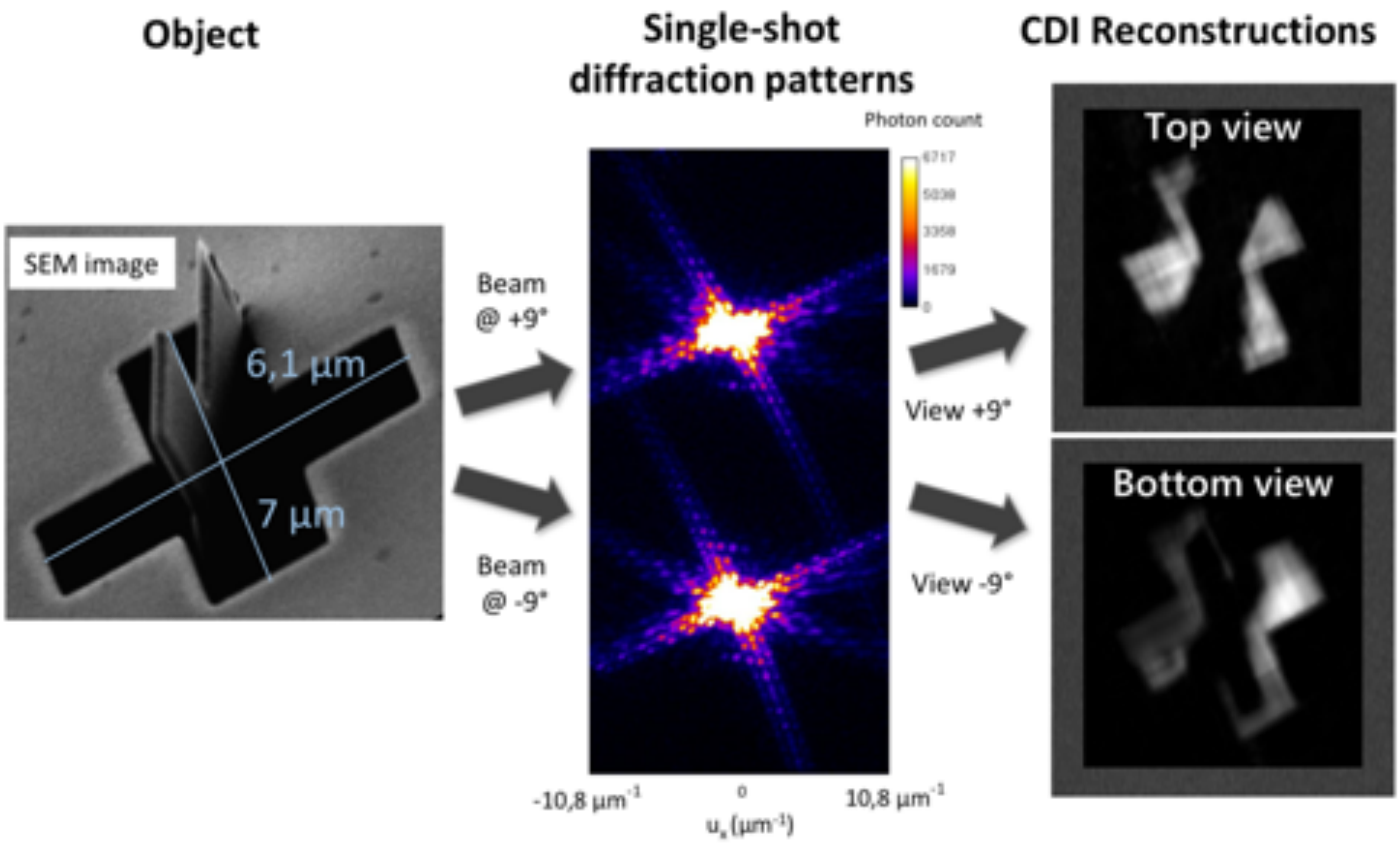


- Short exposure time (20 fs)
- Resolves dynamical processes
- 3D perspective

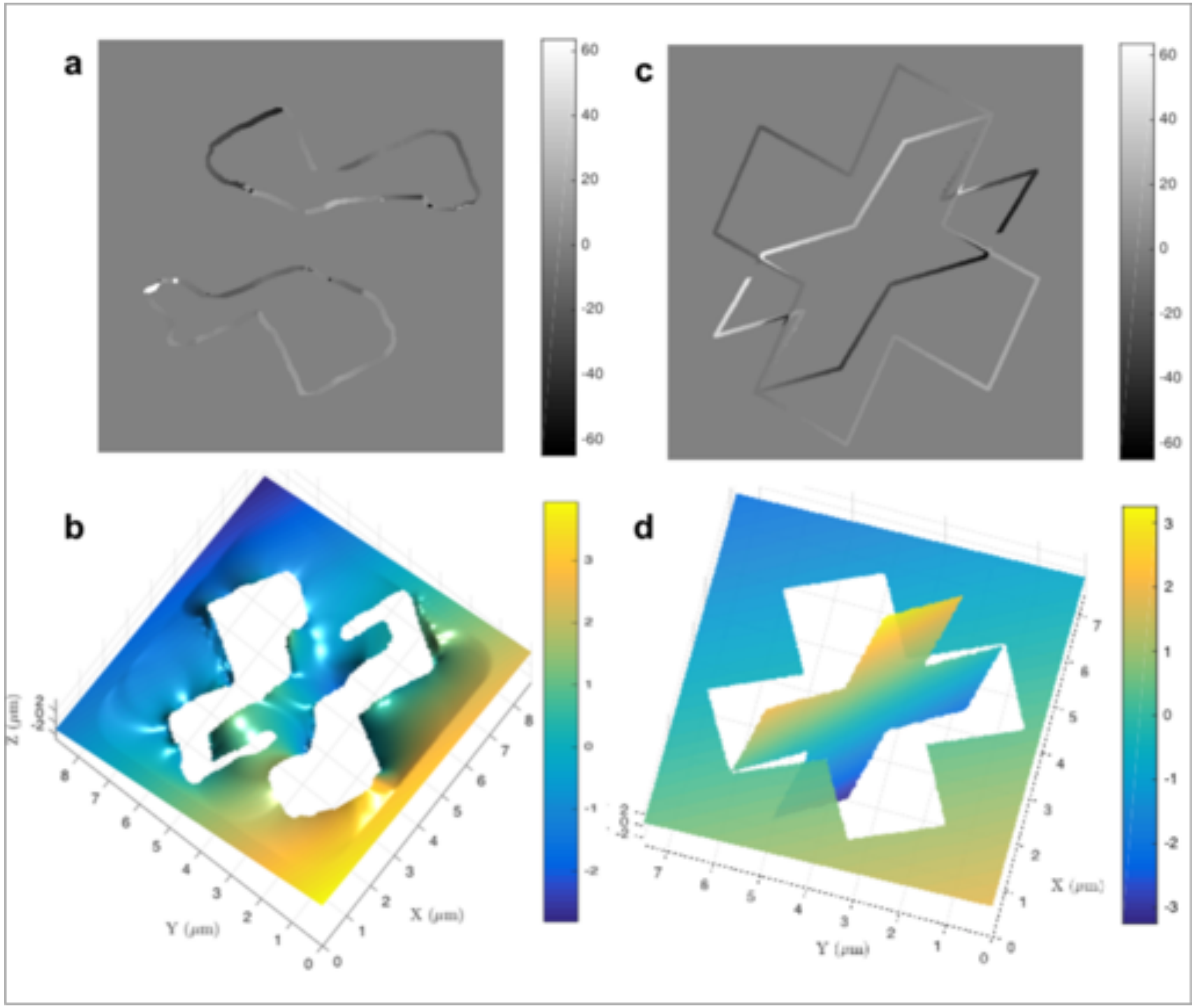
3D single-shot technique!



