
ESRF
The European Synchrotron

Laser-induced dynamic compression at ESRF

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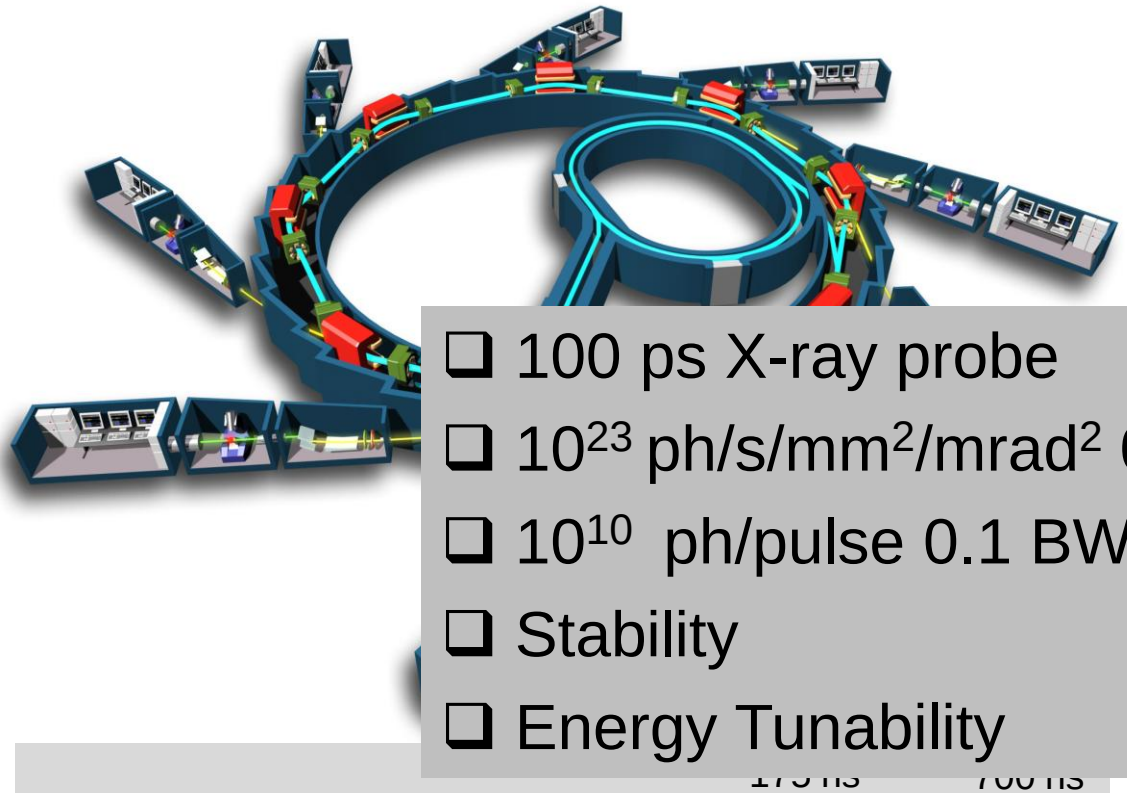
THE ESRF

- *Société civile under French law*
- 20 countries
- 650 staff
- ~ 100 M€ annual budget

- Construction 1988-1994
- First users in 1994
- 844 m circumference
- 6 GeV
- 42 beamlines
- 6000 users/year
- 1800 publications/year

SYNCHROTRON RADIATION



- 100 ps X-ray probe
- 10^{23} ph/s/mm^2/mrad^2 0.1%BW
- 10^{10} ph/pulse 0.1 BW
- Stability
- Energy Tunability

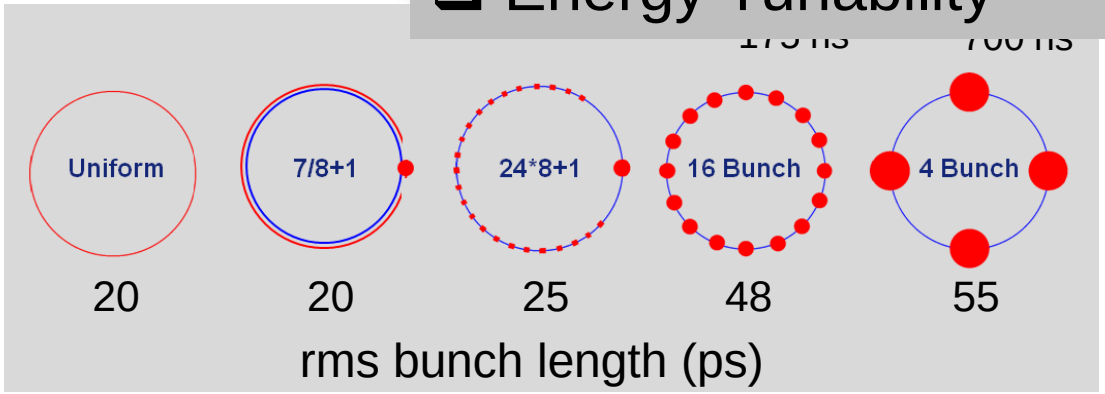
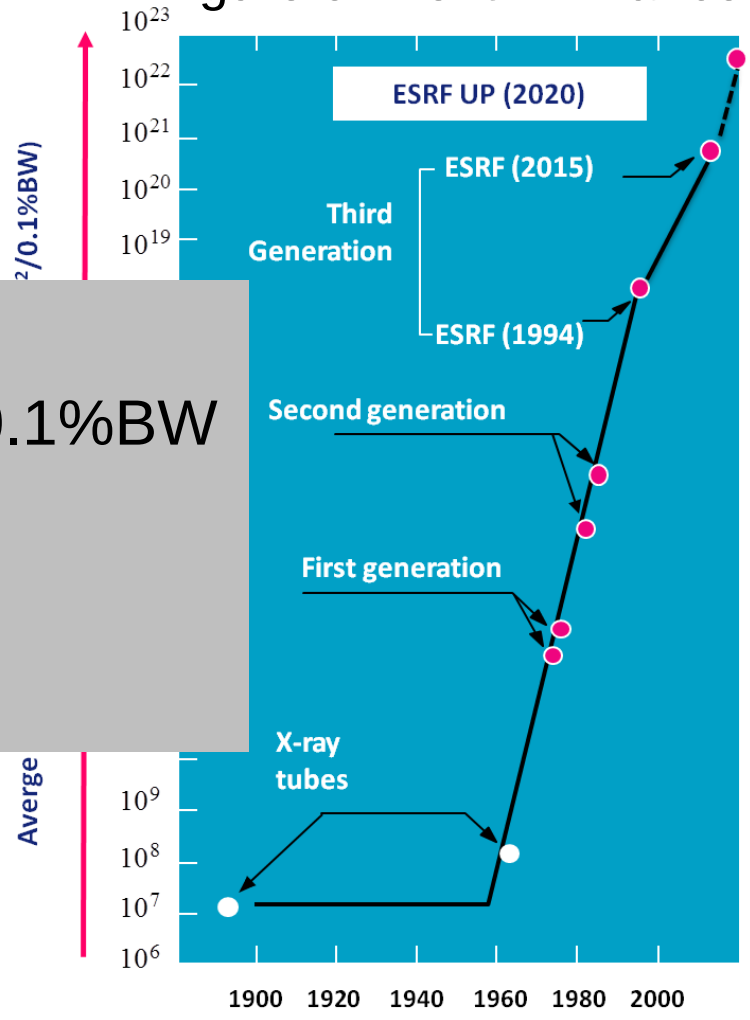


