Dynamics of Crystallization and Melting under Pressure

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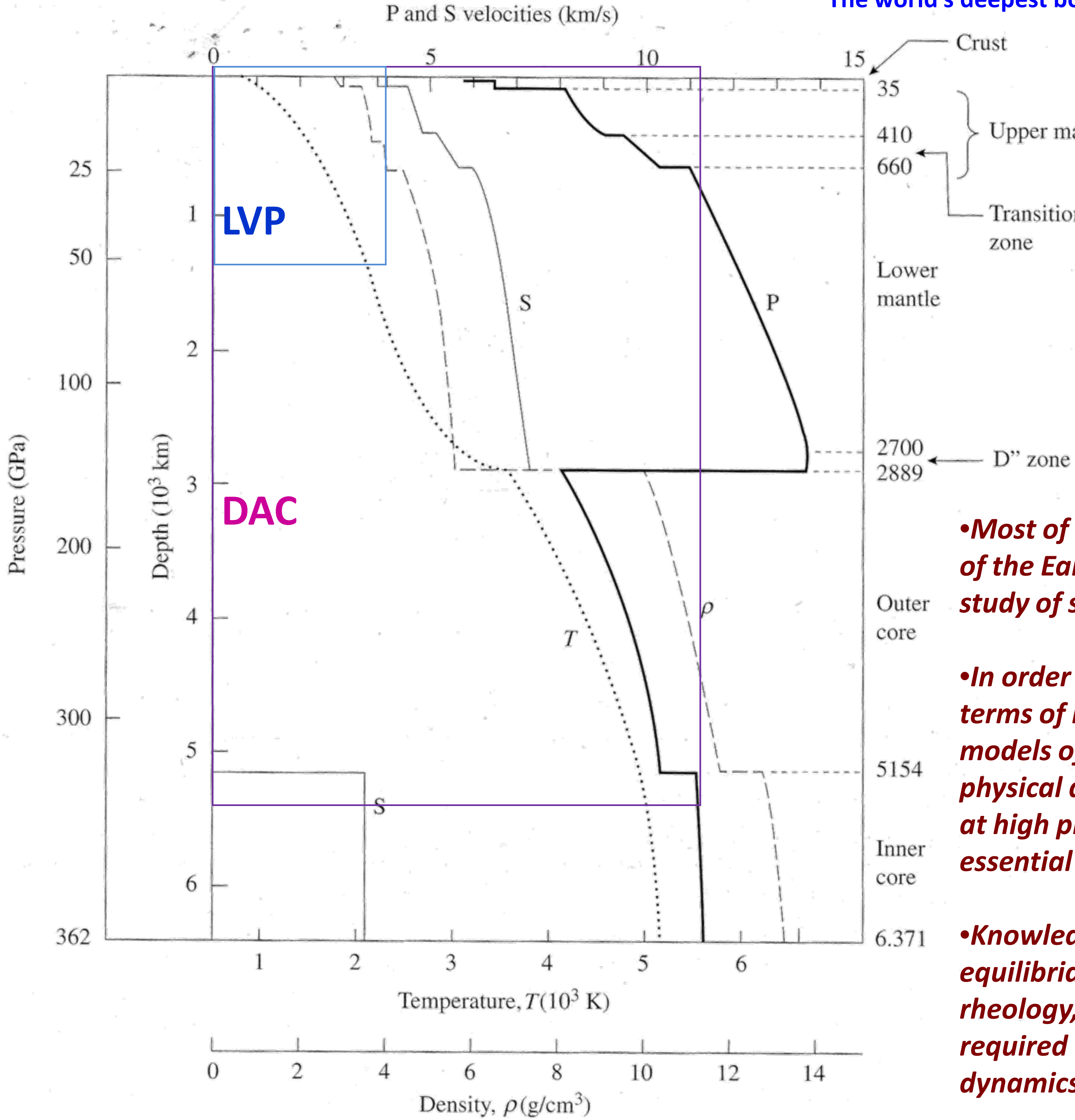
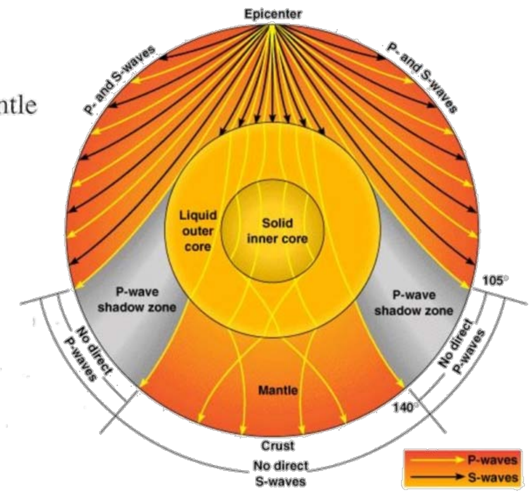
The world's deepest borehole in Sakhalin is 12,345 m (40,502 ft)





•Most of what we know about the structure of the Earth's deep interior comes from the study of seismic wave velocities

•In order to interpret such measurements in terms of mineralogical/compositional models of the Earth's interior, data on the physical and chemical properties of minerals at high pressures and temperatures are essential

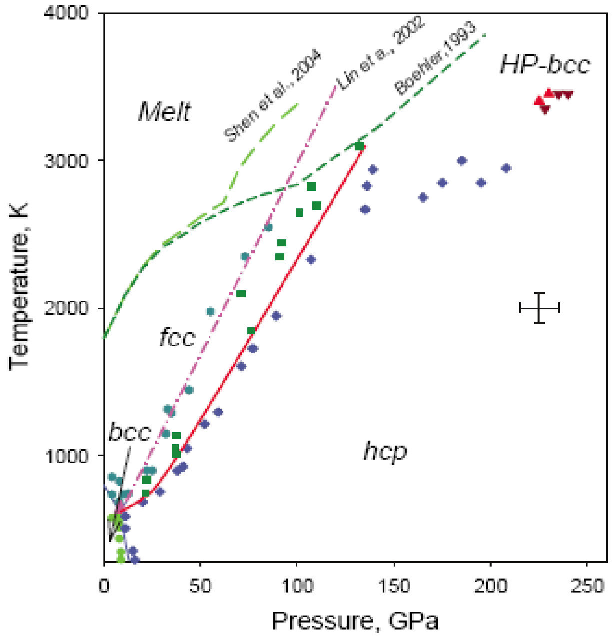
•Knowledge of thermodynamics, phase equilibria, crystal chemistry, crystallography, rheology, diffusion and heat transport are required to characterize the structure and dynamics of the Earth's deep interior

R.Wenk, 2005

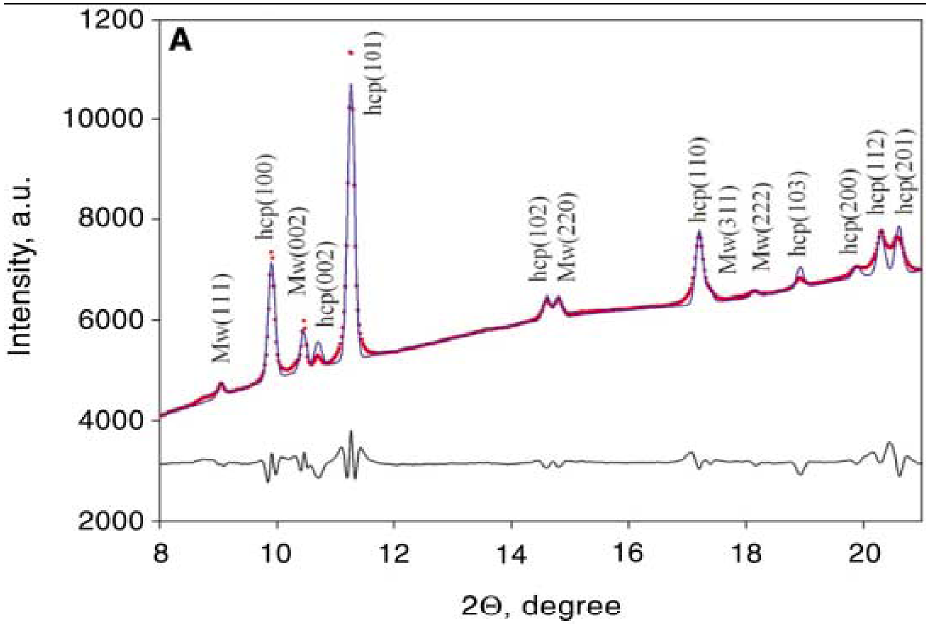
Body-Centered Cubic Iron-Nickel Alloy in Earth's Core

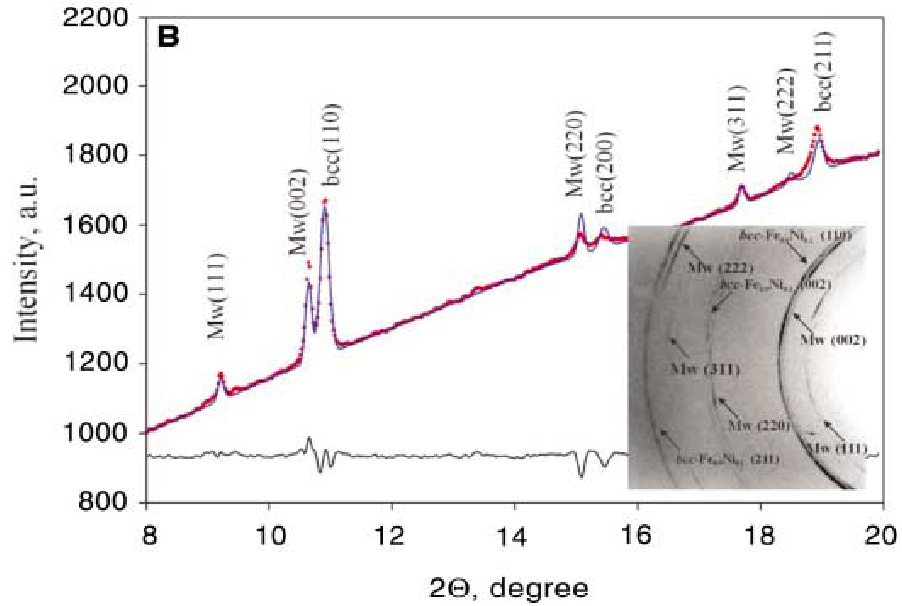
L. Dubrovinsky,[1] N. Dubrovinskaia,[2] O. Narygina,[1] I. Kantor,[1] A. Kuznetzov,[3] V. B. Prakapenka,[3] L. Vitos,[4,5,6] B. Johansson,[4,5] A. S. Mikhaylushkin,[6,7] S. I. Simak,[7] I. A. Abrikosov[7]

Science **316, 1880 (2007),** Times Cited: **53**

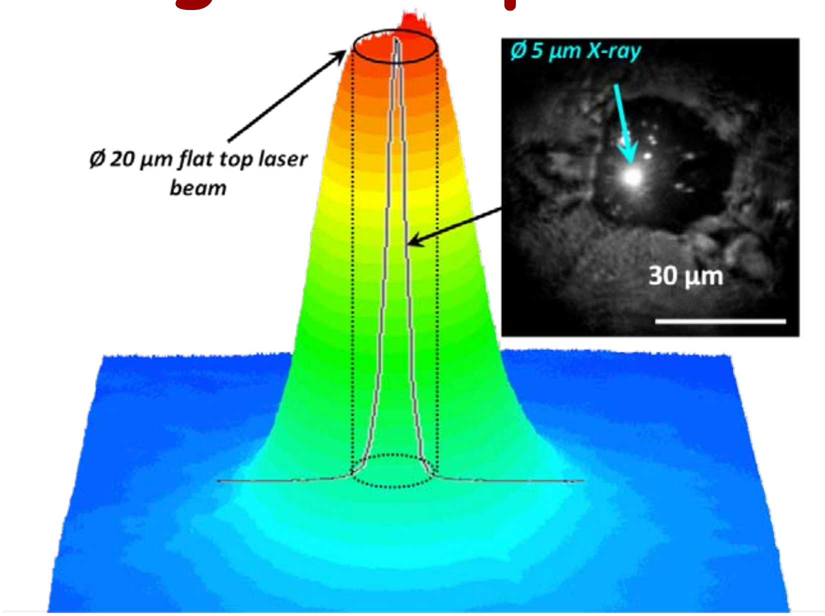


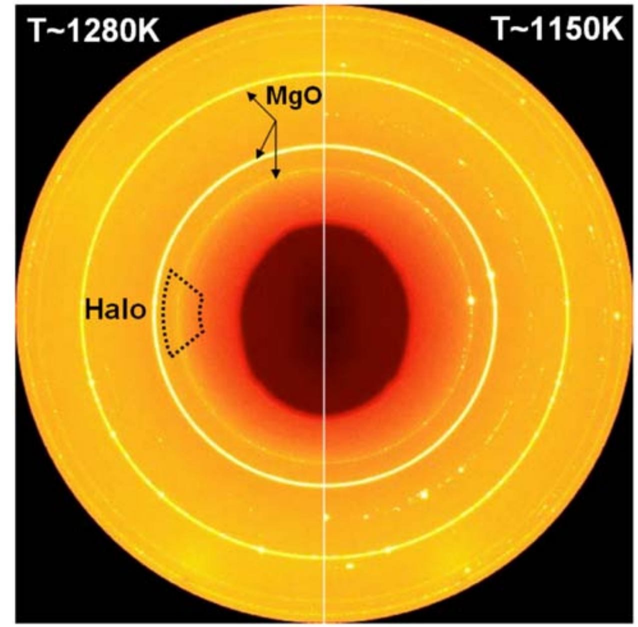
At pressures above 225 gigapascals and temperatures over 3400 kelvin, Fe0.9Ni0.1 adopts a body-centered cubic structure