Experimental Data



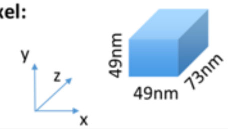
Computed phase stereo lensless X-ray imaging



Depth Accuracy:

$$\Delta_z = \frac{\Delta_r}{2\ tan\theta}\Big|_{\theta=18^o} \sim 73\ nm$$

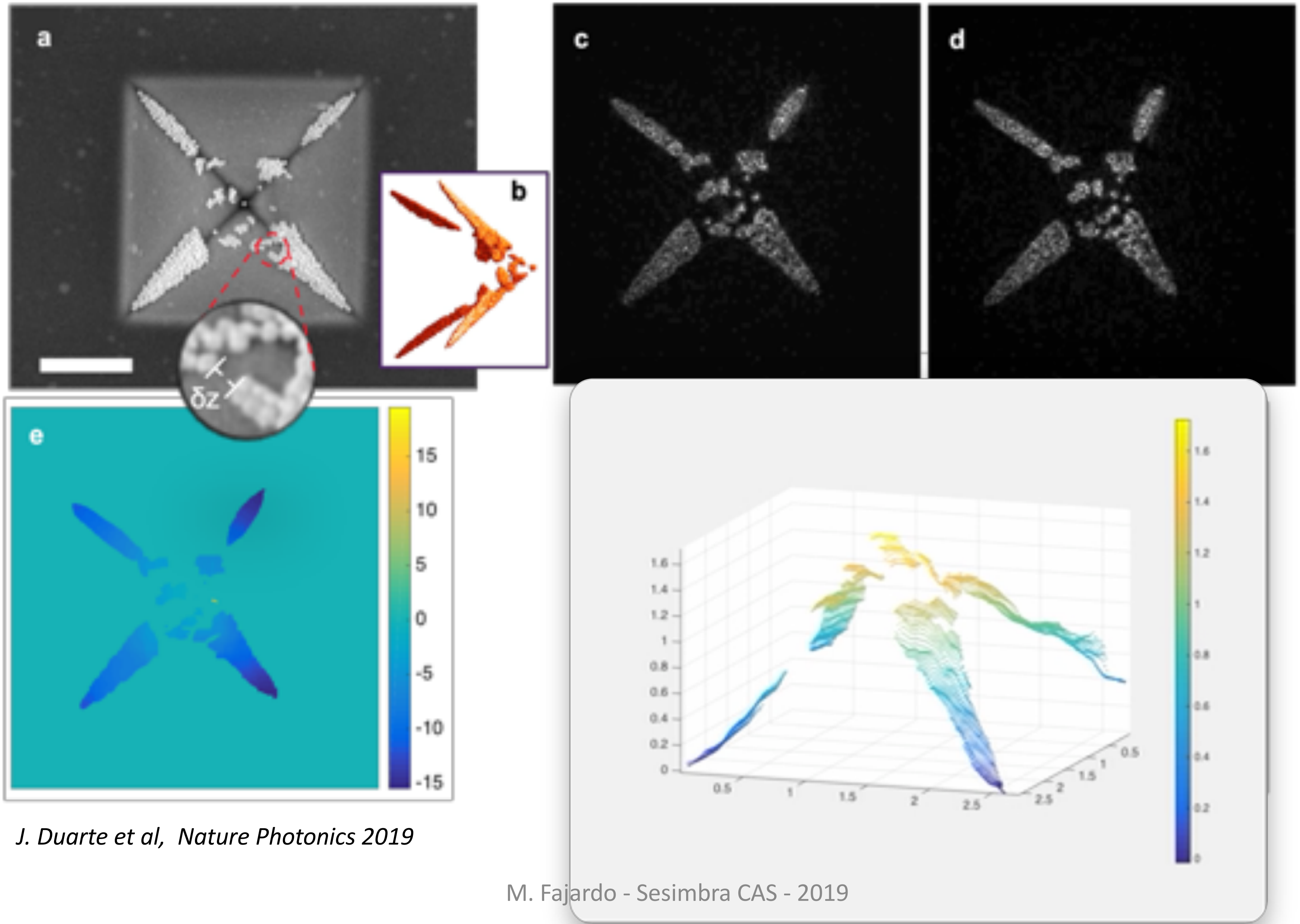
Voxel:



Also in the works:

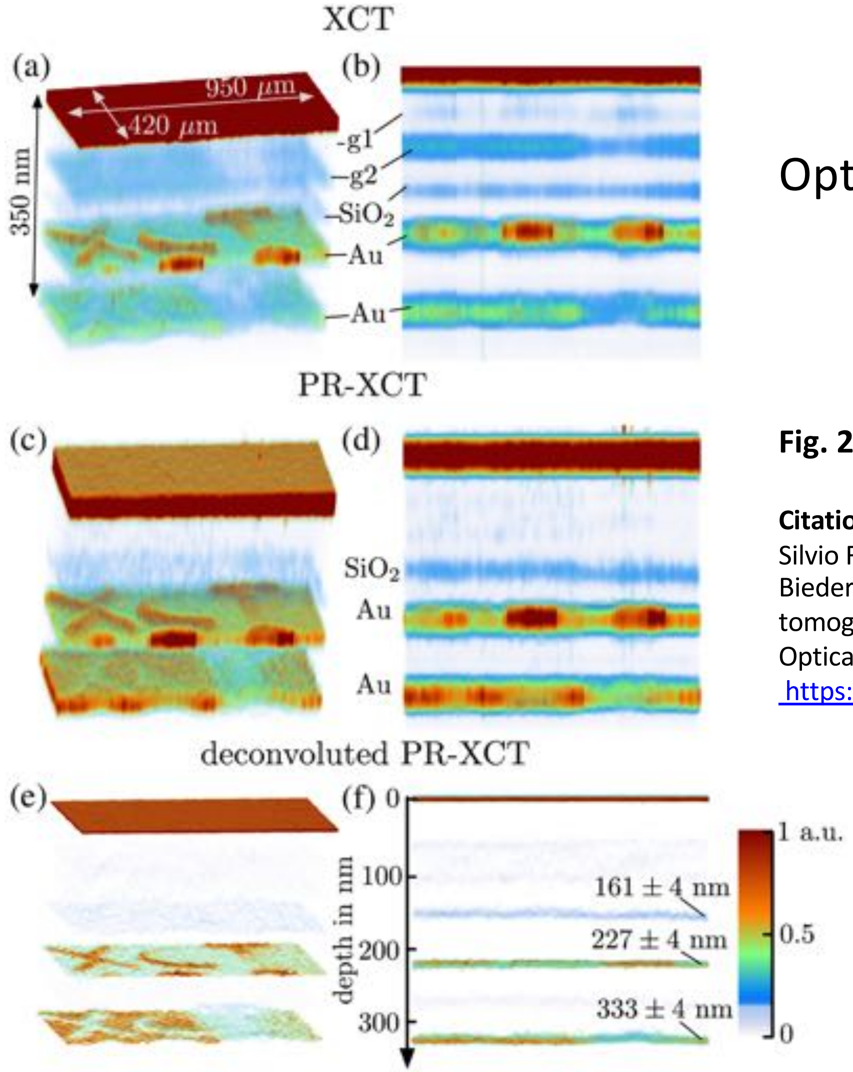
- Fourier and Gabor holography
- Wavefront sensing
- Refractive index measurement

Computed phase stereo lensless X-ray imaging : synchrotron data



J. Duarte et al, Nature Photonics 2019

Novel developments – promising perspectives for tabletop coherent imaging



Optical Coherence Tomography

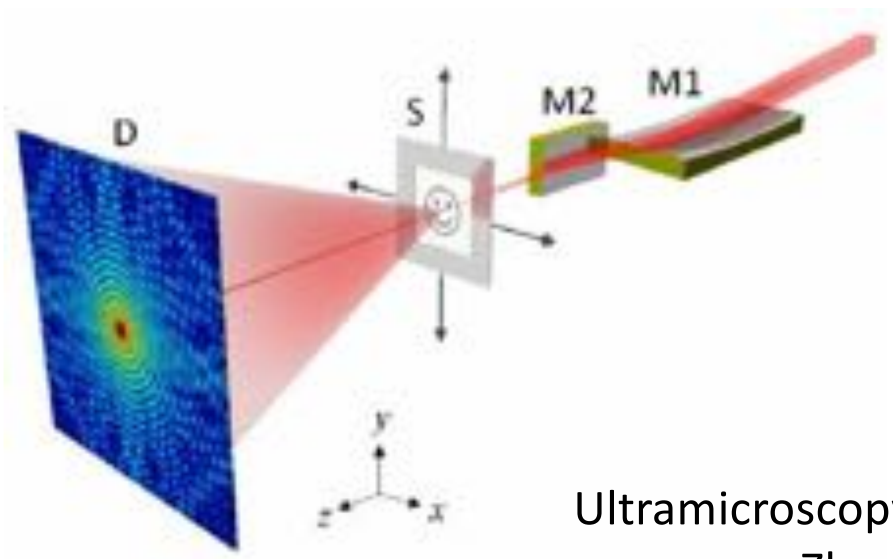
Fig. 2.