Figure of merit: Brilliance



HIGH PRESSURE SCIENCE AT ESRF TODAY

ID06, ID15, ID27 : X-ray Diffraction – Structure, Crystallography, Strain, Deformation, …

ID18: Nuclear Resonance Scattering - Magnetism, Phonons

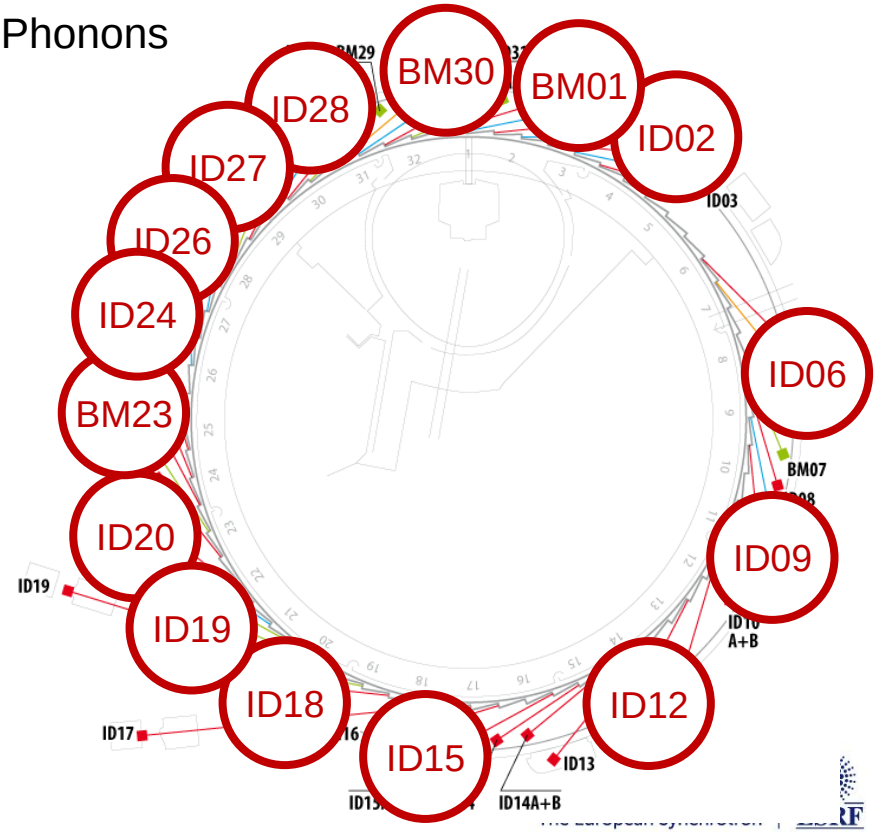
ID20: Resonant Inelastic X-ray Scattering - Electronic and Magnetic Structure

ID12, BM23, ID24: XAS, XMCD - Local and electronic structure, Magnetism, …

ID28: Inelastic X-ray Scattering, Diffuse Scattering - Phonons

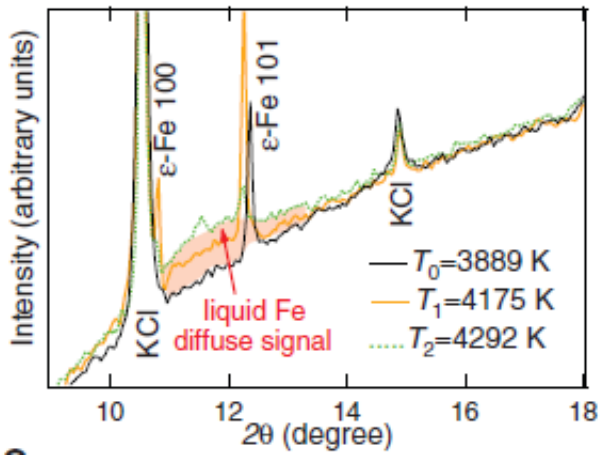
ID02, ID26, BM01, BM30, ID09B, ID19, ….

A very large user community ….