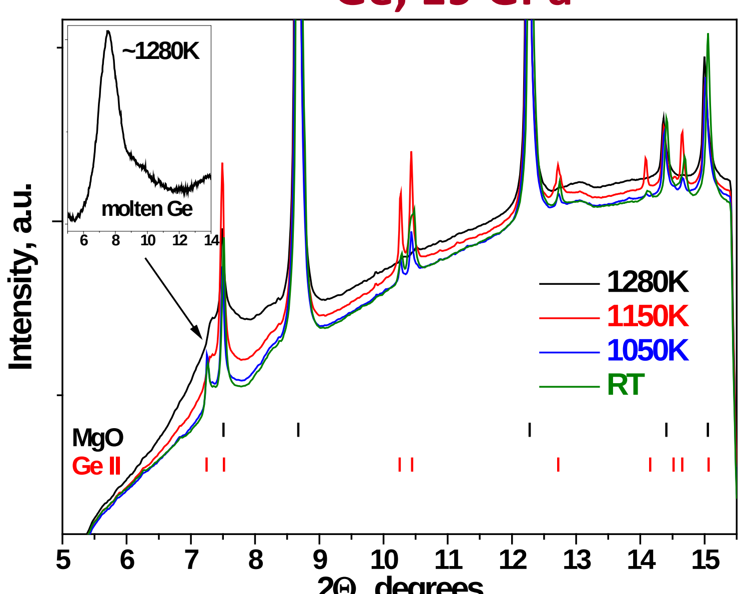


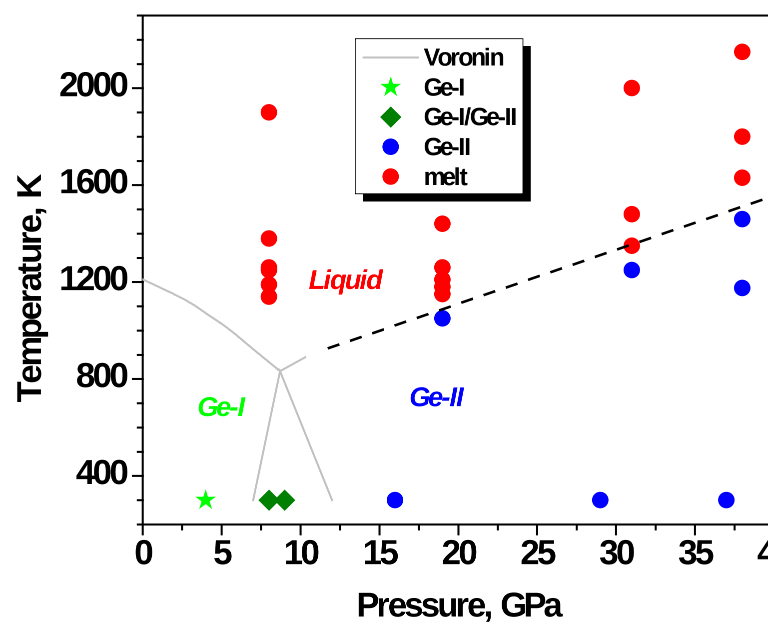


High P-T phase diagram of Germanium

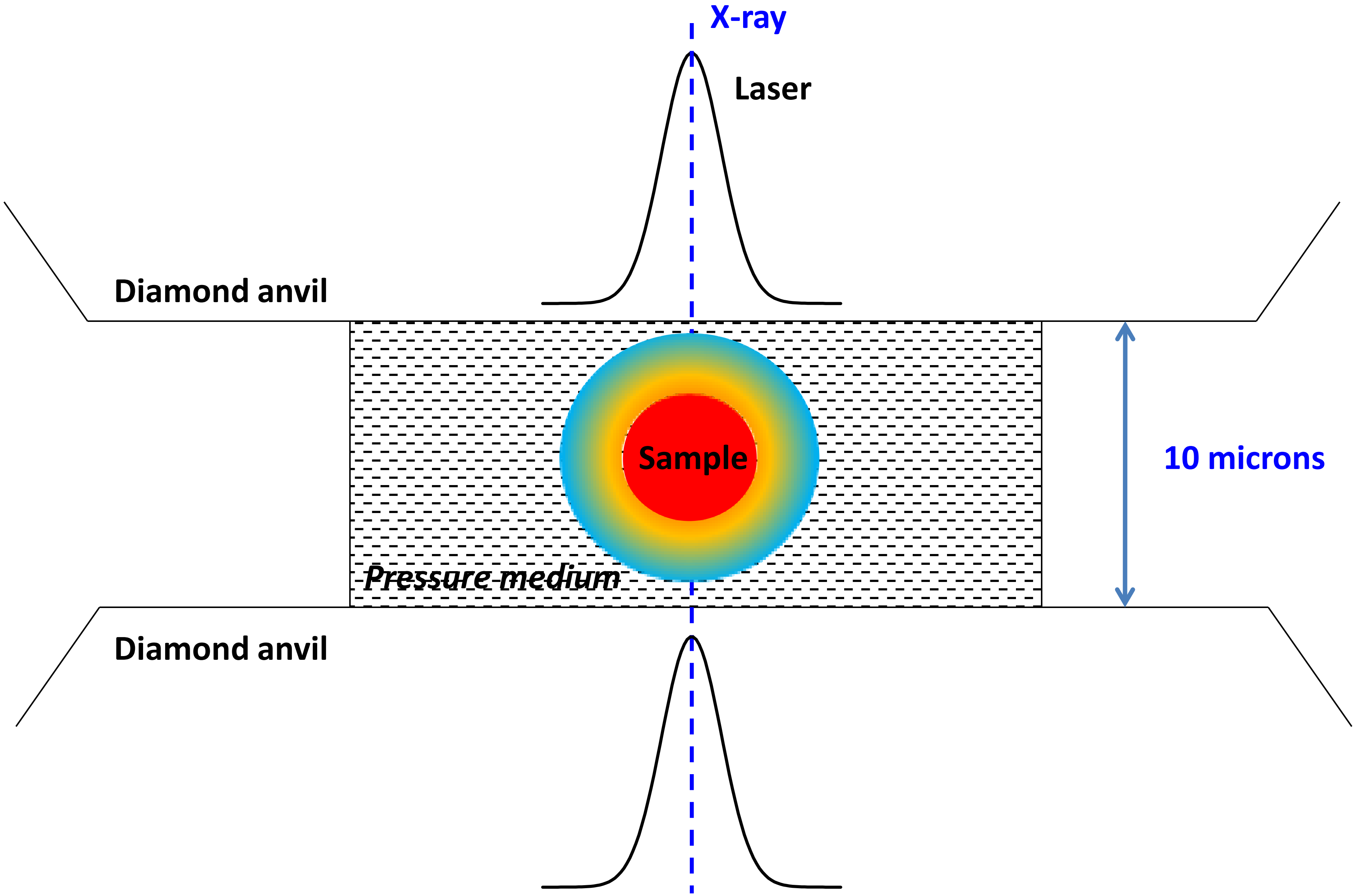






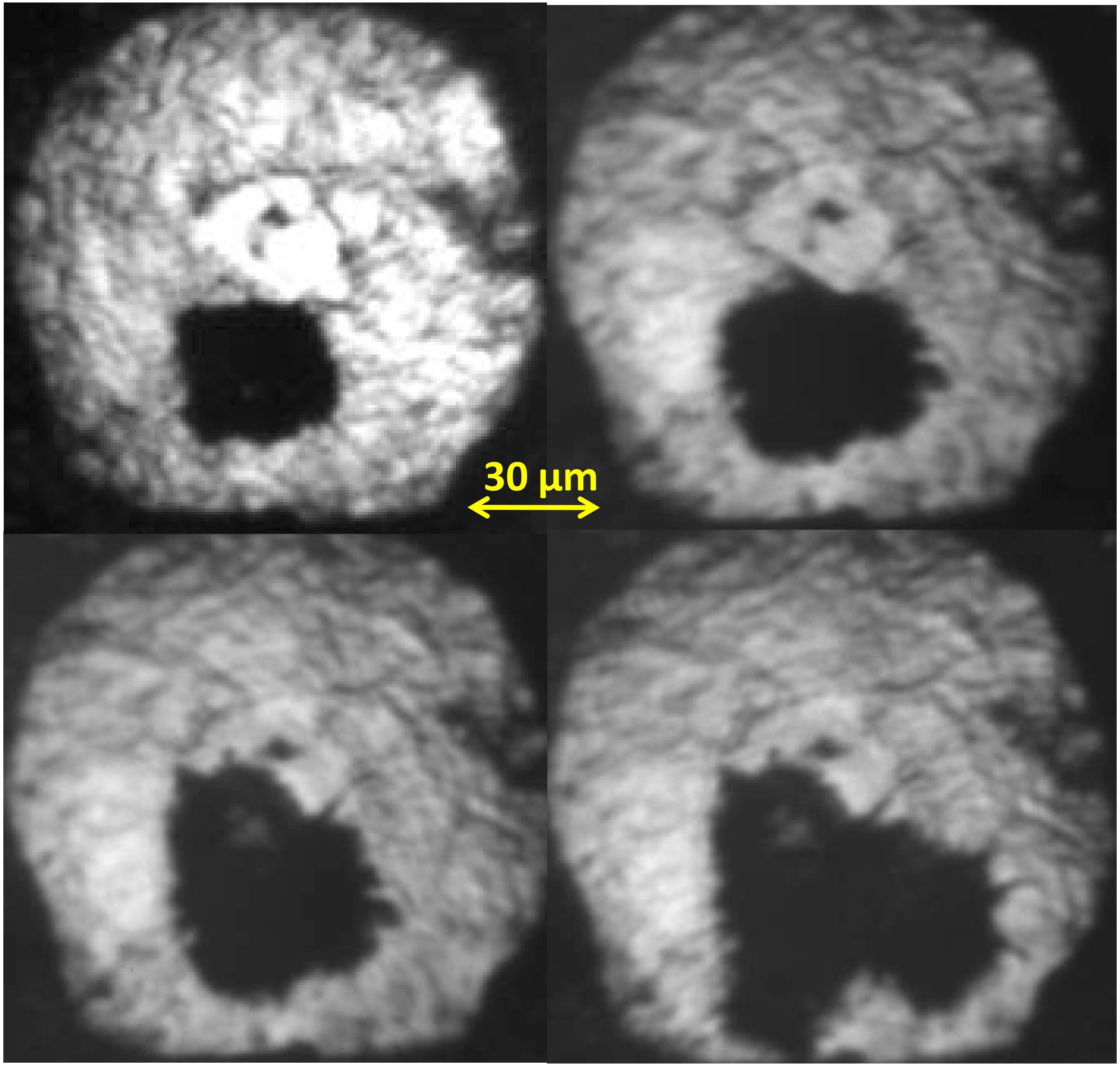


Prakapenka et al., High Pressure Research, 2008 , 28:3,225

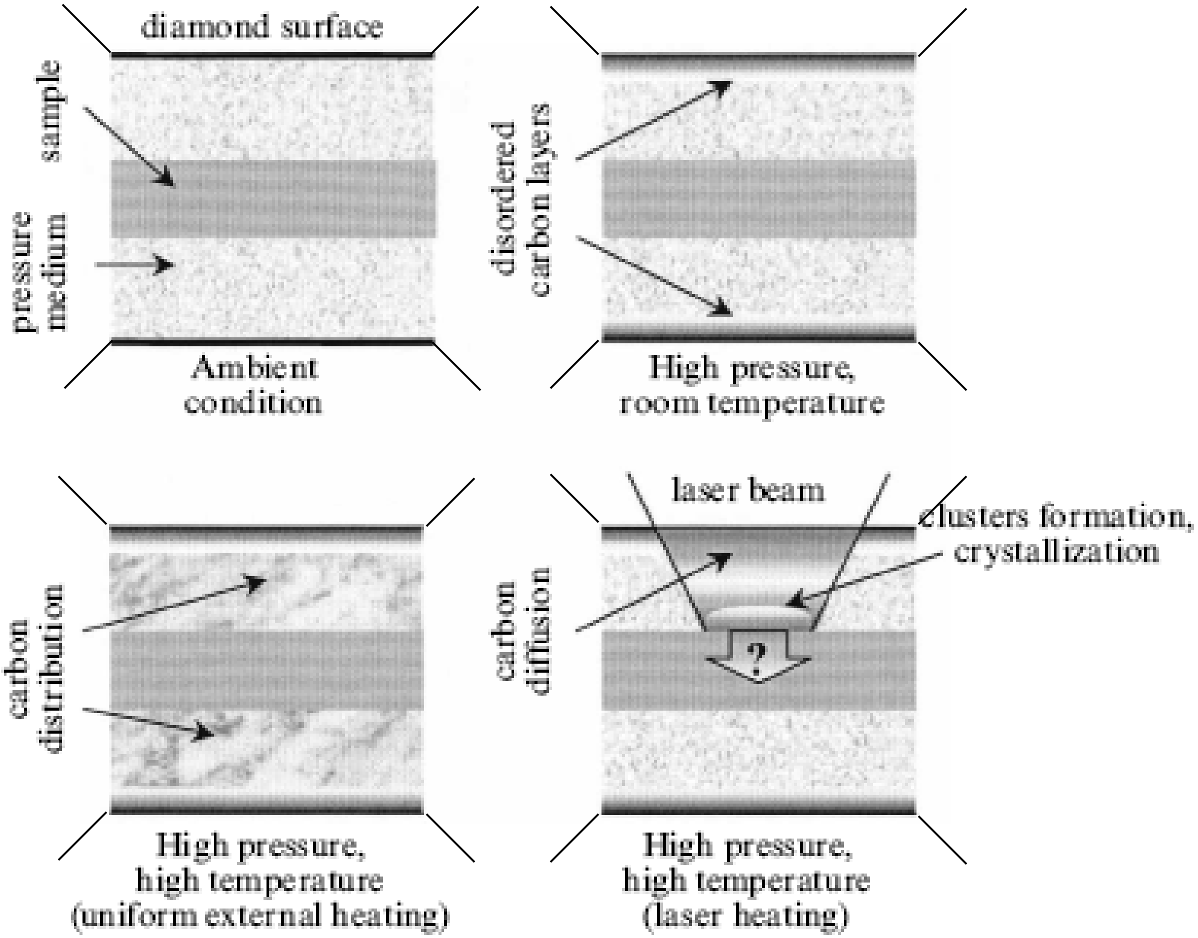


hot spot in the confined space

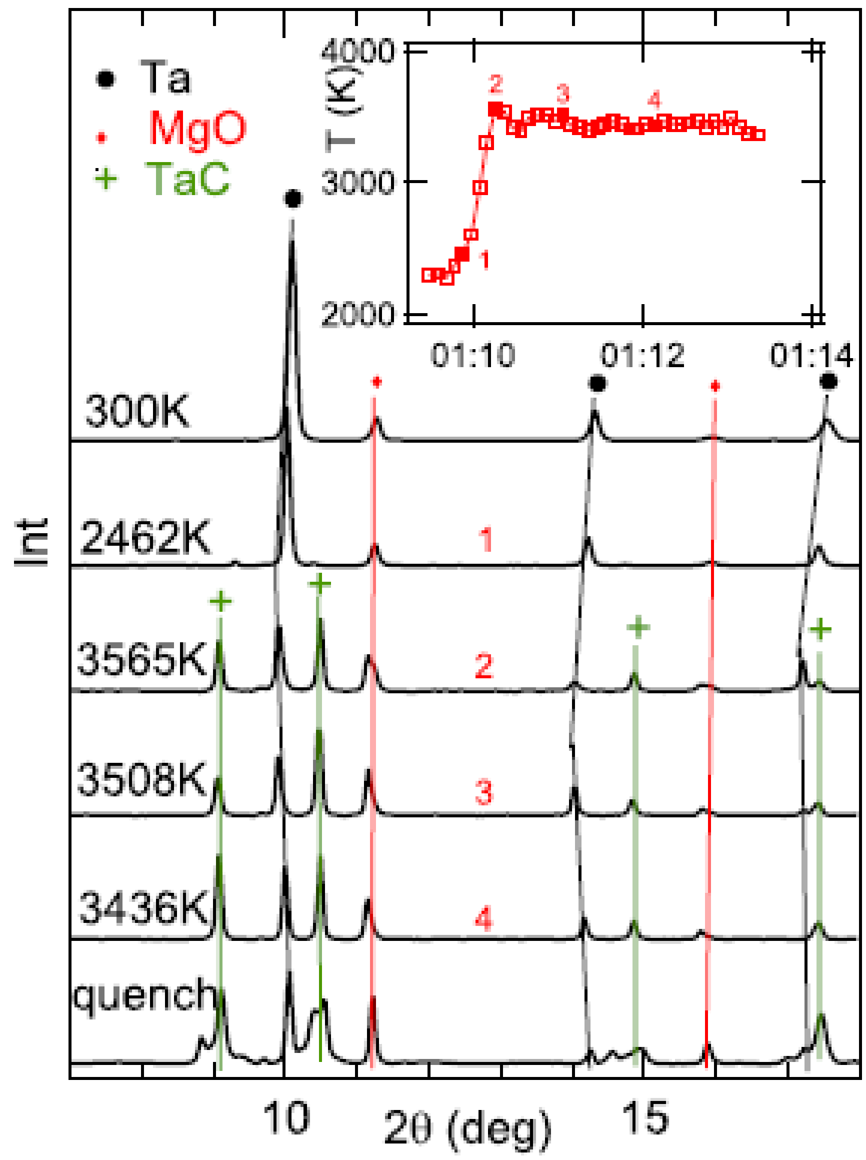
$Fe : SiO_2$, 38 GPa,