Citation
Silvio Fuchs, Martin Wünsche, Jan Nathanael, Johann J. Abel, Christian Rödel, Julius Biedermann, Julius Reinhard, Uwe Hübner, Gerhard G. Paulus, "Optical coherence tomography with nanoscale axial resolution using a laser-driven high-harmonic source," Optica **4,** 903-906 (2017);
https://www.osapublishing.org/optica/abstract.cfm?uri=optica-4-8-903

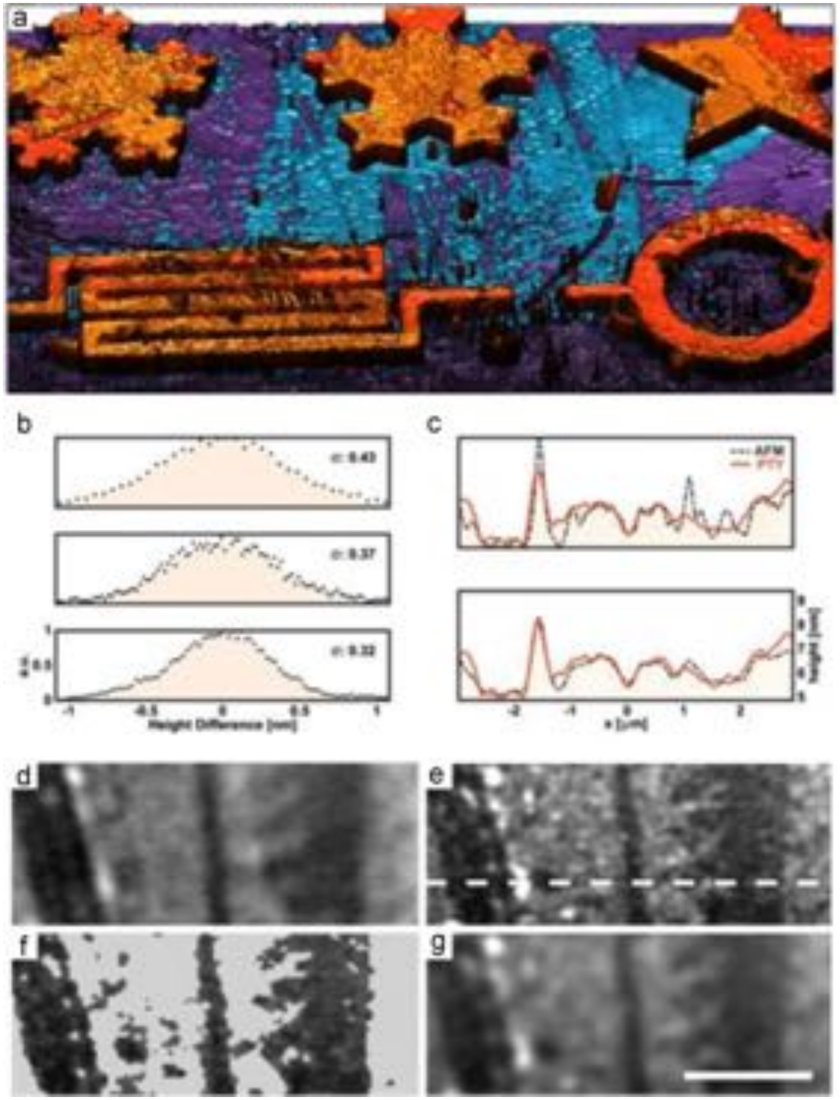
OSA
The Optical Society

Novel developments – promising perspectives for tabletop coherent imaging

X-ray Ptychography
Review: F Pfeiffer, Nature 2018



Ultramicroscopy 2015
Zhang et al



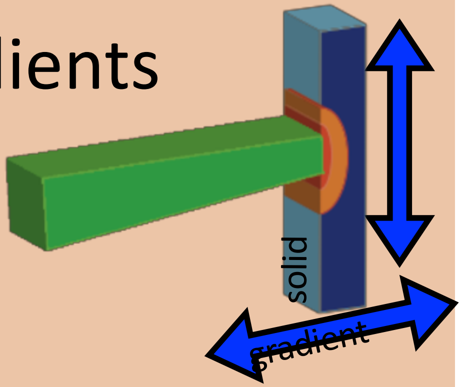
Contents

What are the material and transport properties of Warm Dense Matter

Means of access

Short-pulse IR laser

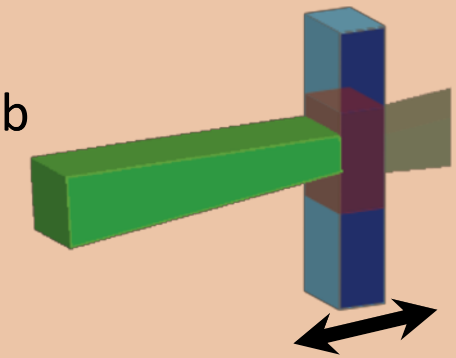
…Strong gradients



X-ray Free Electron Laser:

Macroscopic,

homogeneous slab

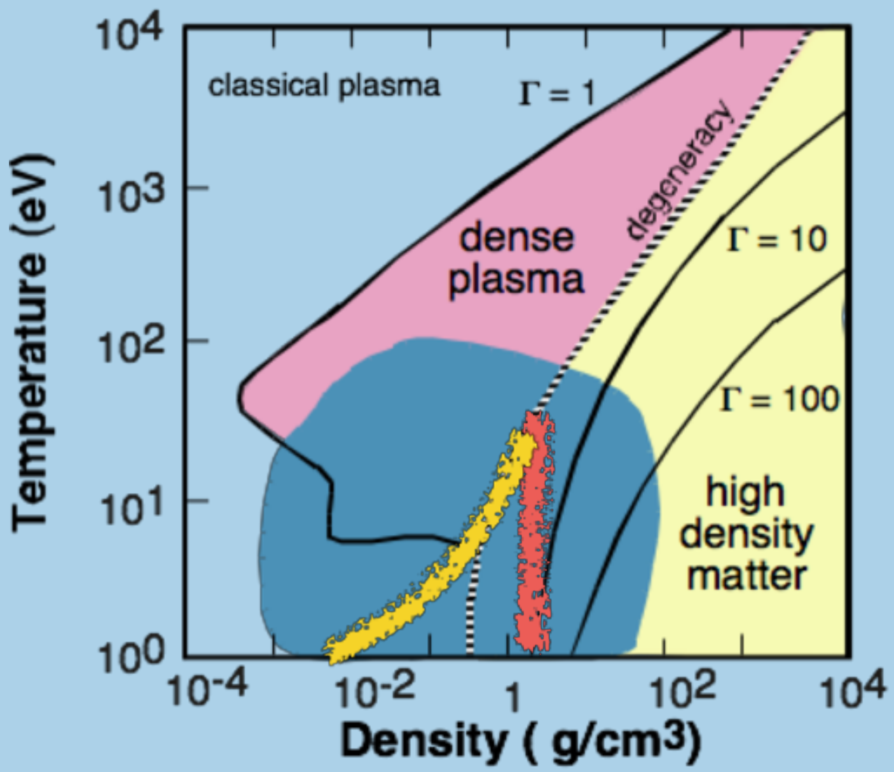


Isochoric heating

Adiabatic release

microns

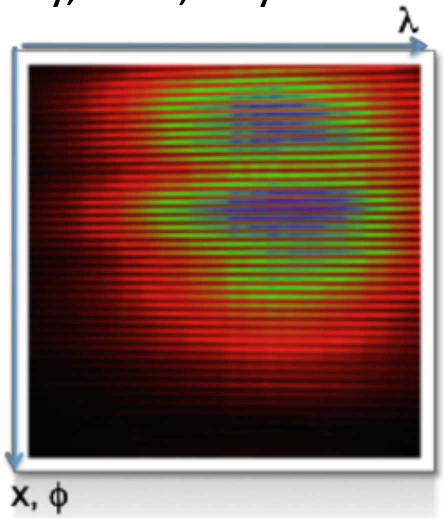
WDM: No small parameters!