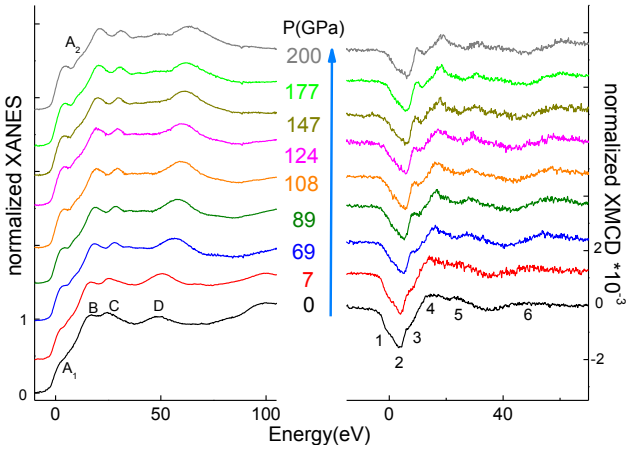
STATIC COMPRESSION AT SYNCHROTRONS TODAY

XRD 1.3 Mbar 4300K



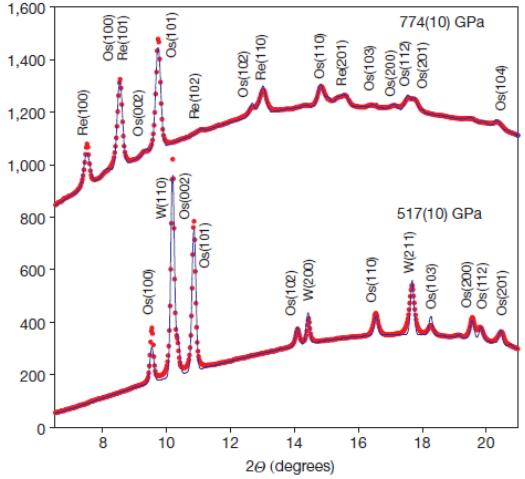
Anzellini Science 2013

XMCD 2 Mbar



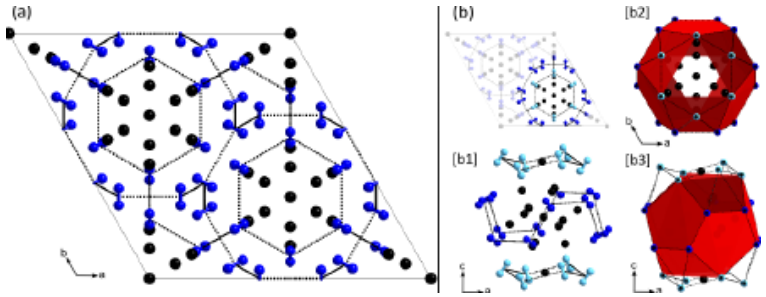
Torchio PRL 2011

XRD 7 Mbar



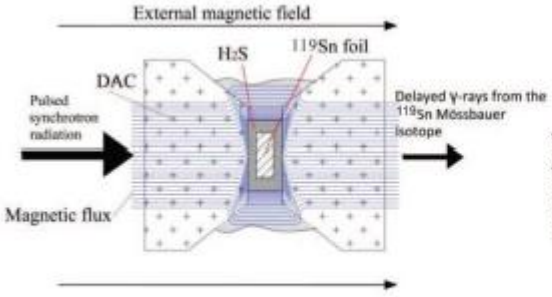
Dubrovinsky Nature 2015

Single Crystal XRD

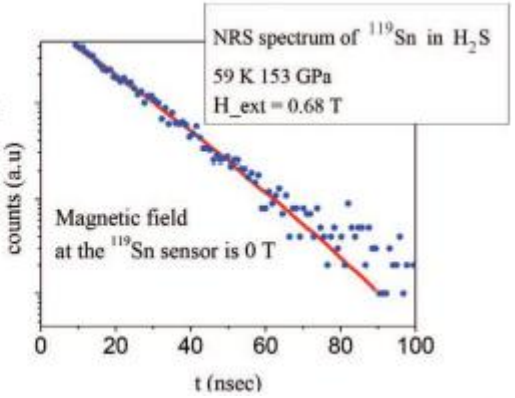


Spaulding Nature Comm. 2014

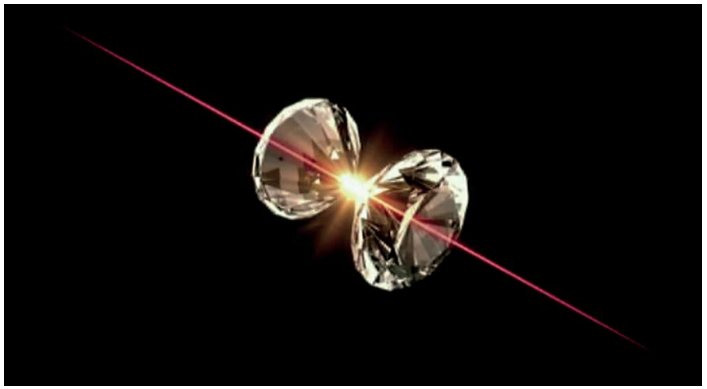
Nuclear Resonance Scattering



Troyan Science 2016

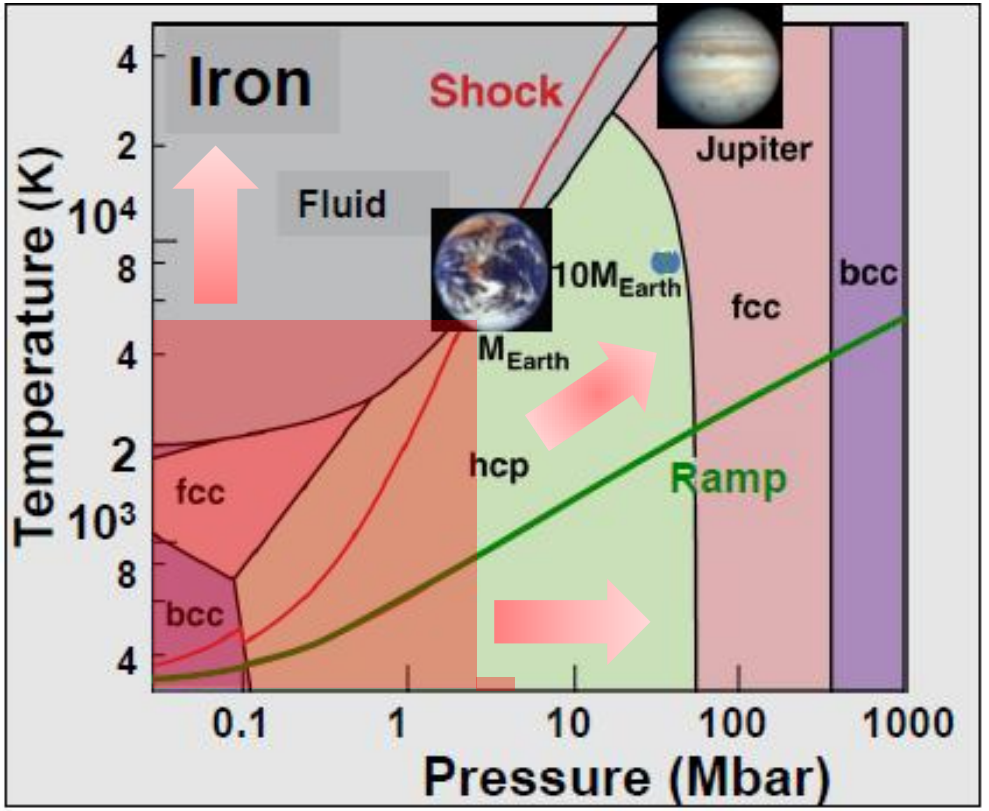


GOING BEYOND THE LIMIT OF STATIC COMPRESSION



Static compression with LH–DAC covers Earth's core conditions

~ 360 GPa, 5500 K



1. What is the stability limit of hcp phase in solid Fe ?
2. What is the local structure in the liquid ?
3. What is the nature of ion-ion correlations in the WDM regime ?

Can we create and probe WDM at the synchrotron, with data quality as "at ambient" ?

PUSHING THE FRONTIERS

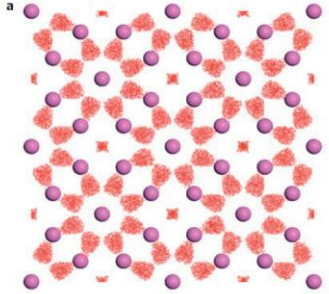
❑ Go more extreme → TPa & eV

Conditions beyond those existing in our planet → Input for planetary models

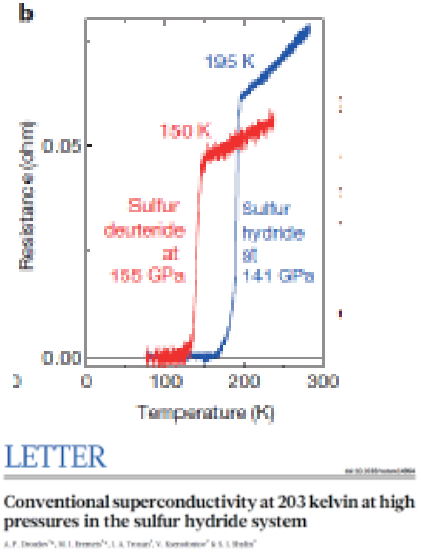
Synthesis of novel materials

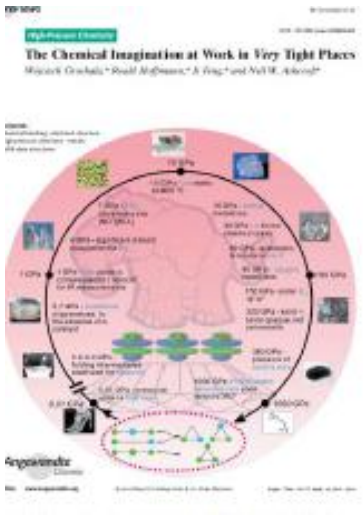
Reveal new physical chemistry