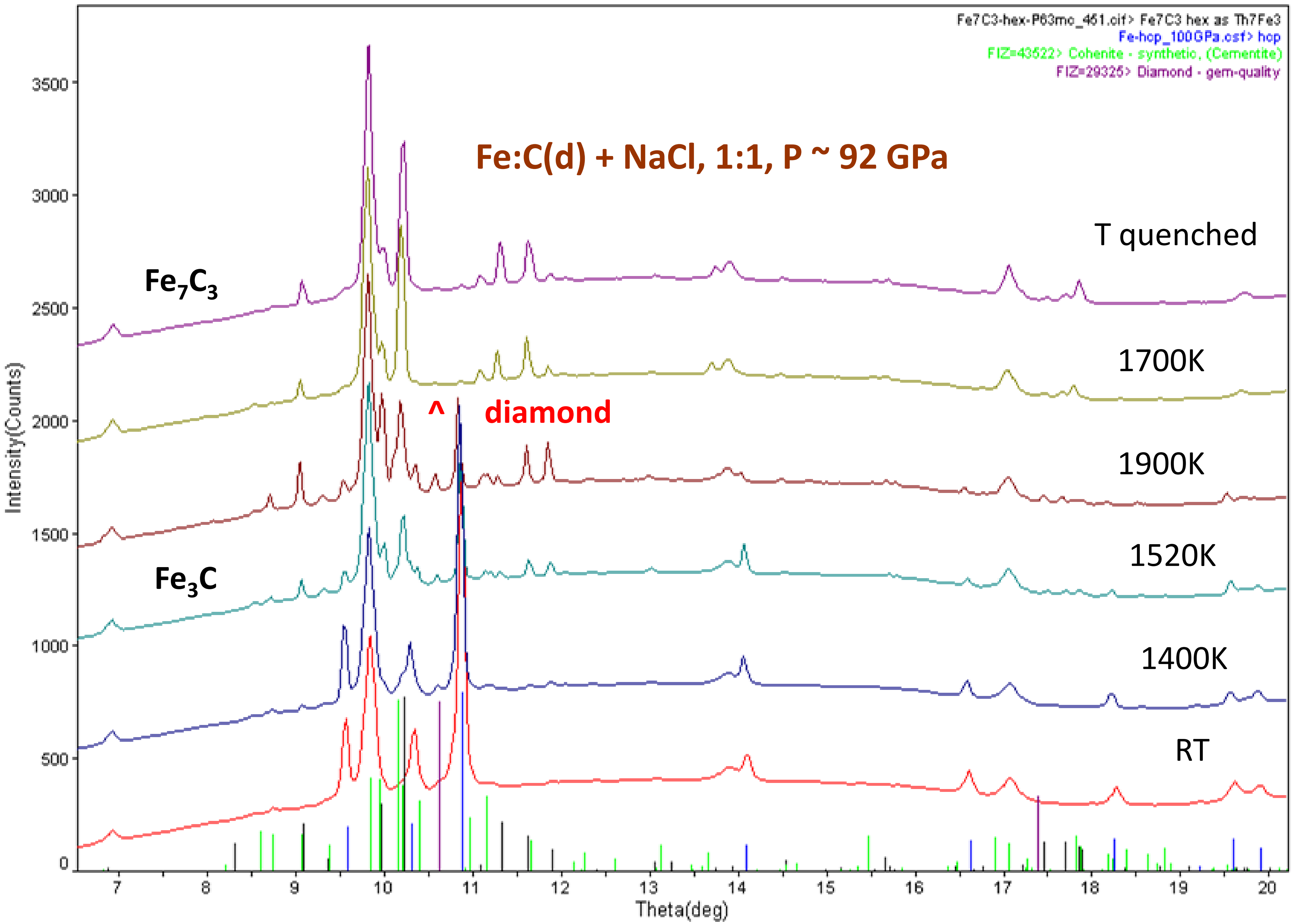
Carbon transport in diamond anvil cells



Prakapenka et al, High Temperatures High Pressures, 2003/2004, volume 35/36, pages 237-249

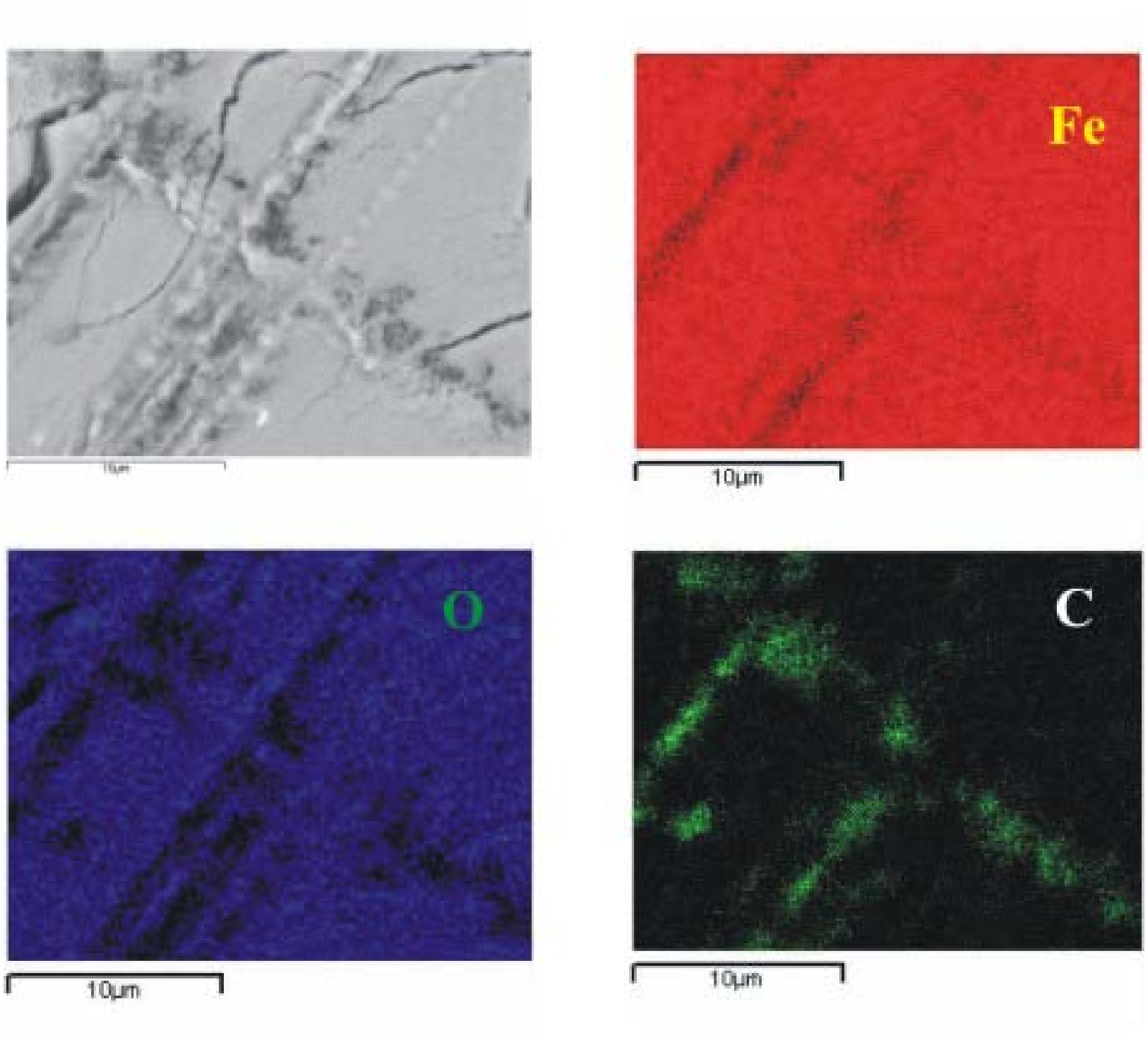


Dewaele et al, PRL, 2010



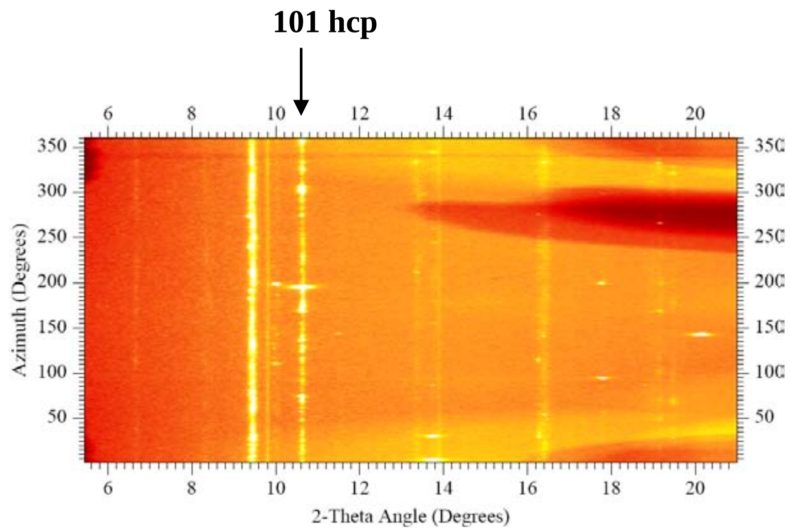
Prakapenka et al, 2011

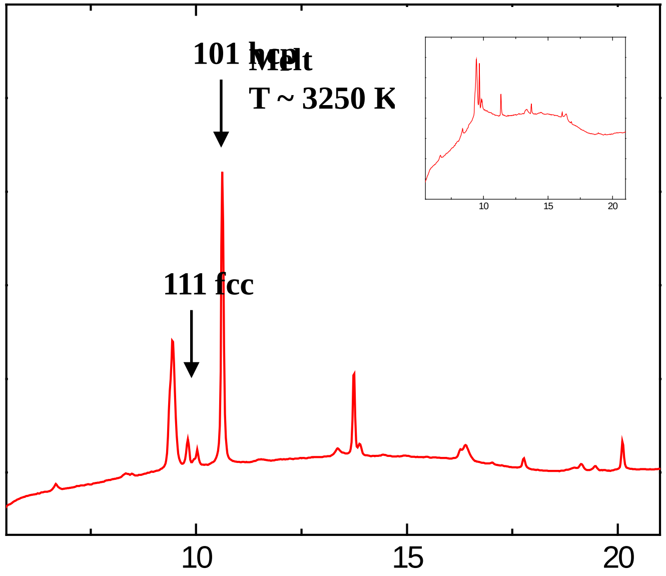
SEM images of FeO sample after laser heating