First studies

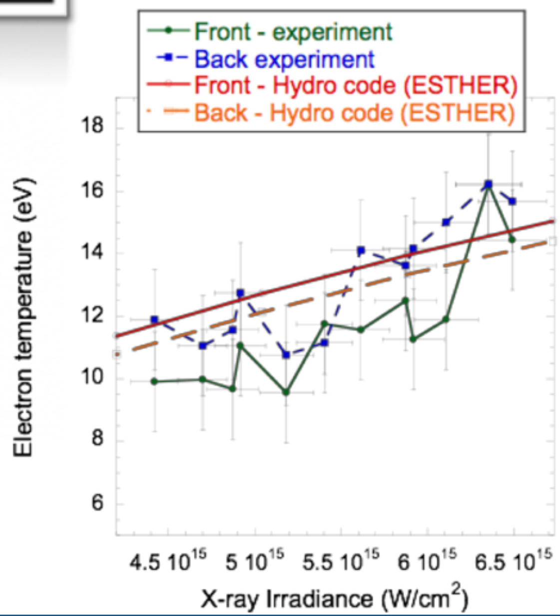
Isochoric heating, isentropic release

A. Levy, et al, Phys. Plasmas 22, 030703 (2015)



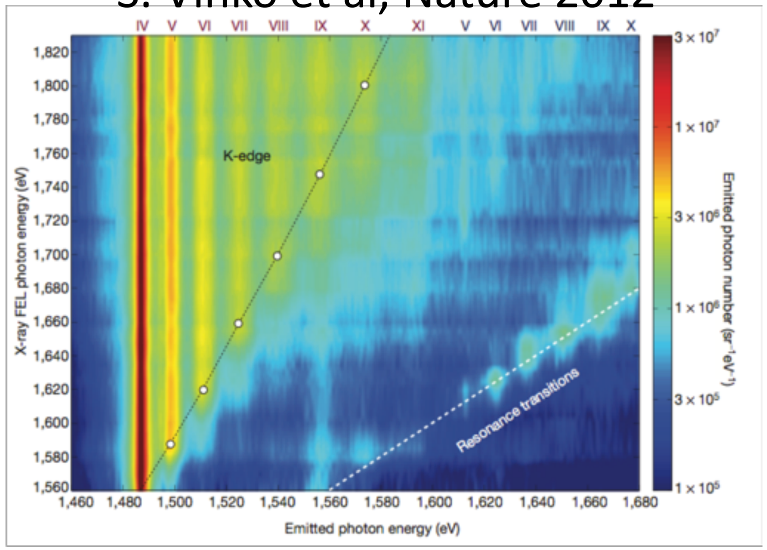
Time and space resolved interferometry of freely expanding Ag thin foil irradiated by the LCLS