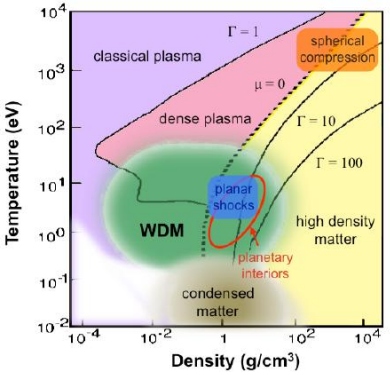
Al @ 1TPa



Pickard and Needs 2010







Particle ejection

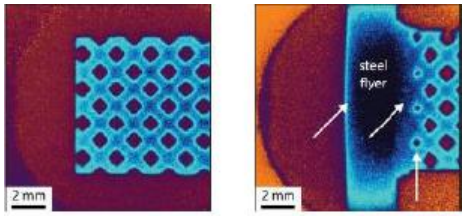
ENSMA Poitiers

❑ Explore the time scale of high pressure phenomena → ns

Dynamic behavior of matter and materials under high strain rates

- Mechanisms and nucleation of phase transitions
- Yield strength (dynamics of dislocations)
- Nanostructuration, amorphisation, metastable phases

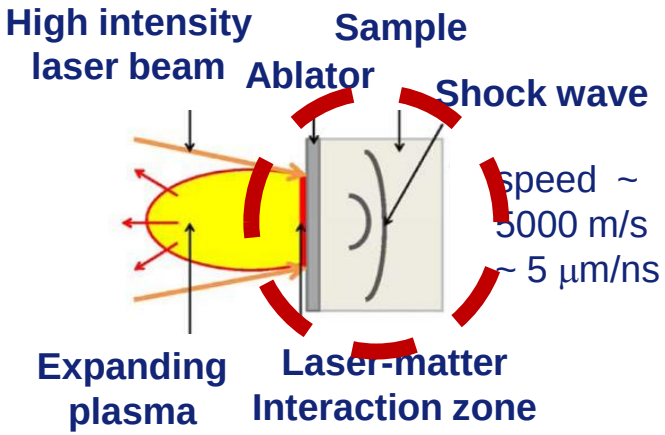
Heterogeneous media



Pre-shot 2.4 μs

ISP Imperial London

DYNAMIC COMPRESSION WITH HIGH POWER LASER



P& T can be maintained relatively constant in time (ns) and space using special confinement by target design.

fs ps ns

energy transfer from excited e- to nuclei

- extreme states of solid matter at T>> T_{melt} in few ps (**highly metastable state**)
- study instantaneous effect of changes in e- distribution on interatomic potential

OUT OF EQUILIBRIUM

- **equilibrium thermodynamical state**
- study samples at very high P and T (~ TPa, ~ eV)

LOCAL THERMAL EQUILIBRIUM

CHALLENGES

1. Timescale of excited state must match time resolution of X-ray probe

~ ns → **Target design**

2. Single shot

Do we have enough photons? → **Target design**

What techniques (XRD, XRI, XAS …) are possible?