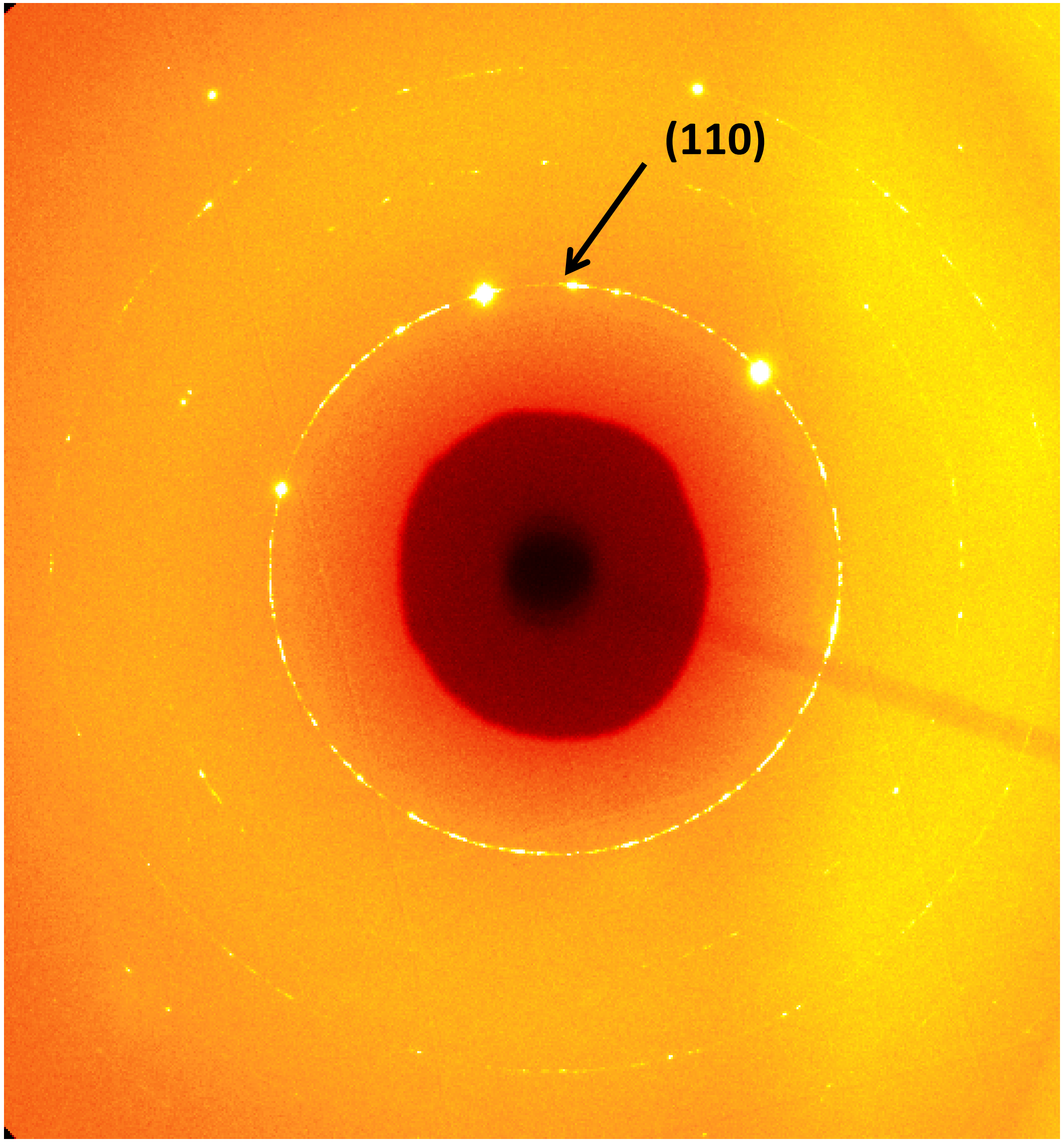
Leonid Dubrovinsky, BGI

Melting of Fe-Ni alloy at 60 GPa

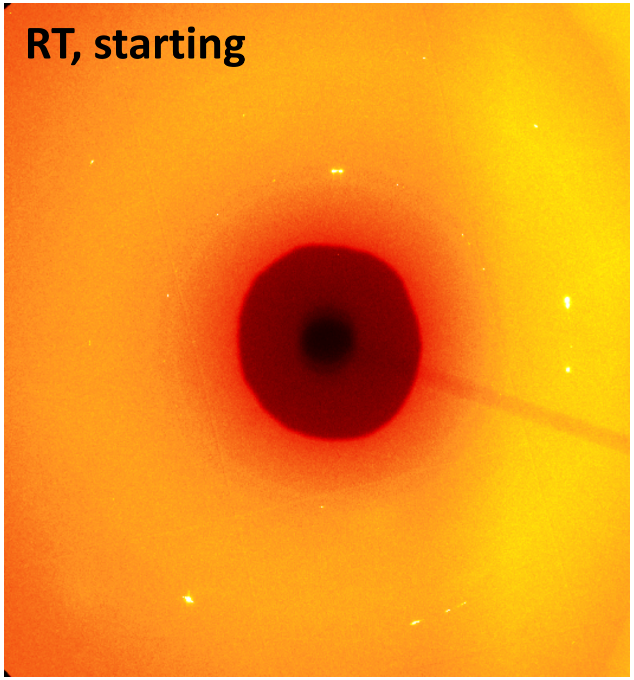




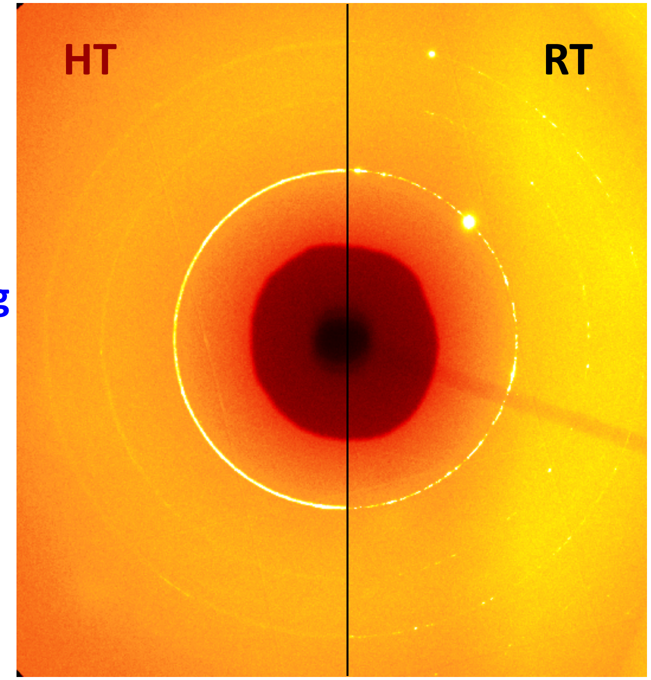
Ice VII, 7 GPa, T_m ~ 600K

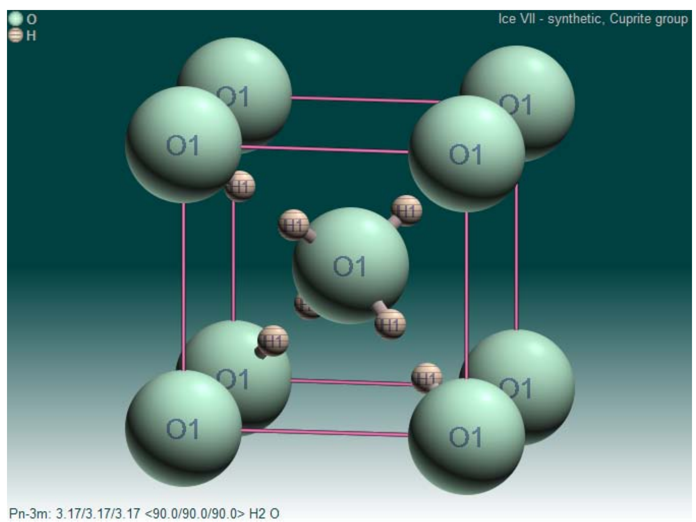


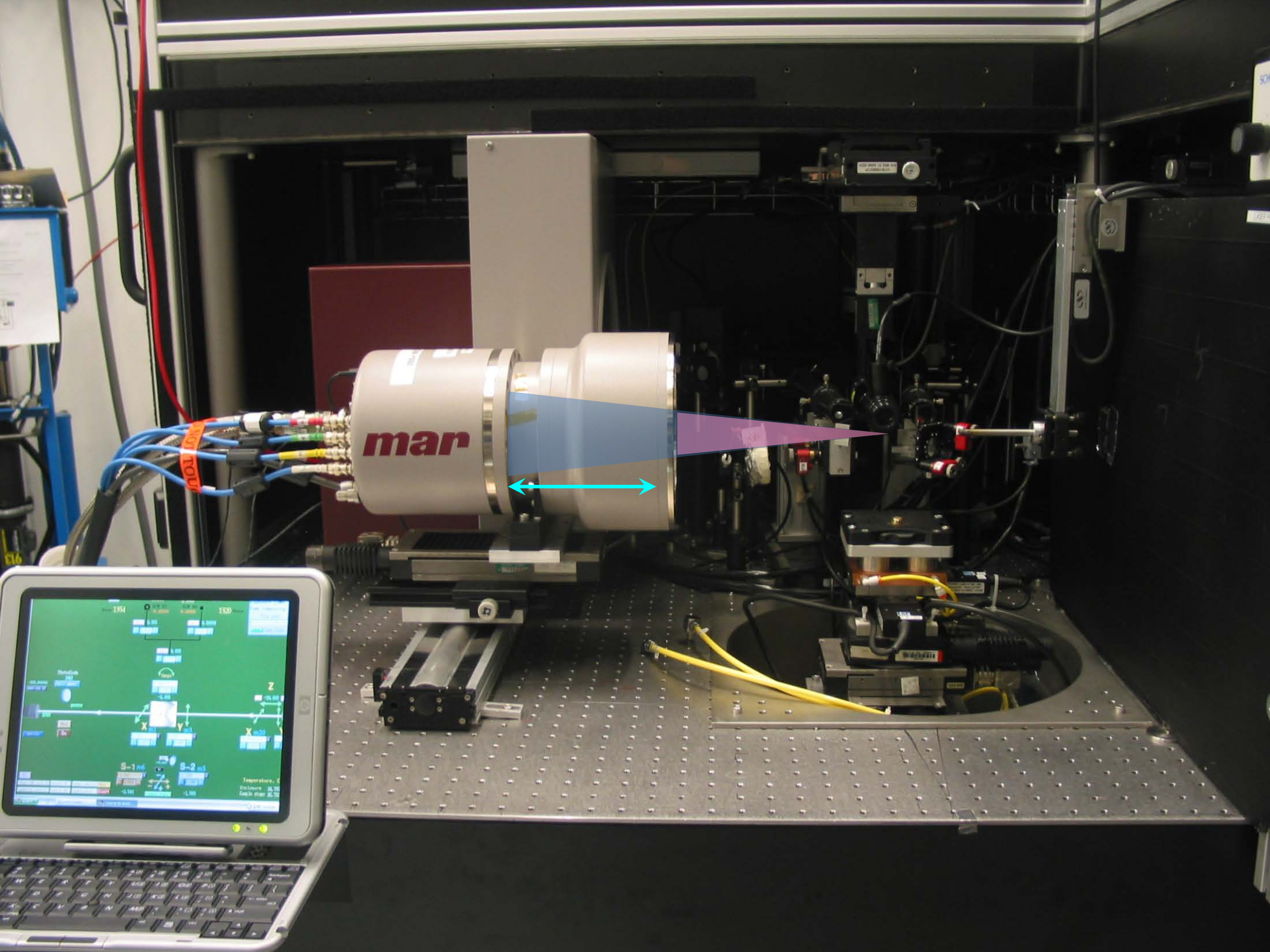
Ice VII, 7 GPa, T_m ~ 600K



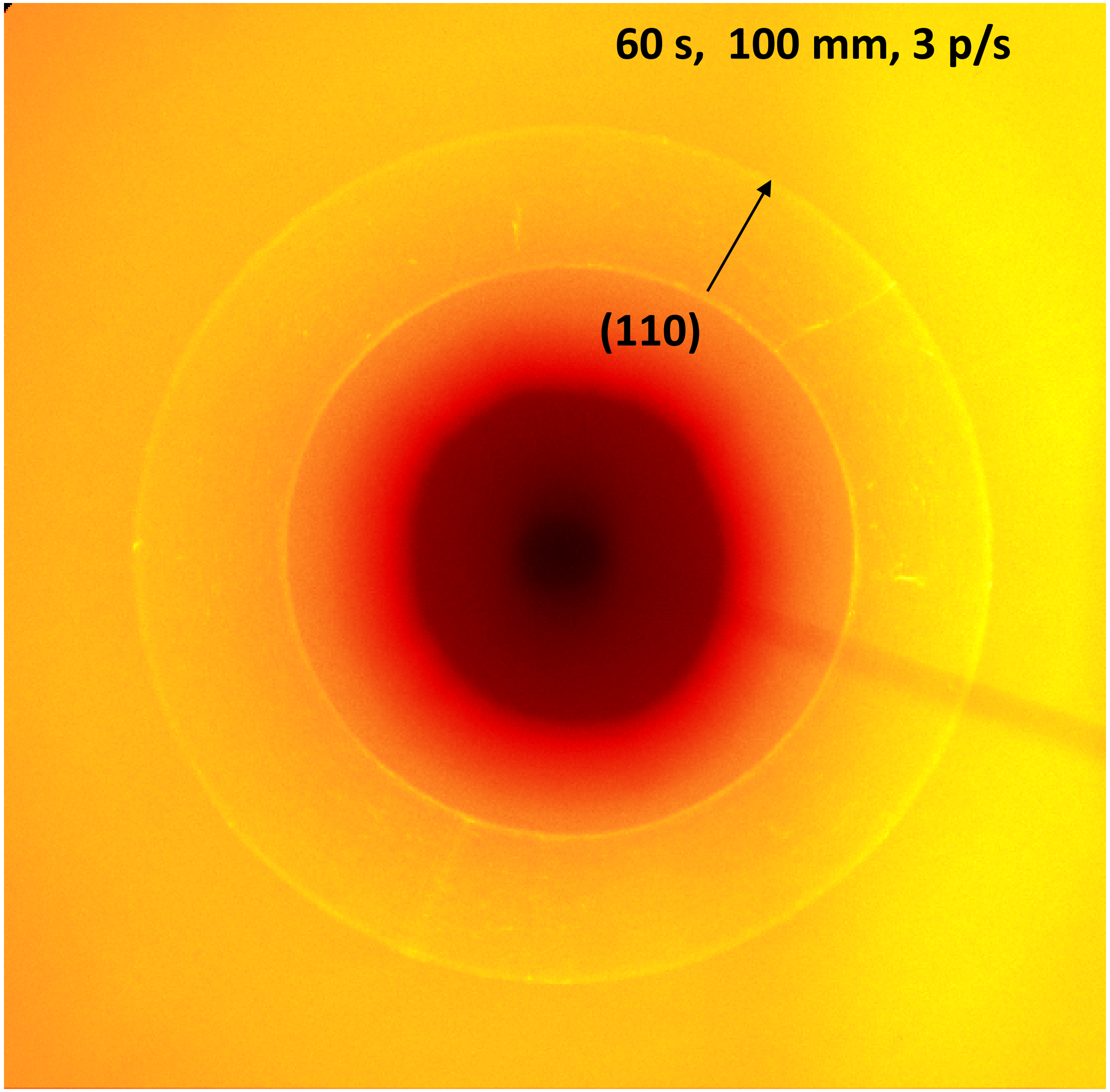
Laser heating





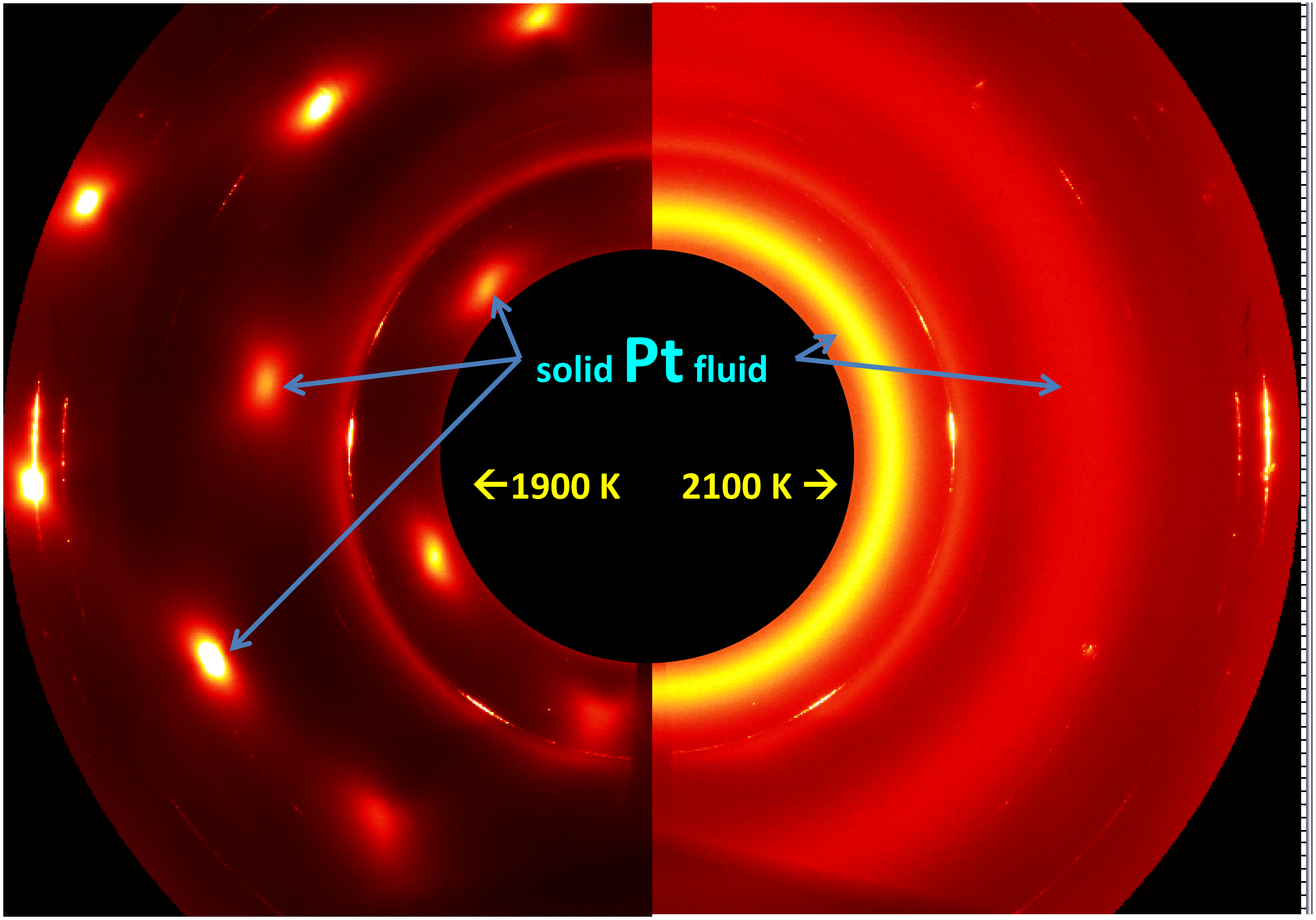

mar

Ice VII, 7 GPa, T_m ~ 600K

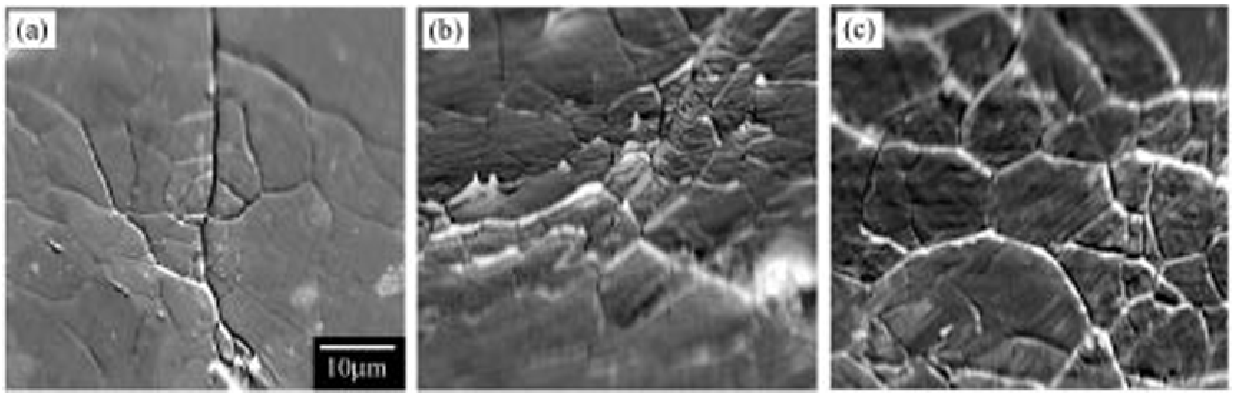


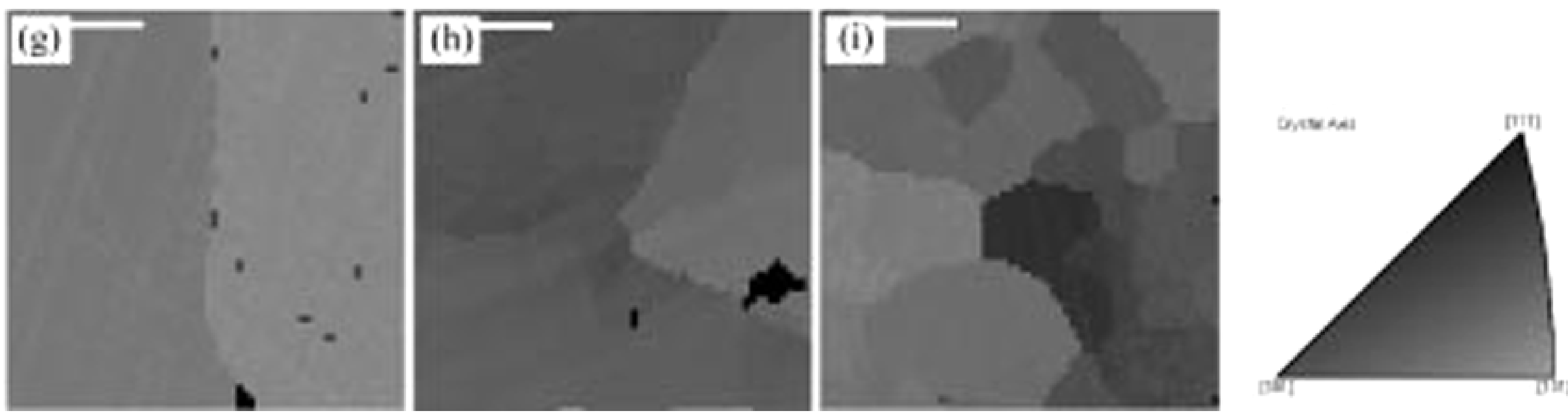
Laser effect?

Pt foil: melting at ambient pressure with double sided laser heating