Confirmation of scenario Hydrodynamic codes describe recorded expansion

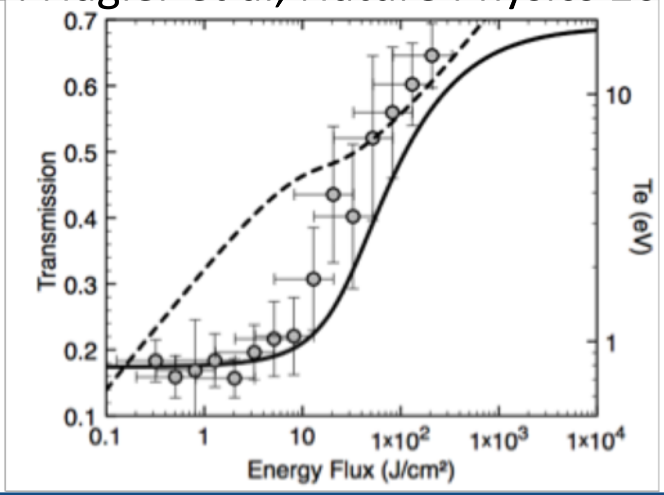


Aluminum

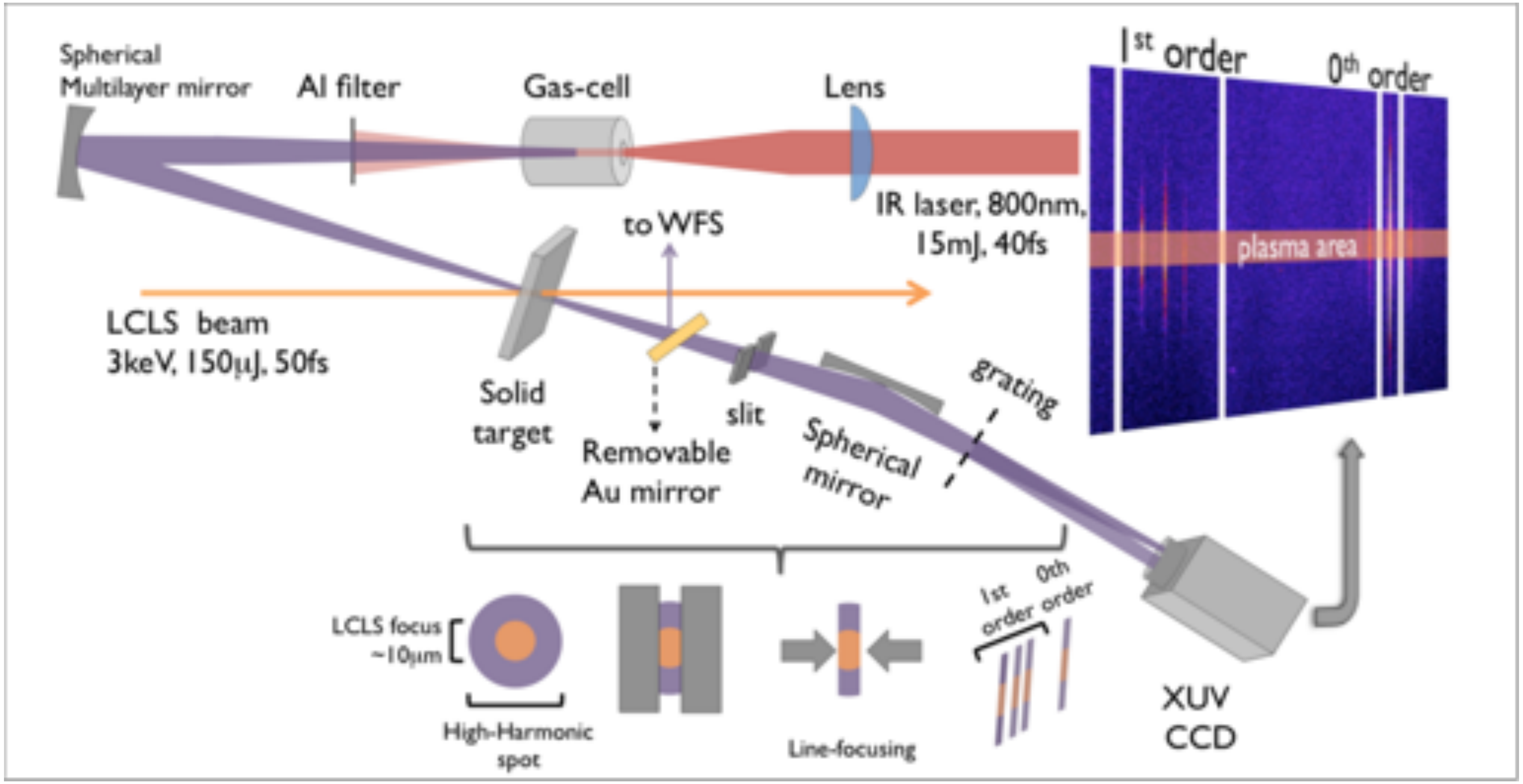
S. Vinko et al, Nature 2012



B. Nagler et al, Nature Physics 2009

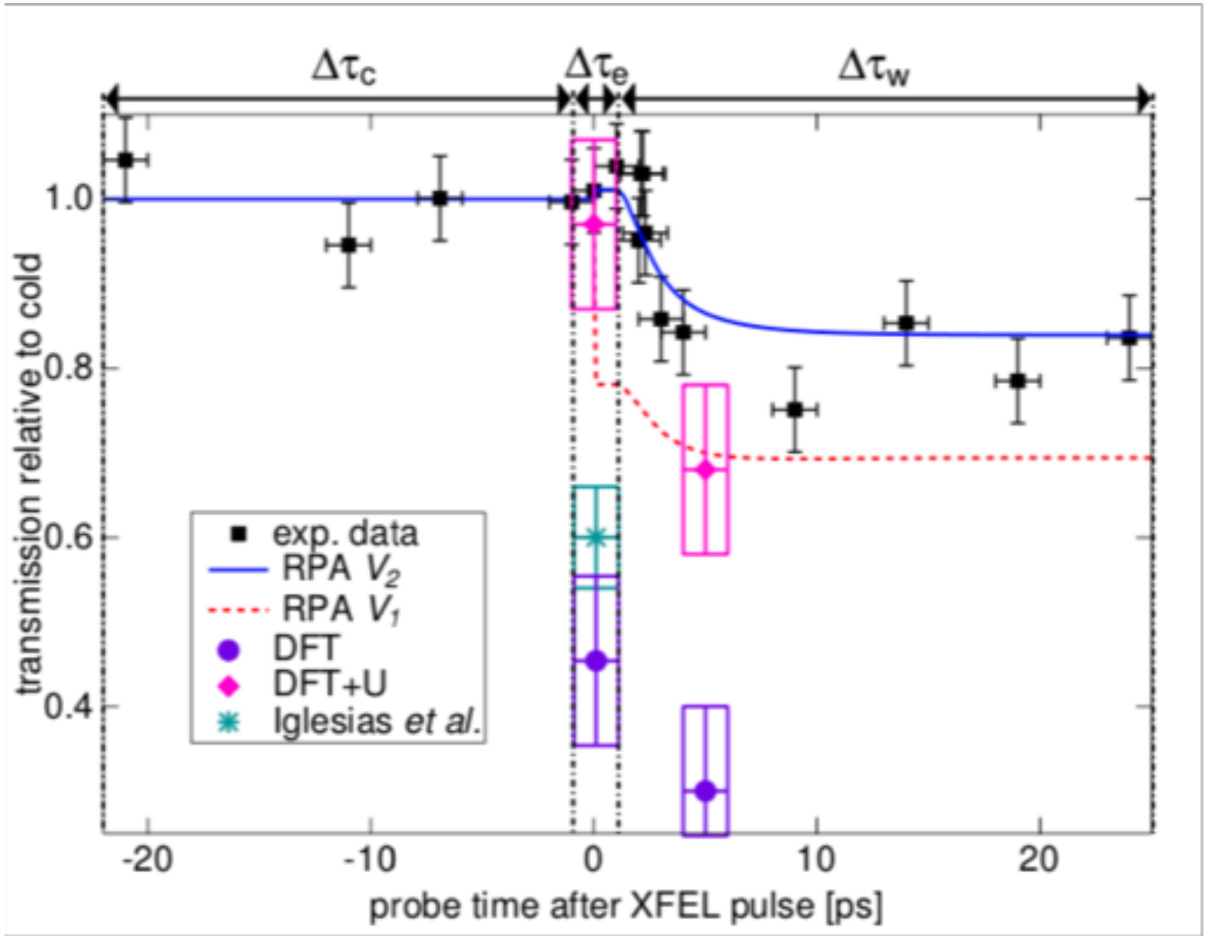


Pumping solid density plasmas with XFELs



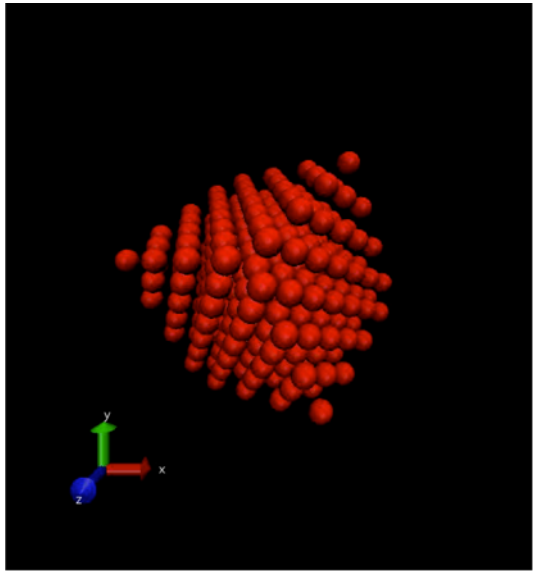
Transient absorption of Warm Dense Aluminum

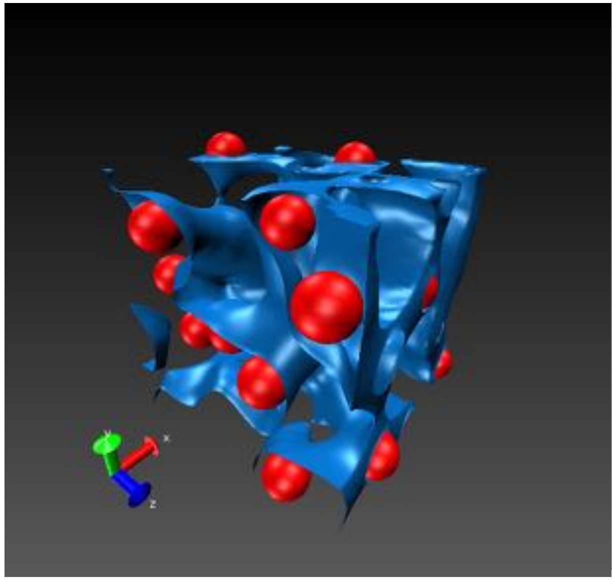
- Al thin foil
- Heated to 6 eV at solid density
- Fermi energy 13 eV