3. High power laser and shock diagnostics interfaced with synchrotron beamline

Do we have enough energy density?

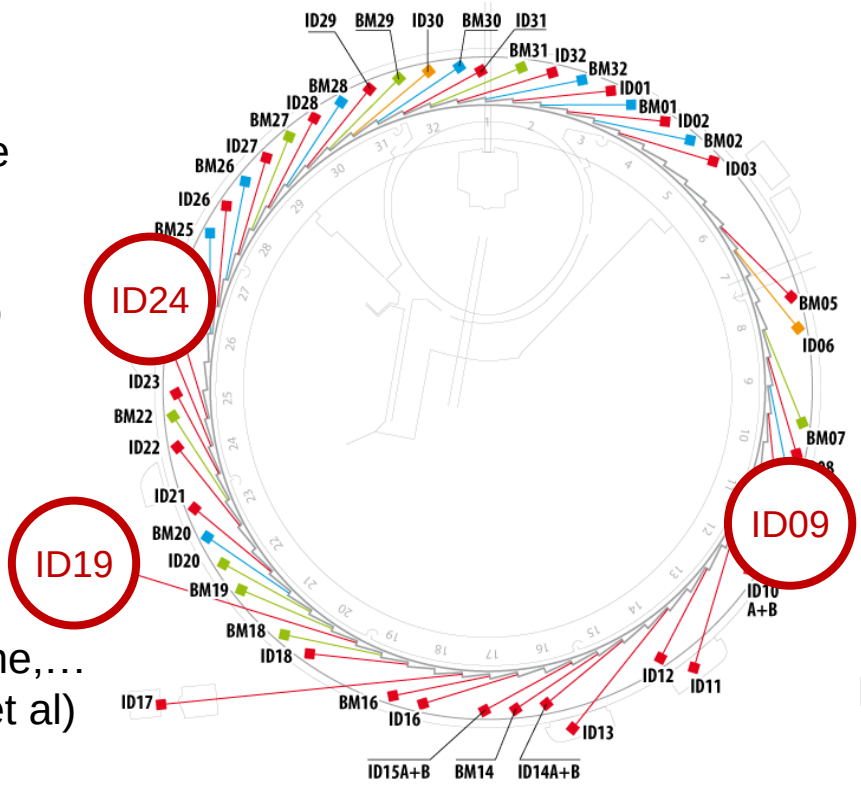
What P, T conditions are achievable? → **Target design**

How do we cope with the lack of expertise?

DYNAMIC COMPRESSION AT ESRF: FIRST STEPS

~ 30 J laser
XAS on warm dense Fe
(Torchio et al.)

O. Mathon, R. Torchio



~ 5 J laser
XRI on Si wafers, polysterene,…
(Cowan, Grenzer, Cantelli et al)

A. Rack, M. Olbinado

~ 0.4 J laser
XRD on Bi
(Occelli et al)