Images of electron back scattered diffraction at 1000”C and 0.5/sec under various strains; (a) 10%, (b) 50% and (c) 500%

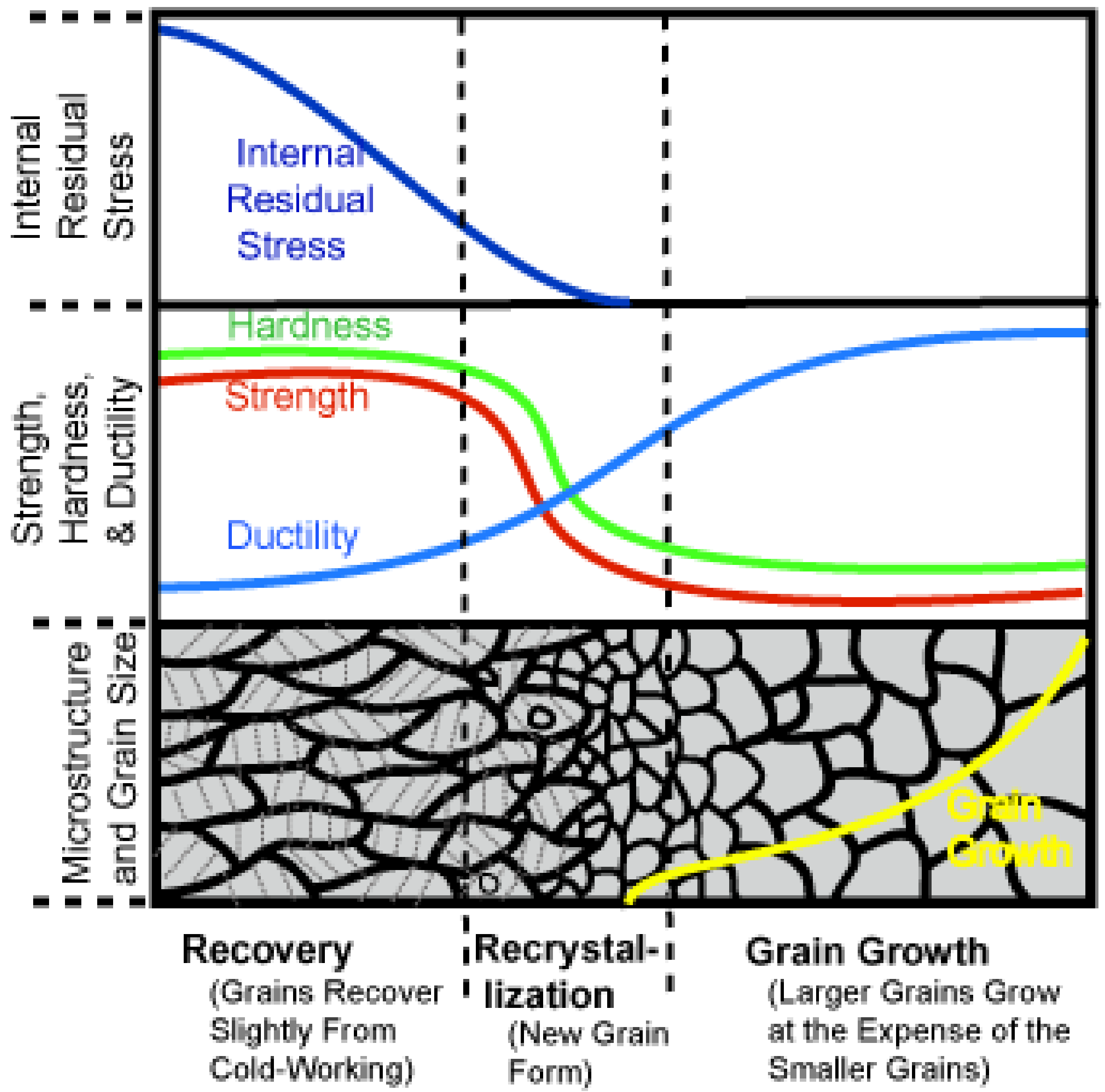




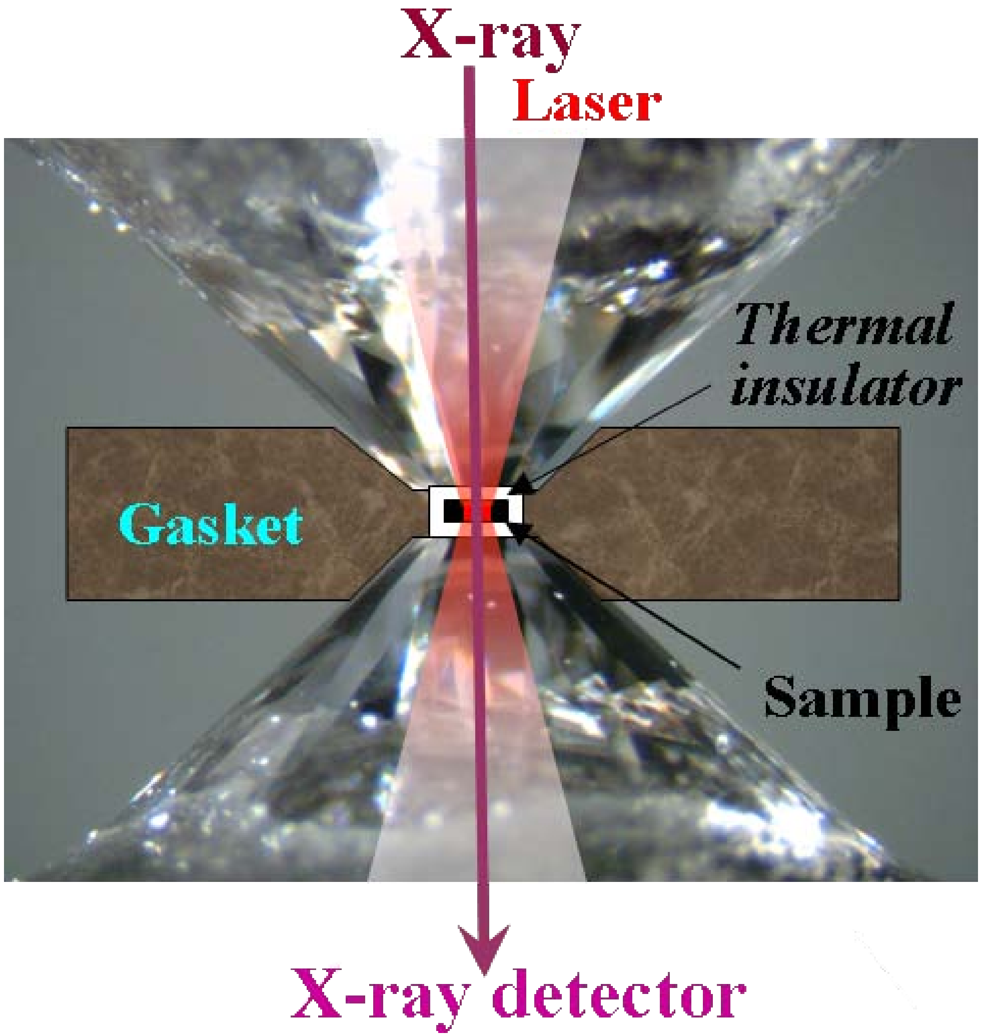
Grain boundary misorientation maps of electron back scattered diffraction

Kim et al, METALS AND MATERIALS International, Vol. 8, No. 1 (2002), pp. 7~13

Dynamic recrystallization

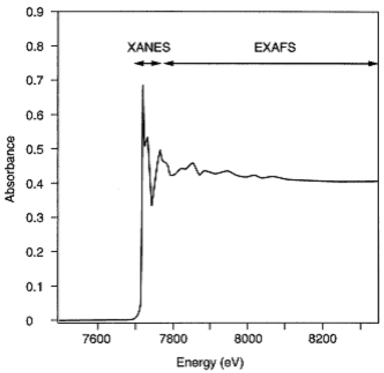


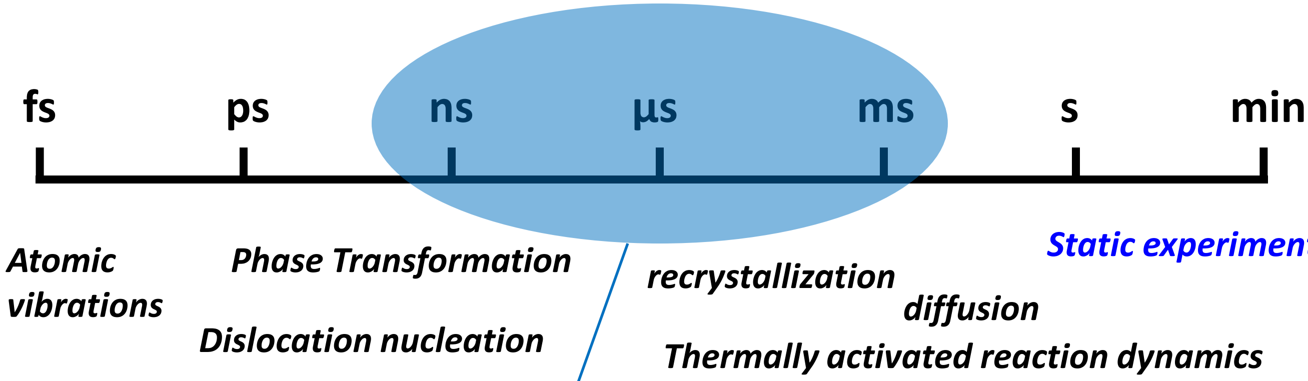
http://www.ndt-ed.org

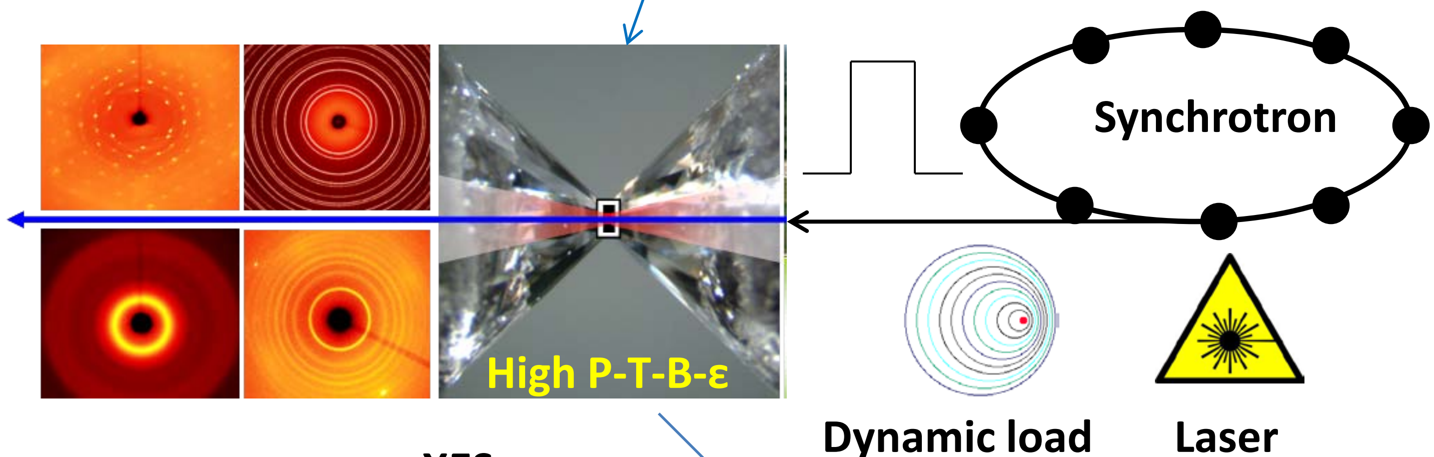


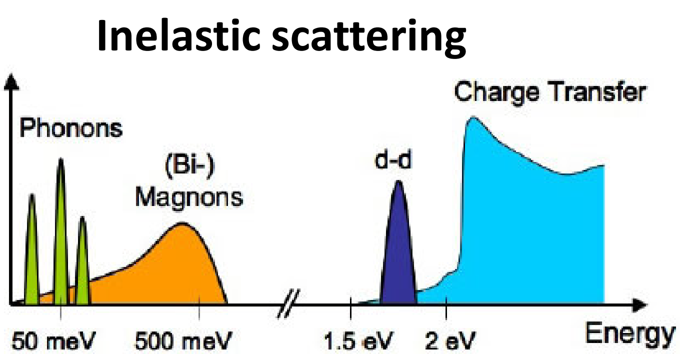
- *Chemistry*
- *Sample diffusion*
- *Crystallization*