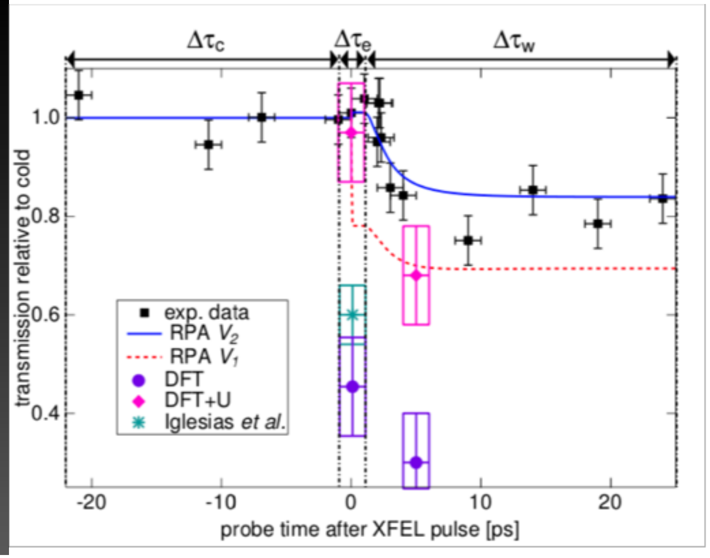


G. Williams et al, PRA 2018

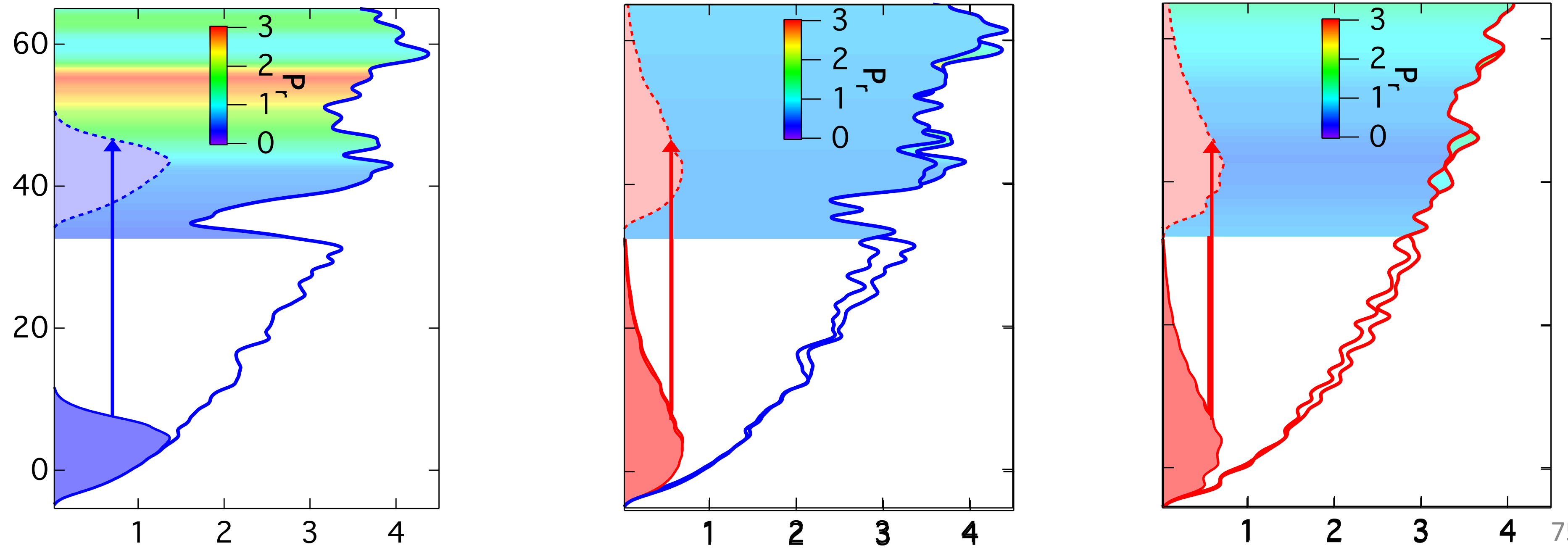
The answer from QMD





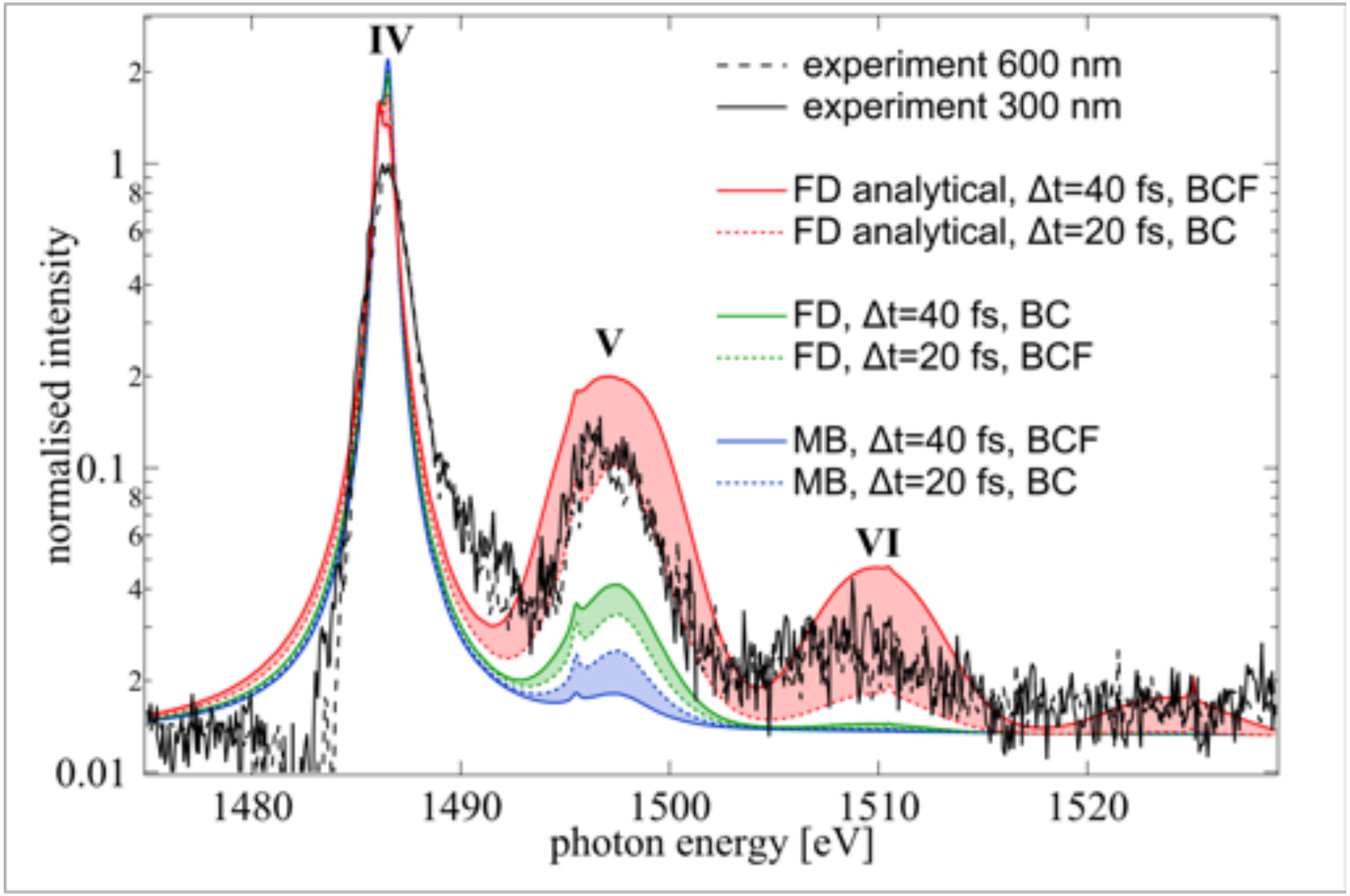


DFT calculations using VASP: Density of states, electron occupation and transition probabilities