M. Wulff, F. Zontone

1ST TEST EXPERIMENT COMBINING ED-XAS AND LASER SHOCK

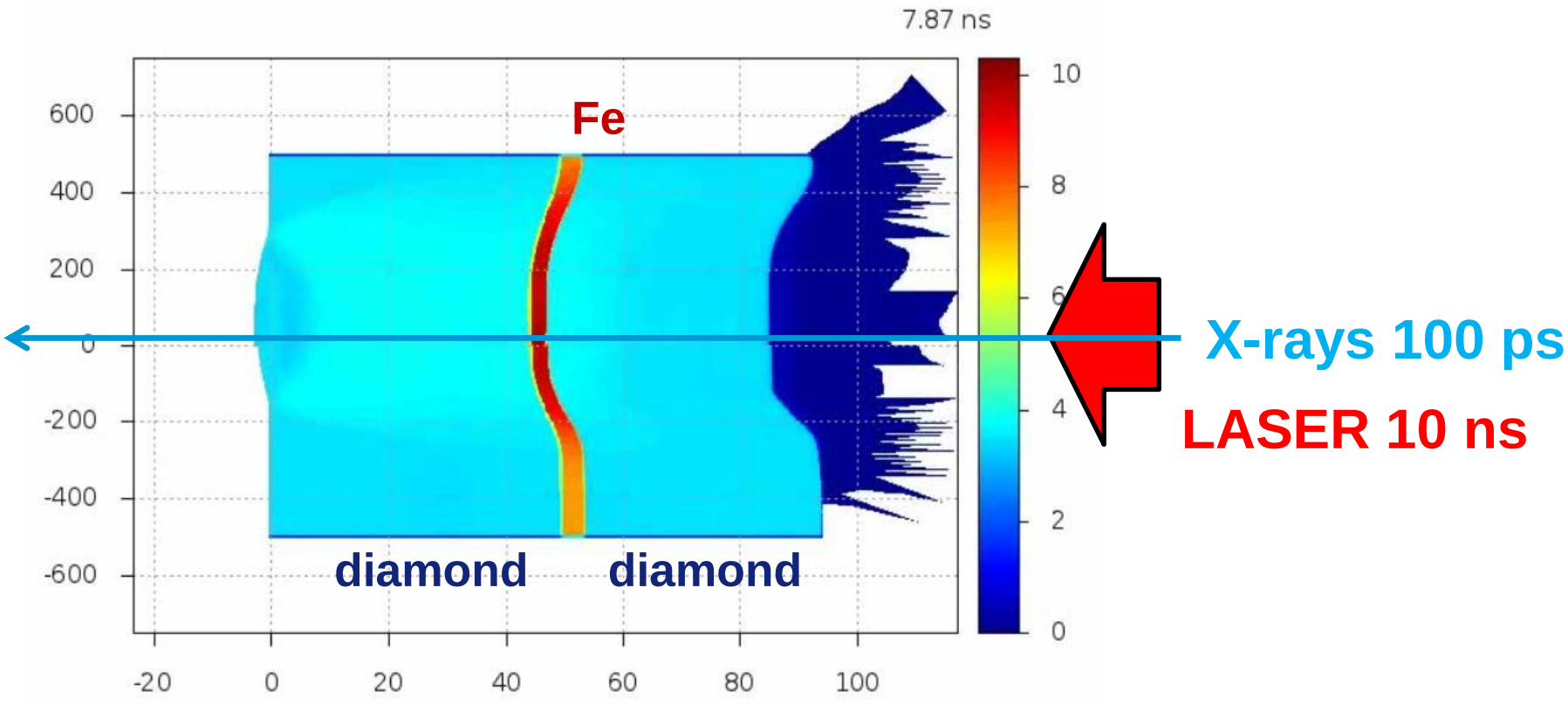
ID24

Hydrodynamic simulations

Shock diagnostics

Laser: 30 J
1057 nm
10 ns square pulse

XH detector



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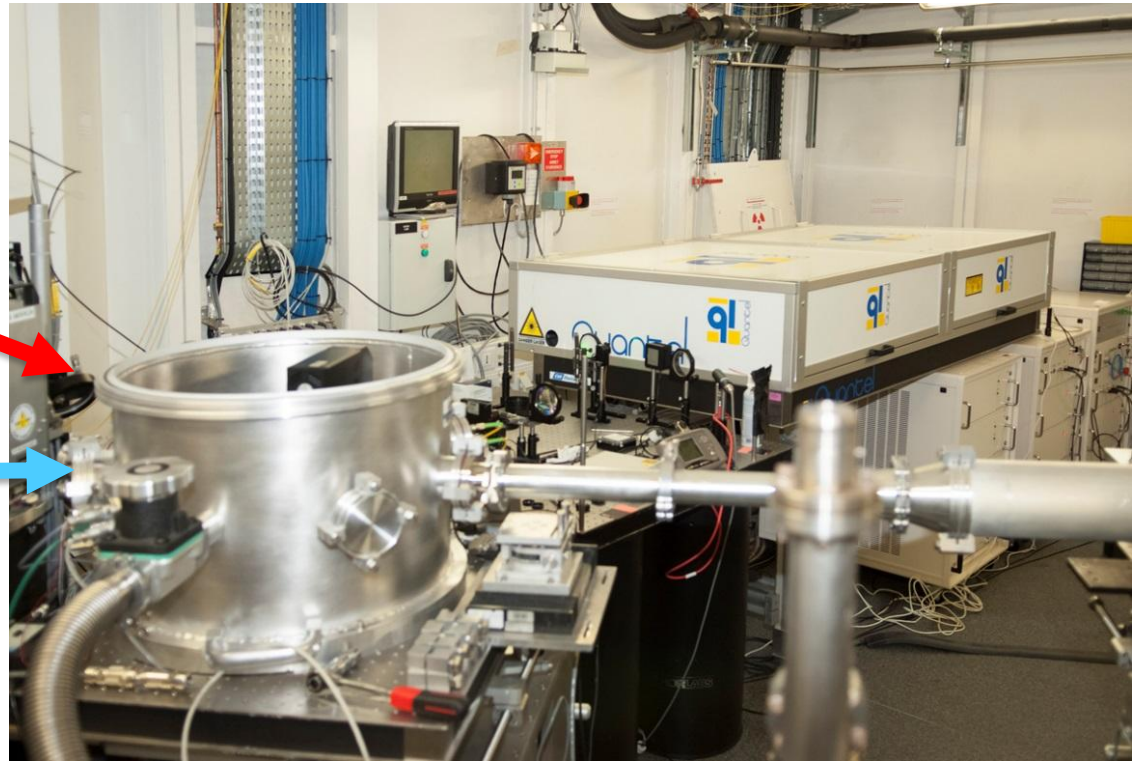
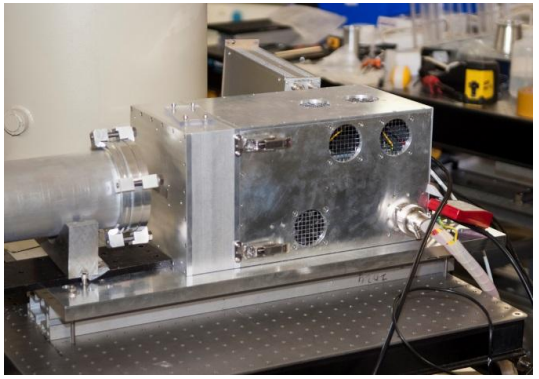
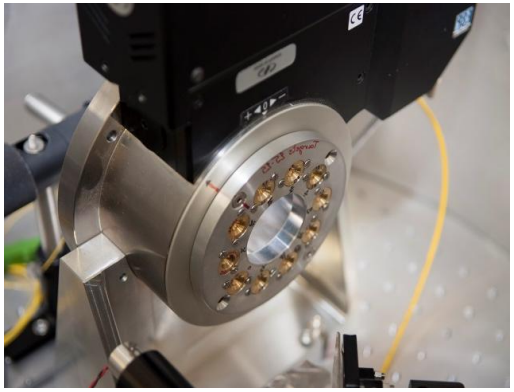