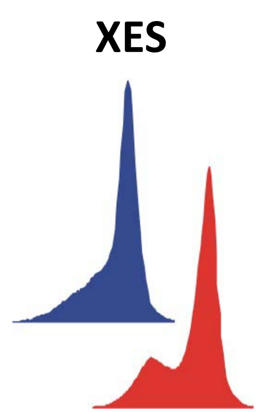
Probing fundamental ultrafast processes





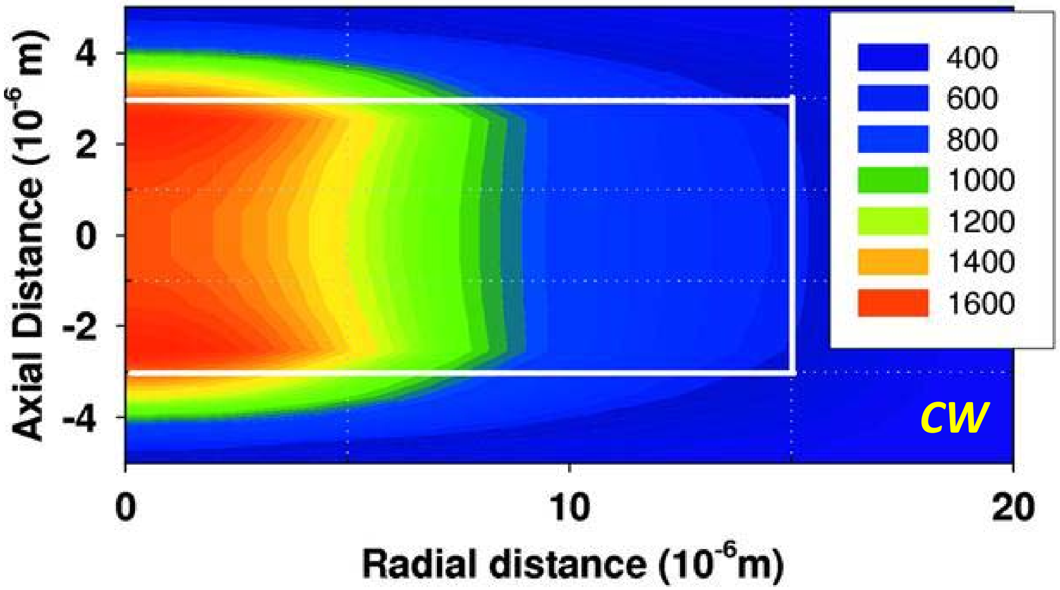




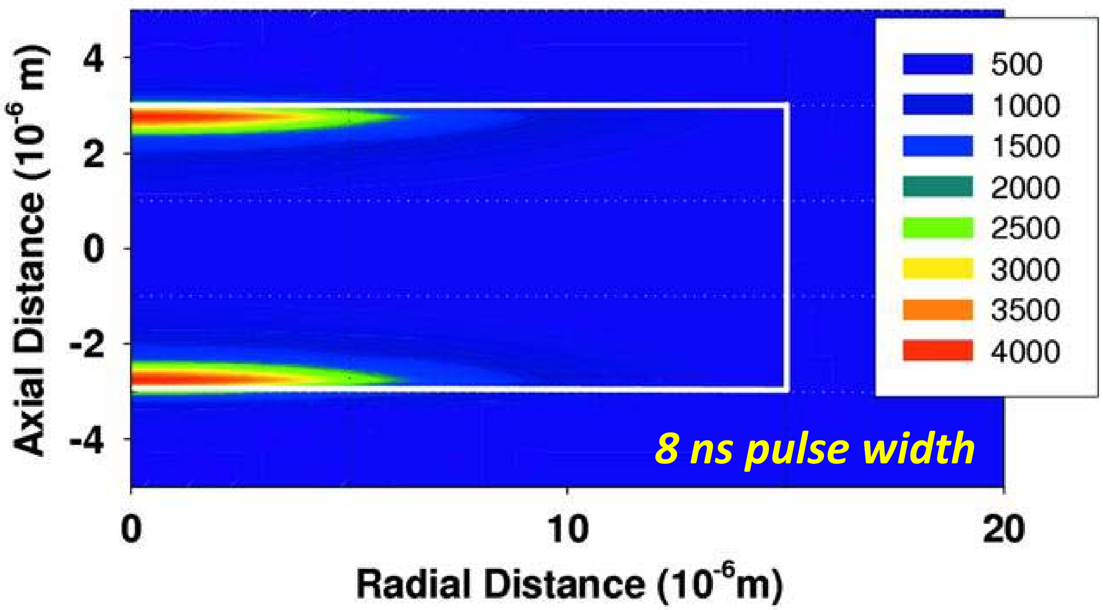


- o phase transition kinetics
- o structural dynamics & deformation
- o chemical reaction dynamics
- o transport properties (diffusion)
- o electronic properties

Finite-element calculations of the temperature profiles in the DAC cavity



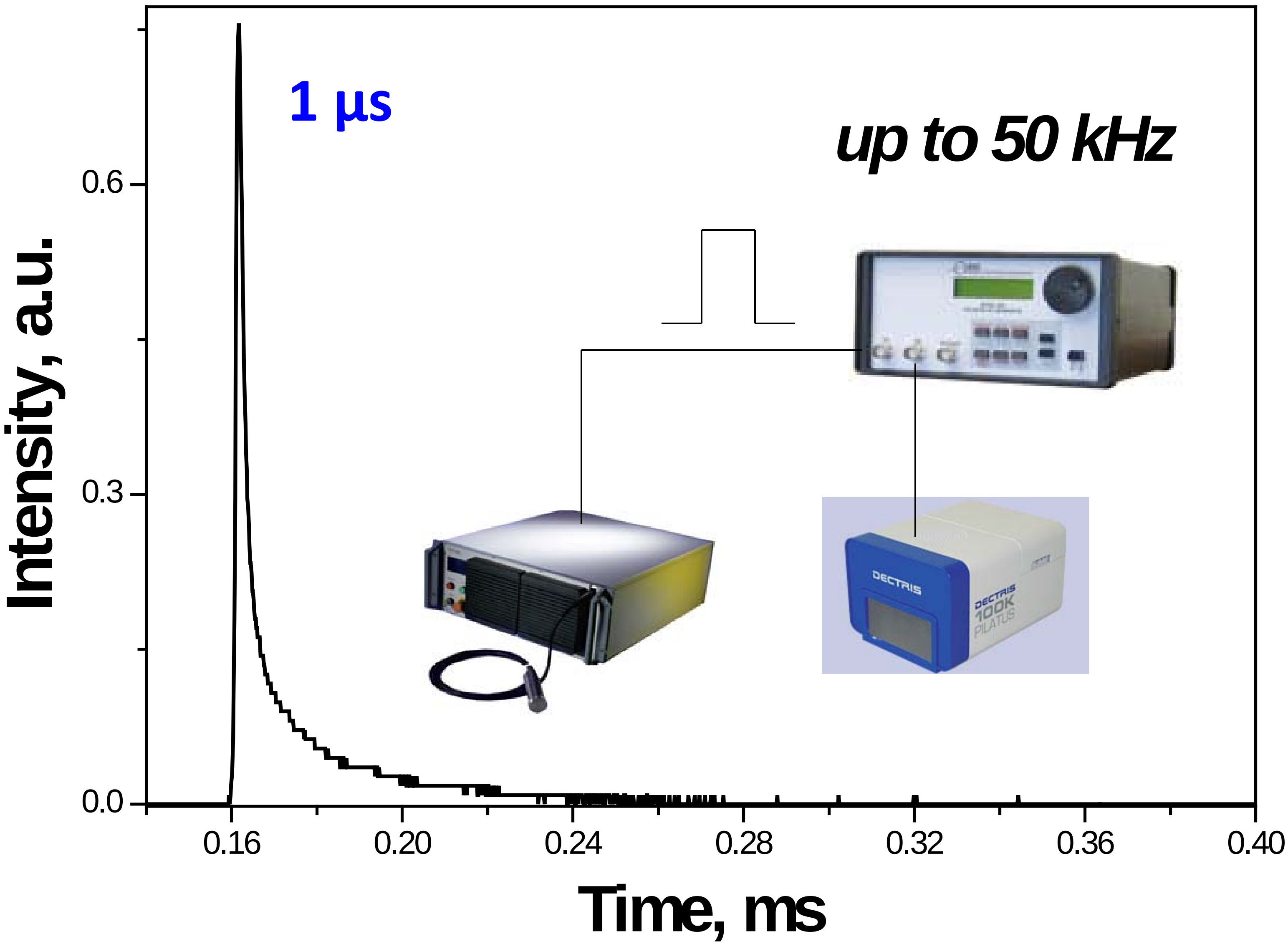
(a)



(b)