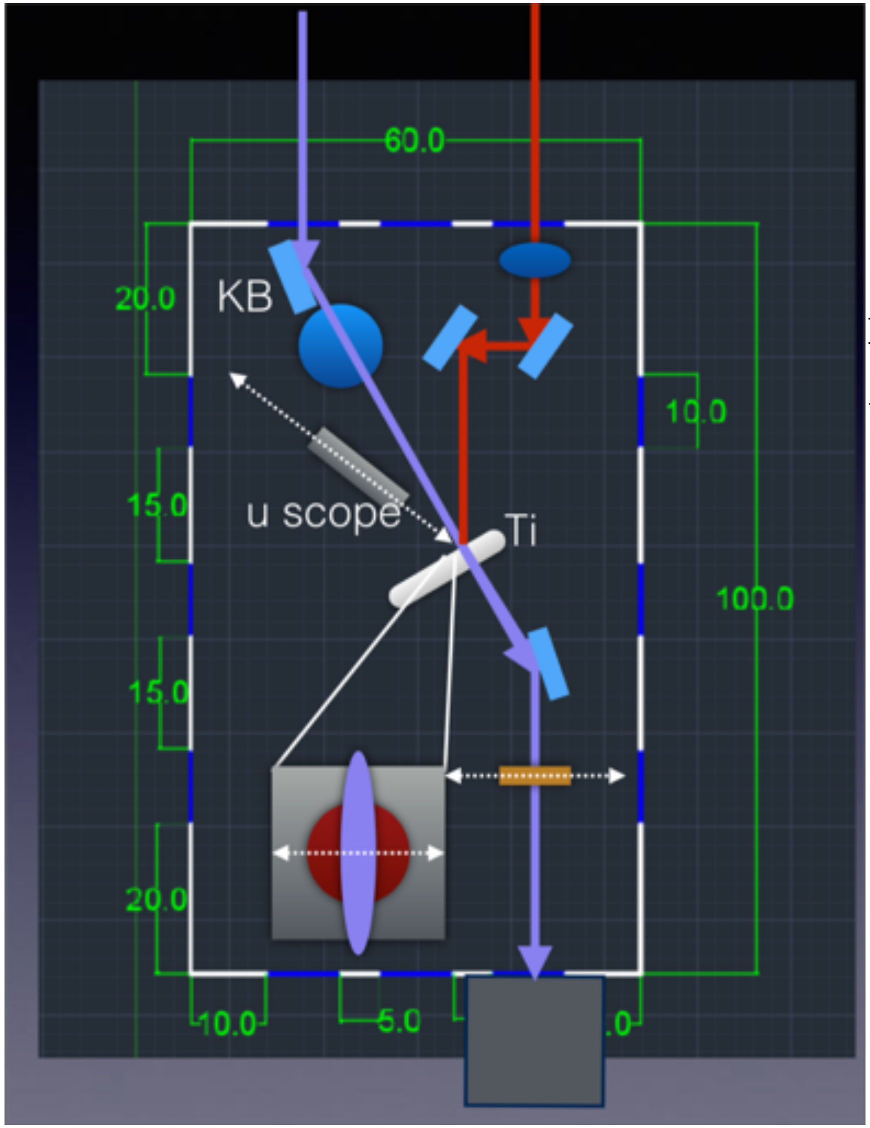


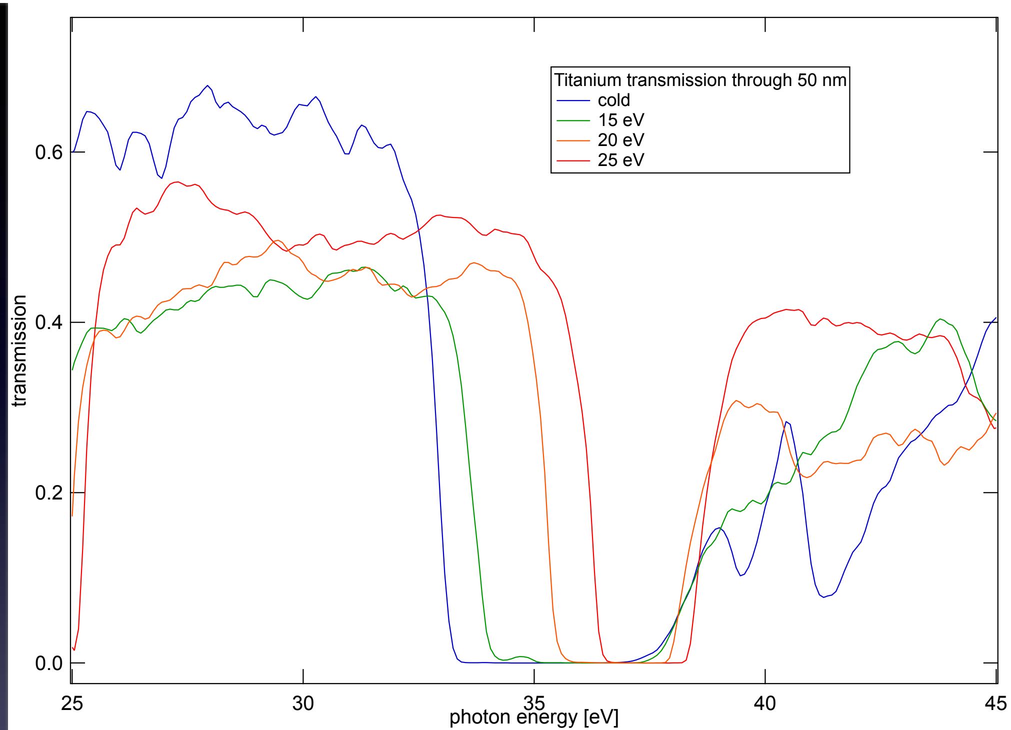
G. Williams et al, PRA 2018

Self emission spectrum shows signatures of degeneracy



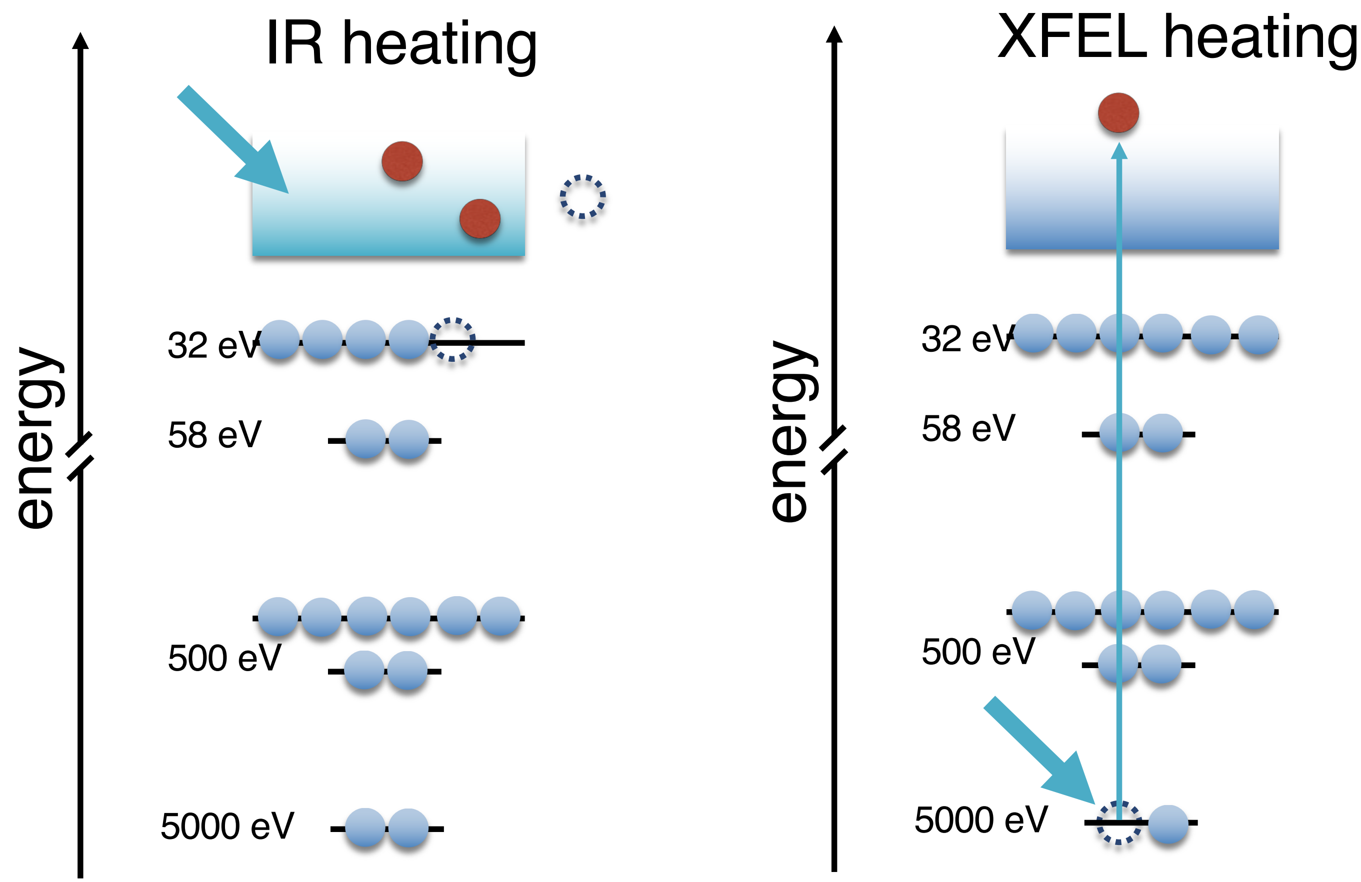
VOXEL Station
a platform for WDM studies