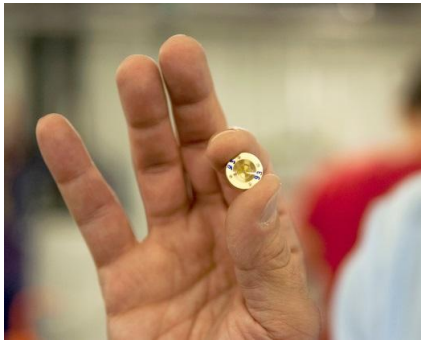
GCLT laser 30J-10 ns



XH detector

Sample changer In vacuum chamber

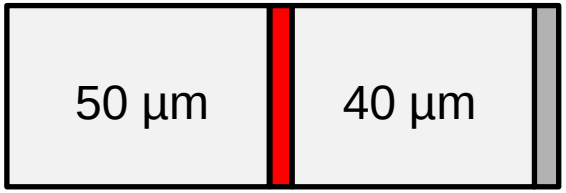




Target

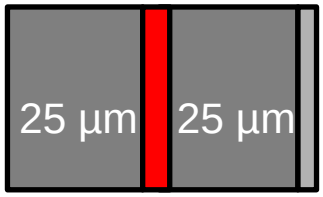
1ST TEST EXPERIMENT COMBINING ED-XAS AND LASER SHOCK

I (W/cm^2)	Laser spot (μm)	P(GPa)	T(K)
0.4 10^{13}	350	80	1500
5 10^{13}	90	500	13000

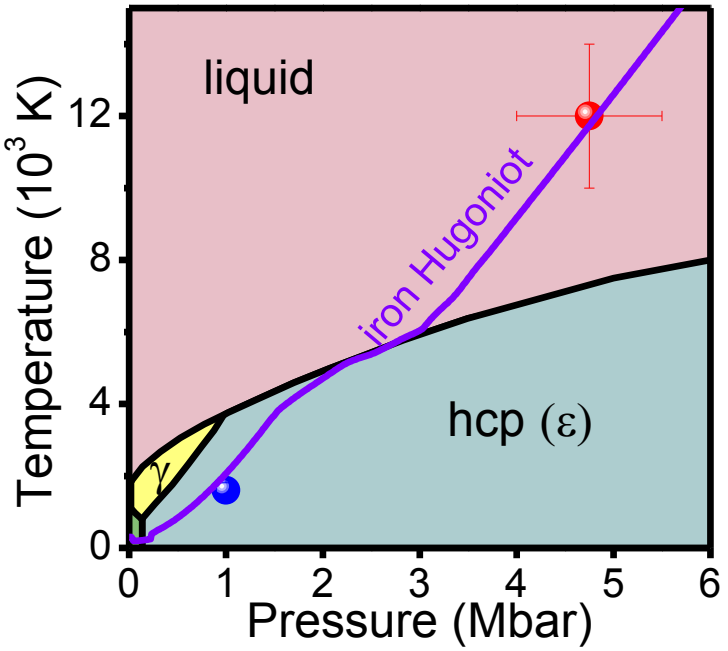


diamond Fe diamond CH

P < 100 GPa
Spot: 350μm



P > 100 GPa
Spot: 90μm



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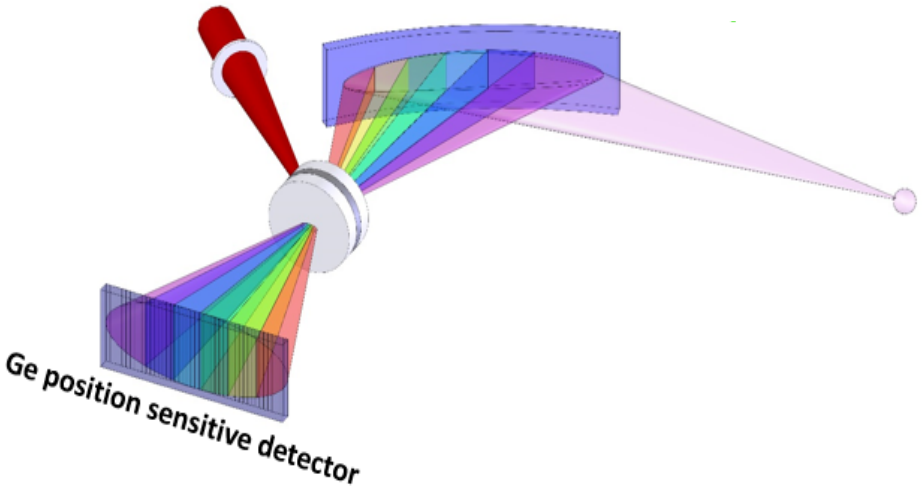
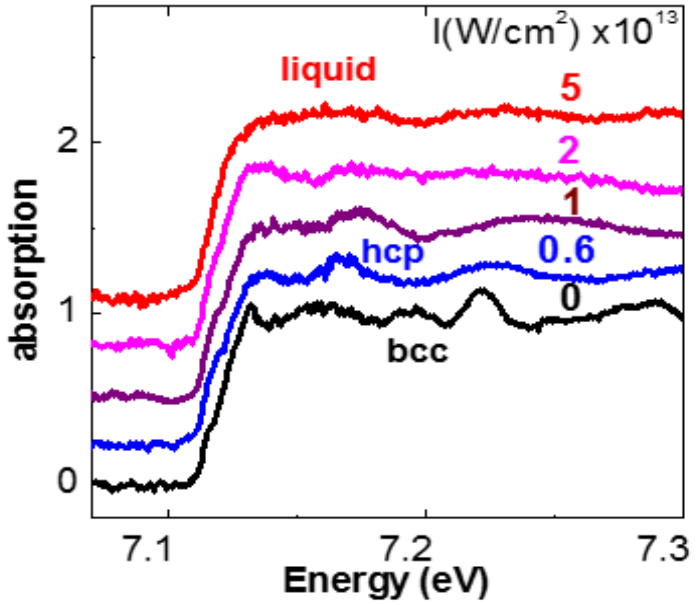
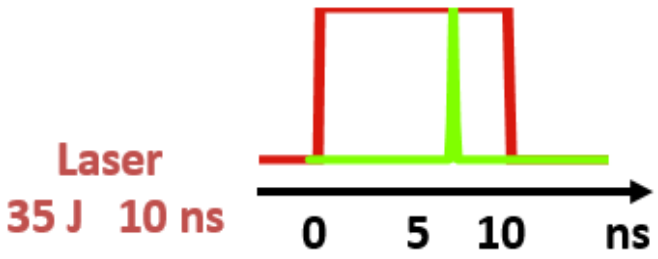
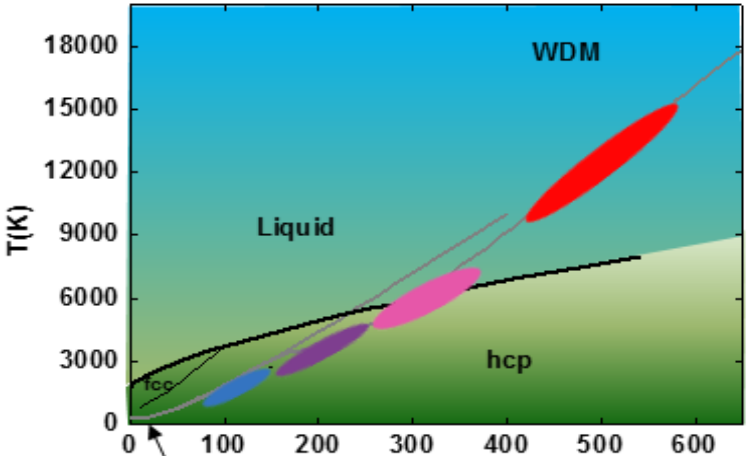