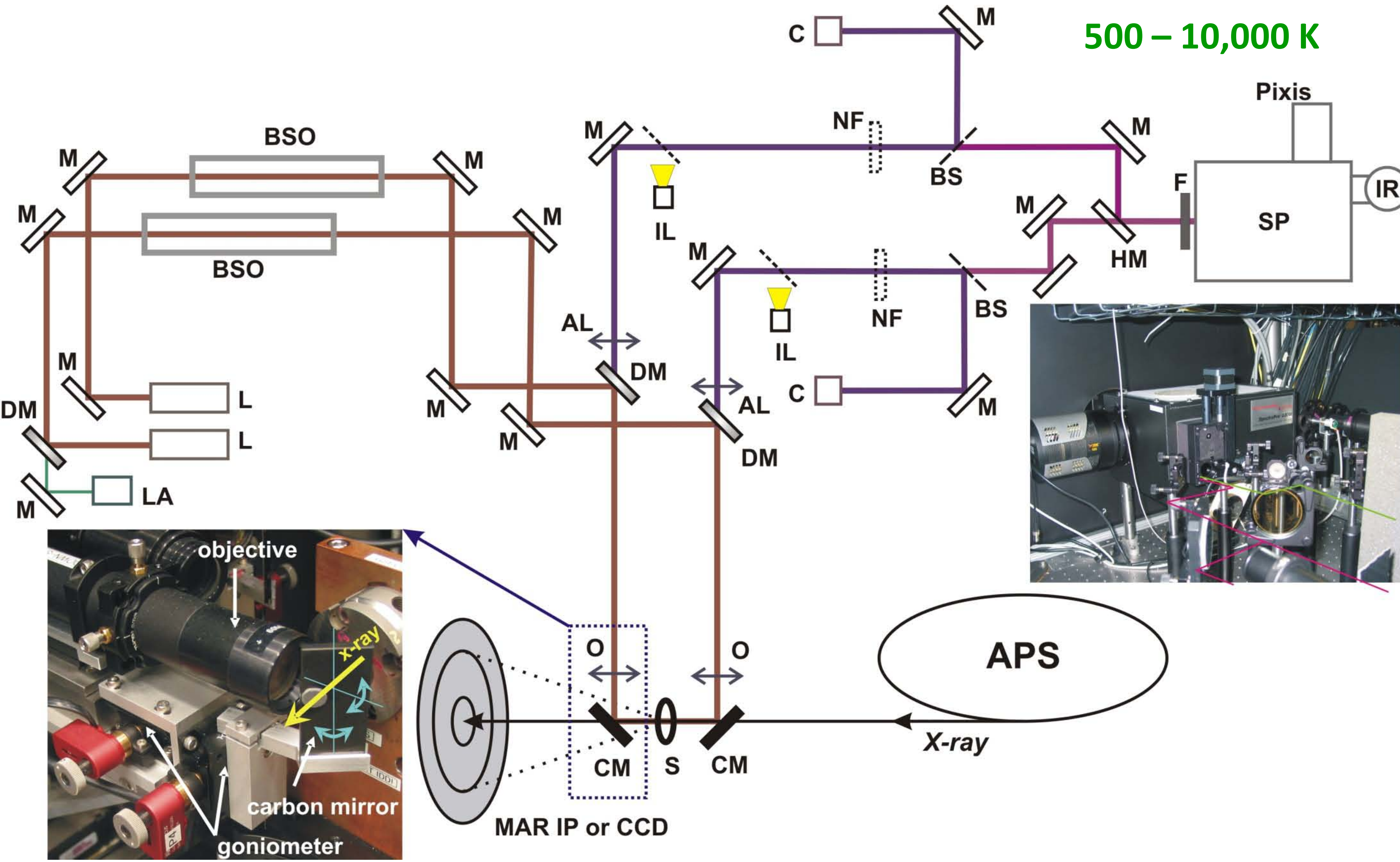
Goncharov, JSR, 2009

Pulse laser heating

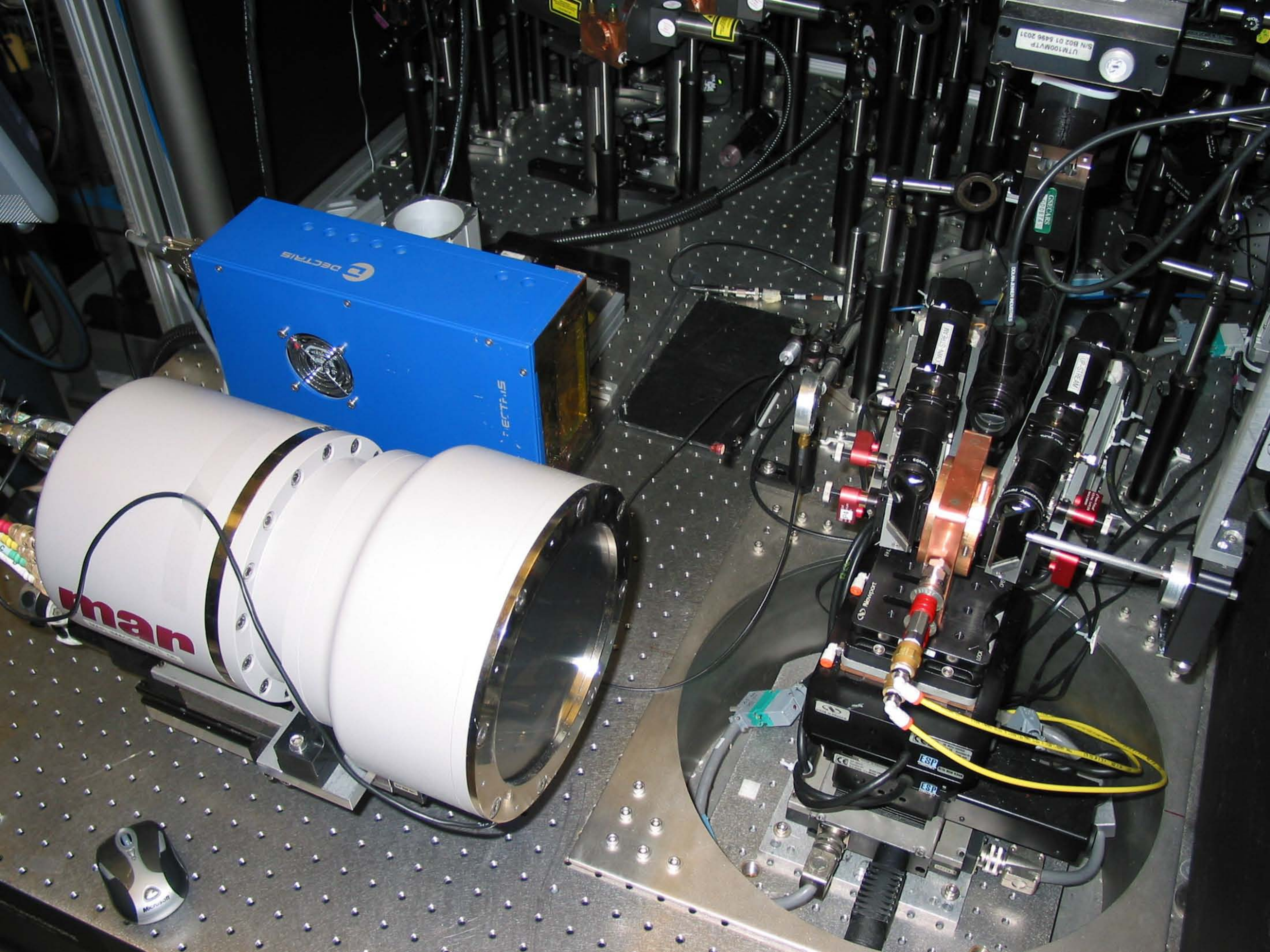


Goncharov, Prakapenka et al, Rev. Sci. Instrum. 81, 113902 (2010)

Optical schema of the on-line, flat top, double-sided laser heating system at GSECARS



Prakapenka et al., High Pressure Research, 2008 , 28:3,225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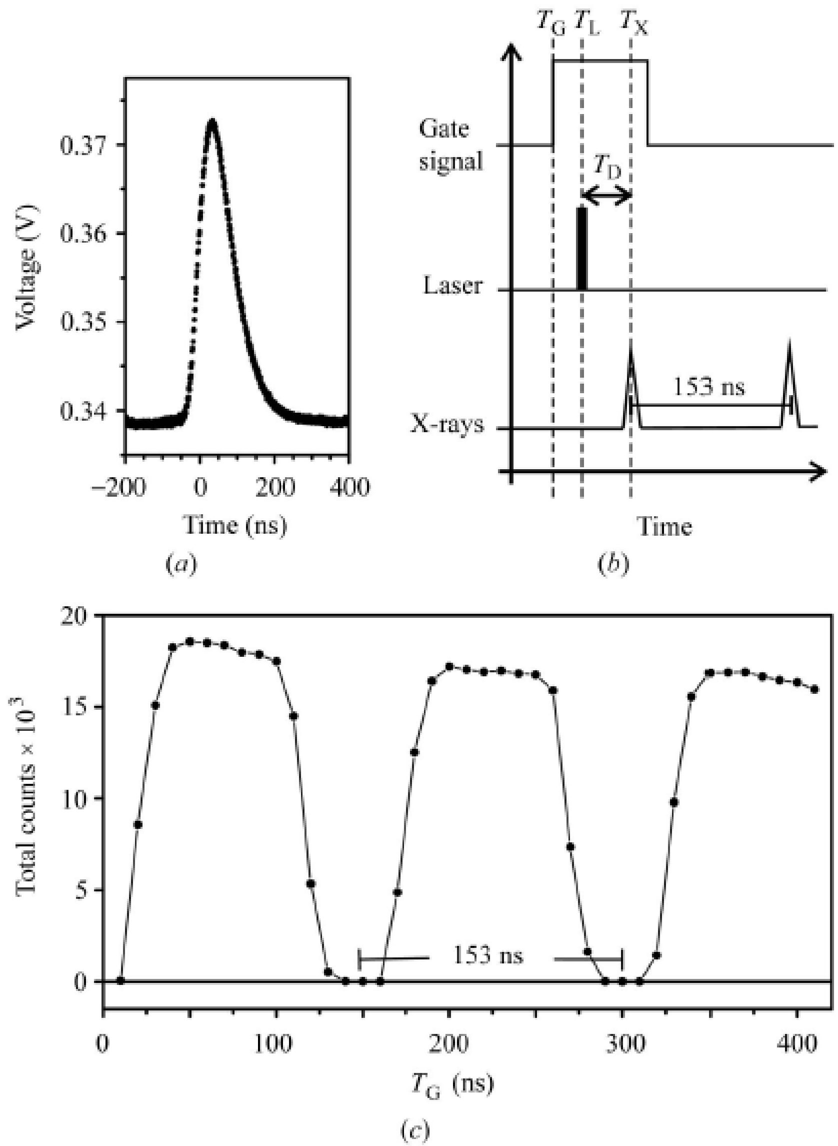
Newport
ESP
ESP

Journal of
Synchrotron
Radiation
ISSN 0909-0495

Picosecond time-resolved laser pump/X-ray probe experiments using a gated single-photon-counting area detector

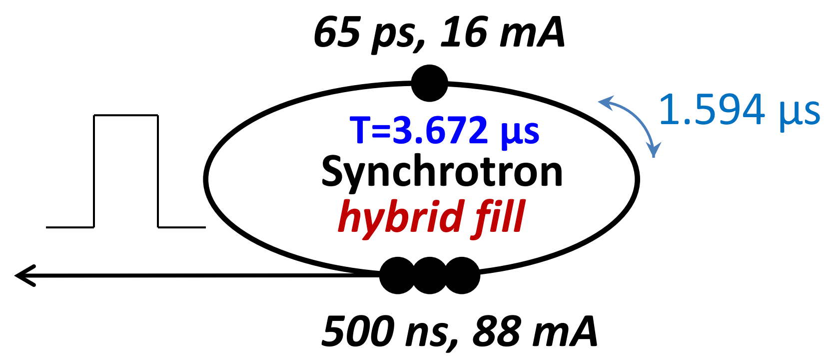
Received 9 December 2008
Accepted 9 February 2009

T. Ejdrup,[a]* H. T. Lemke,[a] K. Haldrup,[a] T. N. Nielsen,[a] D. A. Arms,[b] D. A. Walko,[b] A. Miceli,[b] E. C. Landahl,[c] E. M. Dufresne[b] and M. M. Nielsen[a]



Standard Operating Mode, top-up

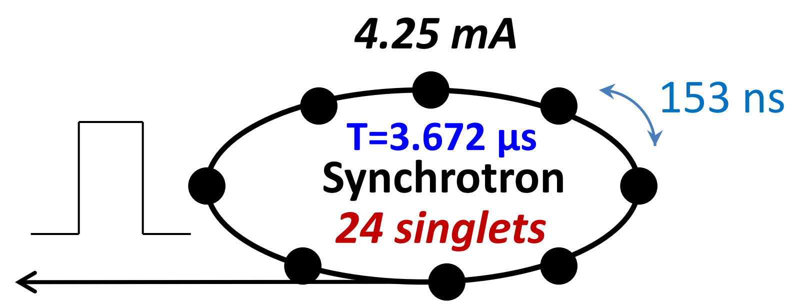
102 mA in 24 singlets (single bunches) with a nominal current of 4.25 mA and a spacing of 153 nanoseconds between 40 ps singlets.



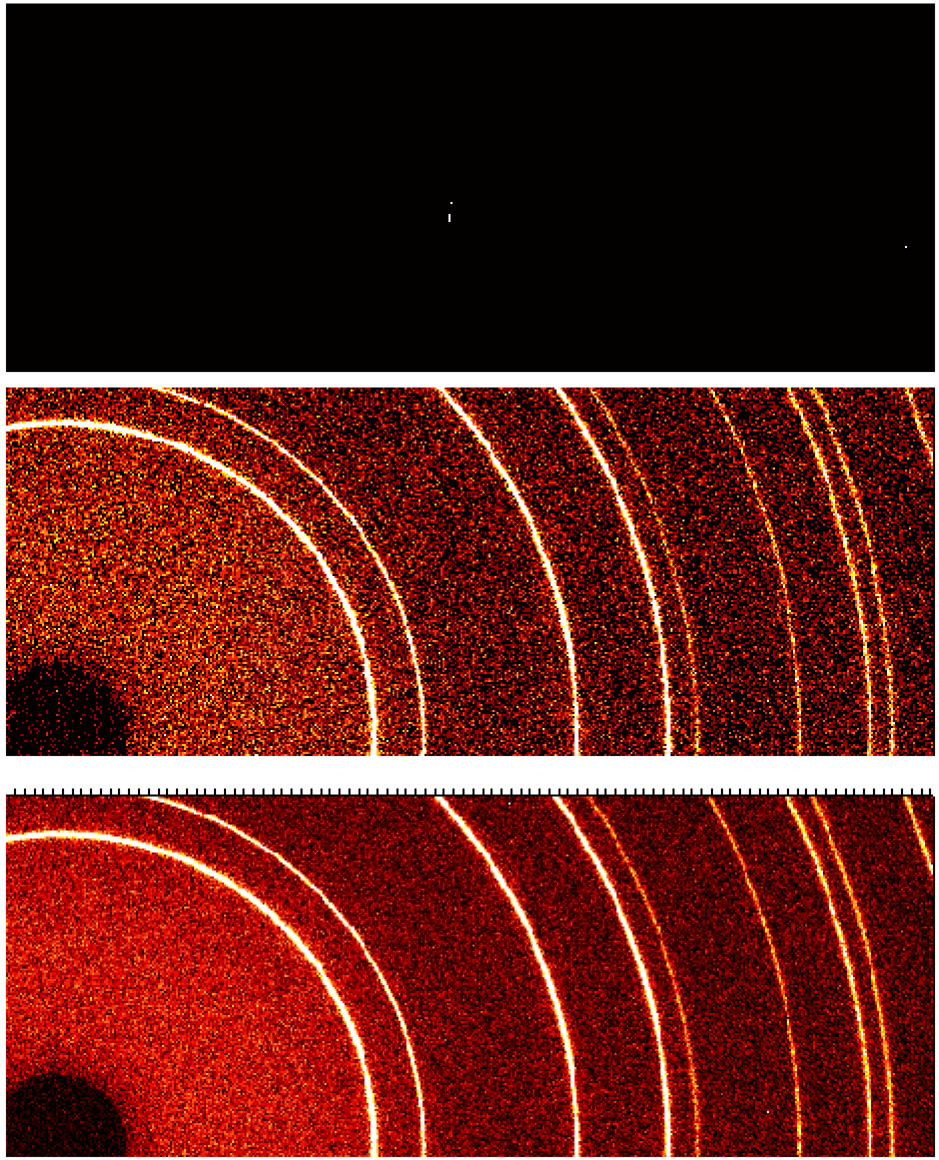
Special Operating Mode - hybrid fill, top-up

Total current is 102 mA. A single bunch containing 16 mA isolated from the remaining bunches by symmetrical 1.594 microseconds gaps.

The remaining current is distributed in 8 group of 7 consecutive bunches with a maximum of 11 mA per group. The total length of the bunch train is 500 ns.