Ongoing experimental campaign:
Ti, Fe, C targets

WDM studies at VOXEL



IR case

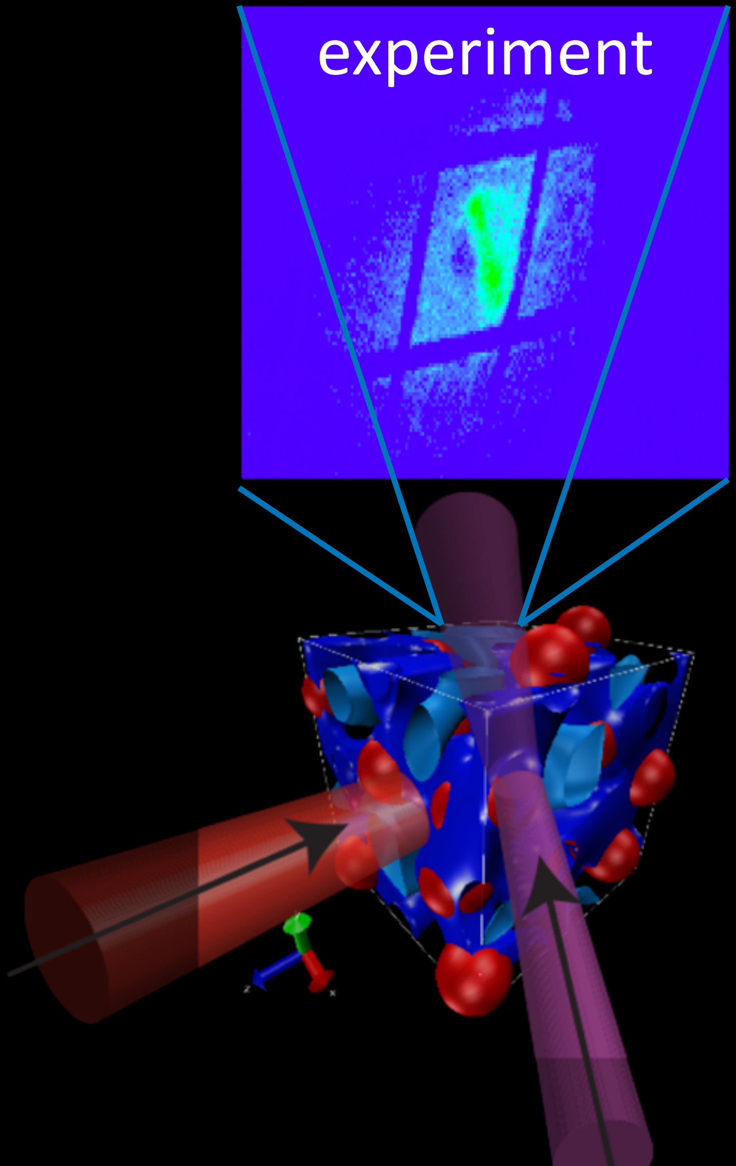
- provides valuable data on ultrafast transition to plasma
- can DFT get it right?

XFEL case

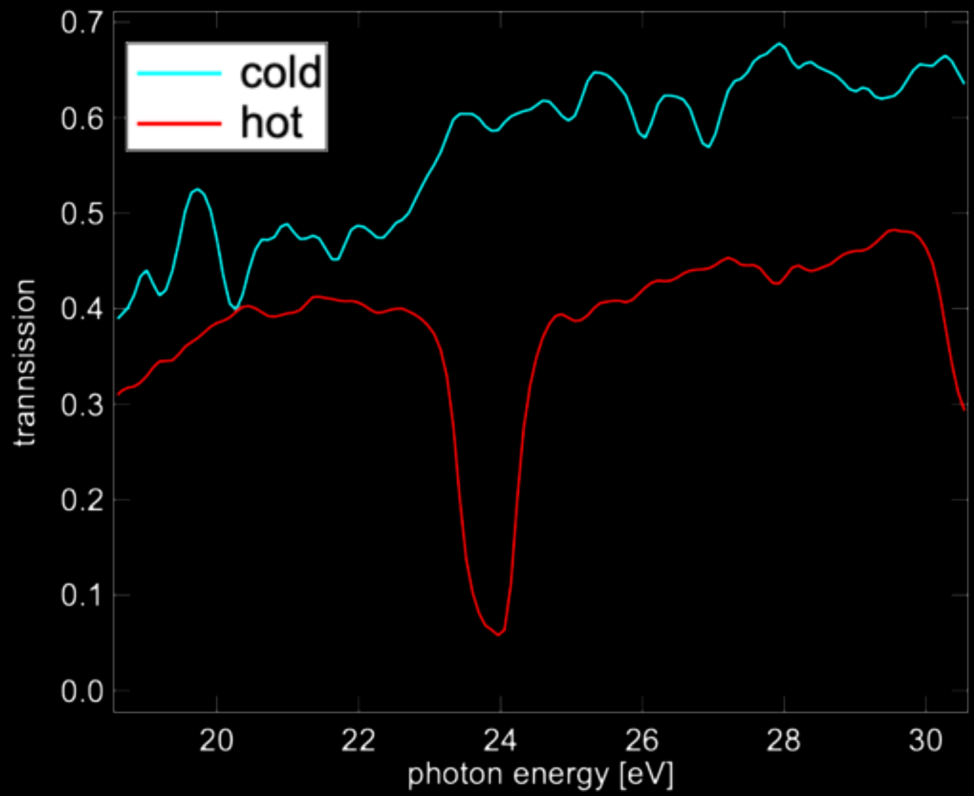
- energy transfer from core electrons to outer electron system: delay?
- electron relaxation timescales in HED plasmas?

Gareth Williams

XUV KB grazing optics for pump probe studies



Optical properties
DFT calculations
Solid titanium



Conclusion

High brightness coherent sources:

- X-ray Free Electron Lasers - Record intensities in X-rays due to extreme brightness
- High Harmonic Generation – Record short pulse duration, tabletop

Advances in ultrafast imaging and dynamics

- High resolution imaging: Holography & CDI: Unprecedented spatial and temporal resolution
- Warm dense matter: Pump and probe starting to unveil dynamics

XUV team@GOLP

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Gareth Williams

Thomas Wodzinski

2019 Trainees
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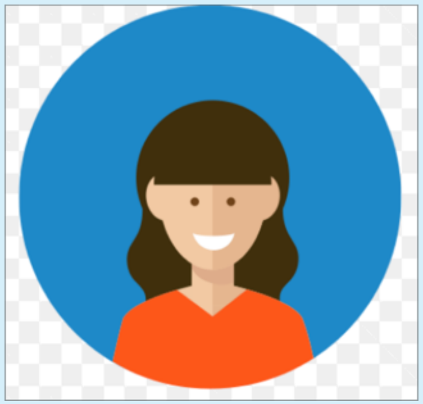
Fernando Lima
Robin Sureau

Mukhtar Hussain

Patricia Estrela

Filipa Ribeiro



Joana Duarte

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MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

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