X-ray bunch
100 ps



Torchio et al. Sci Rep. 2016

Covers region of phase diagram unexplored by XAS

A HIGH POWER LASER FACILITY (HPLF) AT ESRF

HPLF-I

Jan-March 2016:	Feasibility study ~100 J laser + laser cabin on ID24.
April 2016 :	Deliverable: full proposal w/cost estimates, model for operating the laser.
Mid 2016:	**CFT for 100-200 J** laser (upgradable), delivery 2018
	Design studies for installation of laser, associated optics, shock diagnostics.
	Allocation of two positions to this project
2018:	Operating laser on ID24
Mid 2018:	**Start of User Operation** of HPLF-I

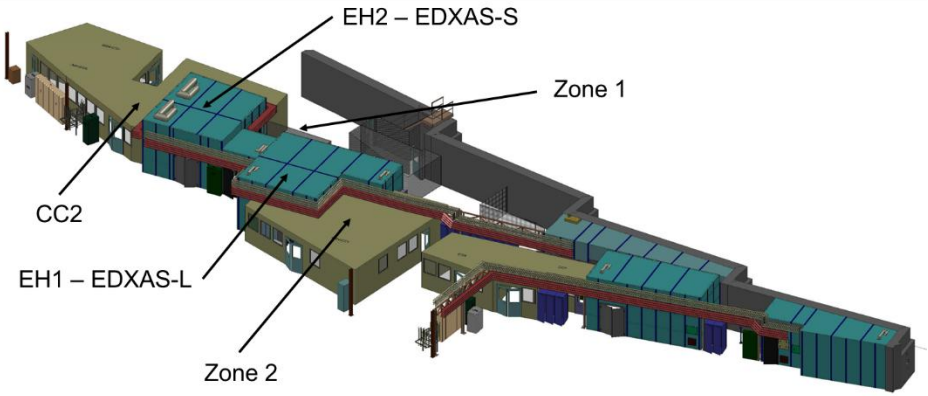
HPLF-II

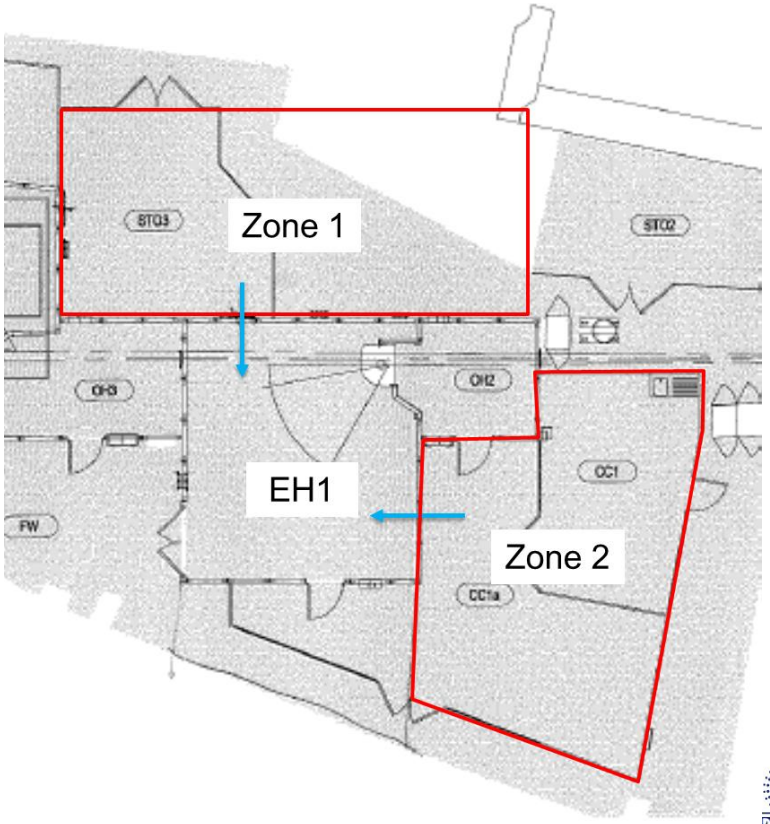
- extension to XRD, XRI, XES on 2 adjacent beamlines
- upgrade of laser power to > 300 J

9-10 Dec 2016:	ESRF-EBS Workshop: discussion of future beamlines w/user community
6-7 June 2017:	2nd Workshop on “Studies of Dynamically Compressed Matter with X-rays”

HPLF-I LOCATION

The laser system will be installed in a dedicated laboratory adjacent to ID24.





OUTLOOK

❑ New perspectives for dynamic compression studies for a wide user community

- Very challenging project.
- Cannot succeed without the help of experts in shock, diagnostics, target design, etc..

❑ Building a strong user community will be a priority in the coming years.

- Strong complementarities with HED @ XFEL
- Longer X-ray pulse, lower flux → Different requirements, constraints on targets

❑ EUCALL and all its initiatives: an important gateway