Pt, 69 GPa

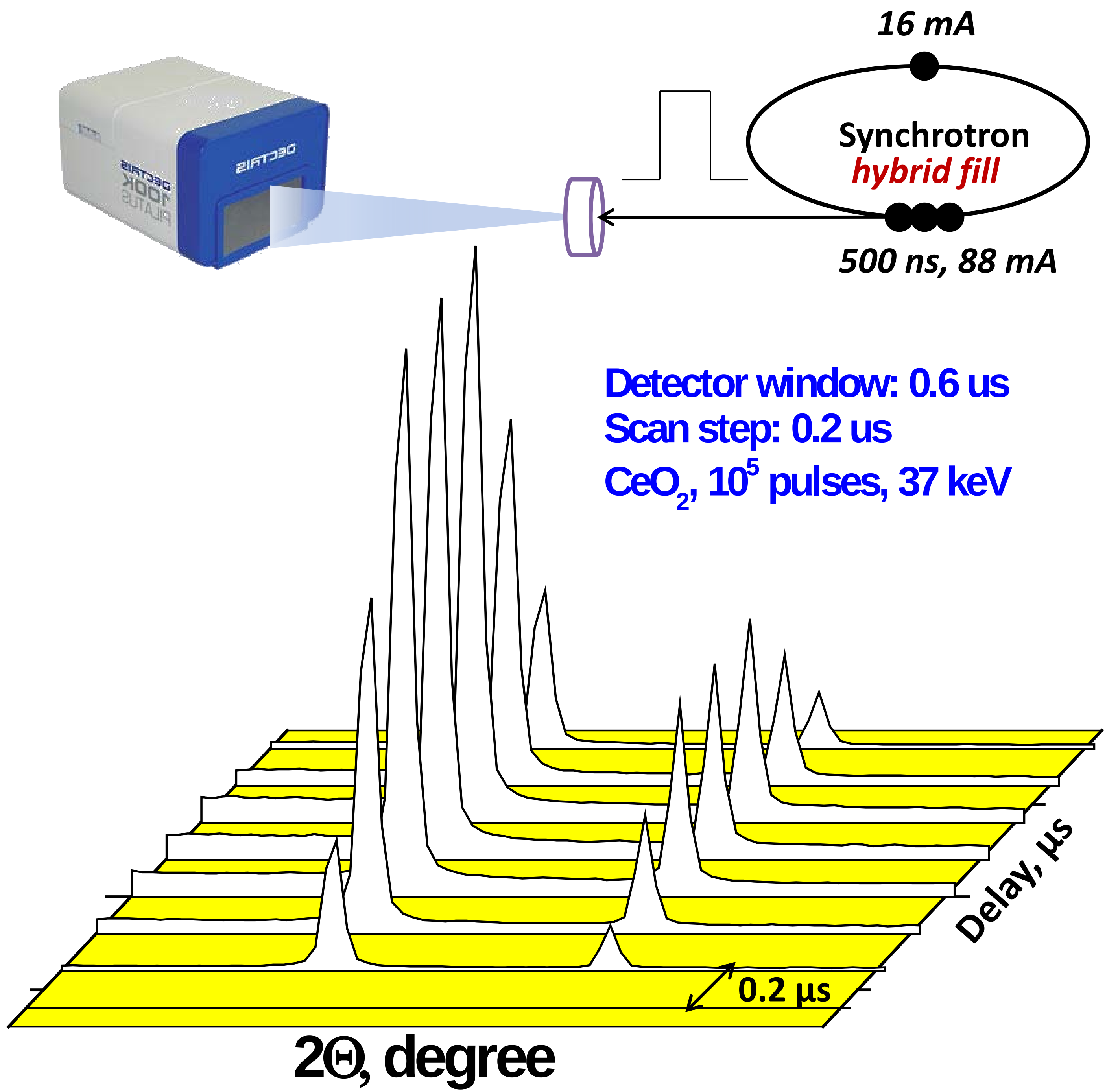


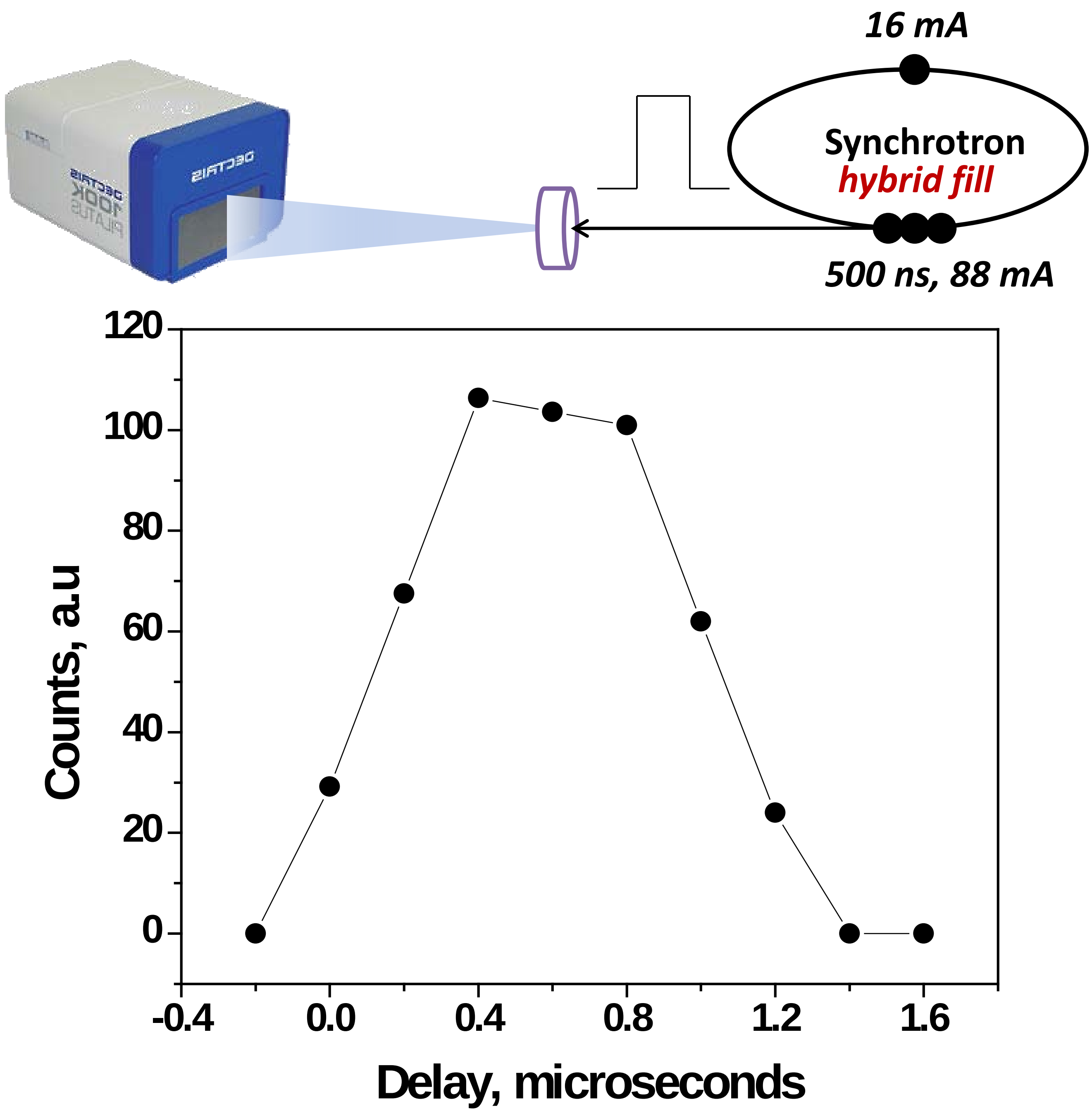
Pilatus, 10000 pls
600 ns width

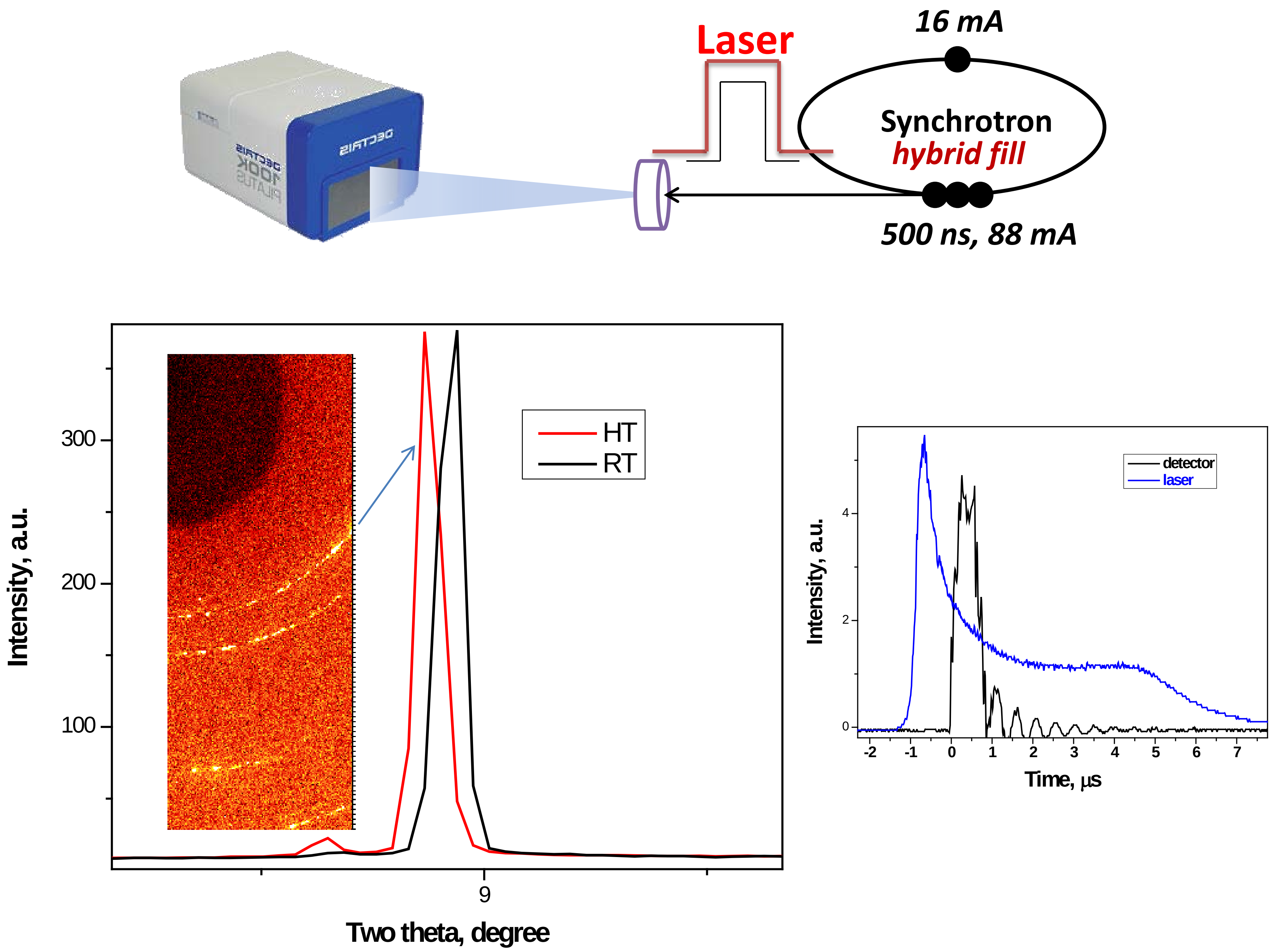
0 ns delay

200 ns delay

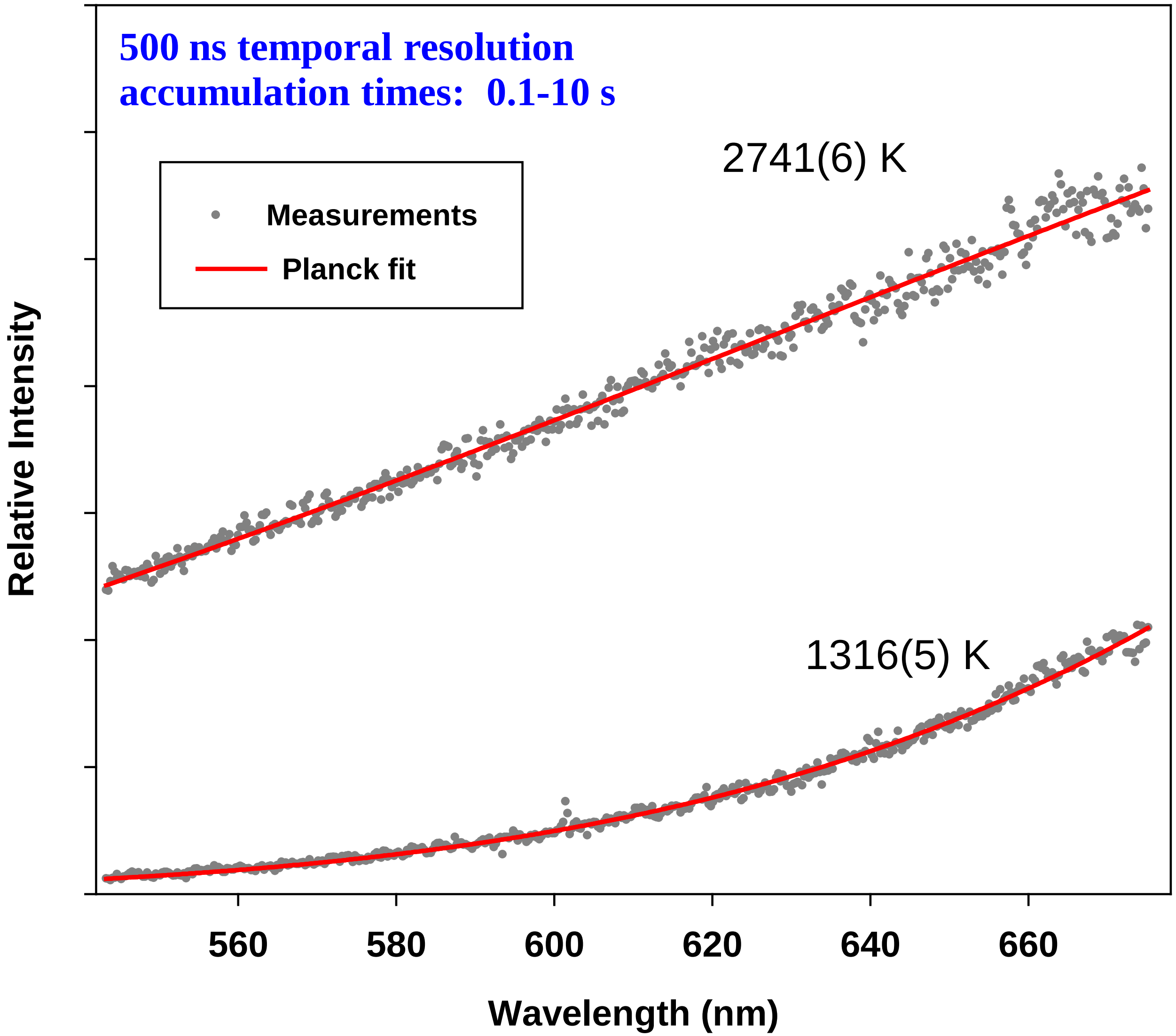
600 ns delay


16 mA
Synchrotron
hybrid fill
500 ns, 88 mA
Detector window: 0.6 us
Scan step: 0.2 us
CeO2, 10^5 pulses, 37 keV
Delay, µs
0.2 µs
2Θ, degree


16 mA
Synchrotron
hybrid fill
500 ns, 88 mA
DECTRIS
100K
PILATUS
120
100
80
60
40
20
0
Counts, a.u
-0.4
0.0
0.4
0.8
1.2
1.6
Delay, microseconds

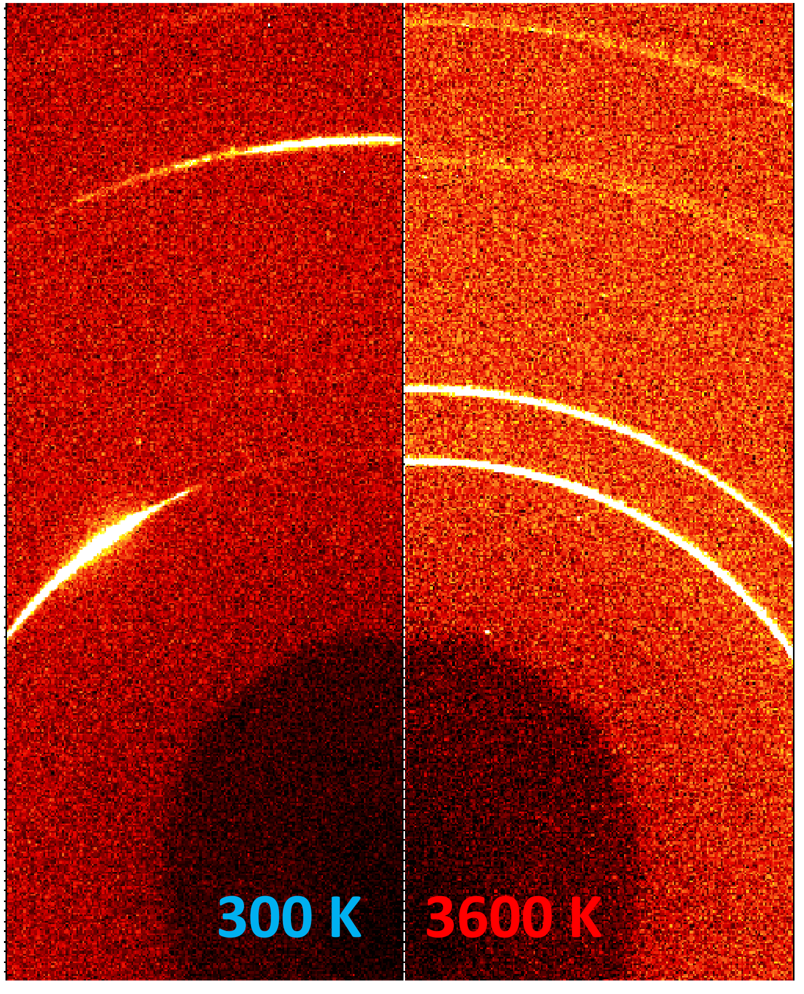

Laser
16 mA
Synchrotron
hybrid fill
500 ns, 88 mA
DECTRIS
HT
RT
300
200
100
9
Intensity, a.u.
Two theta, degree
detector
laser
Intensity, a.u.
Time, µs

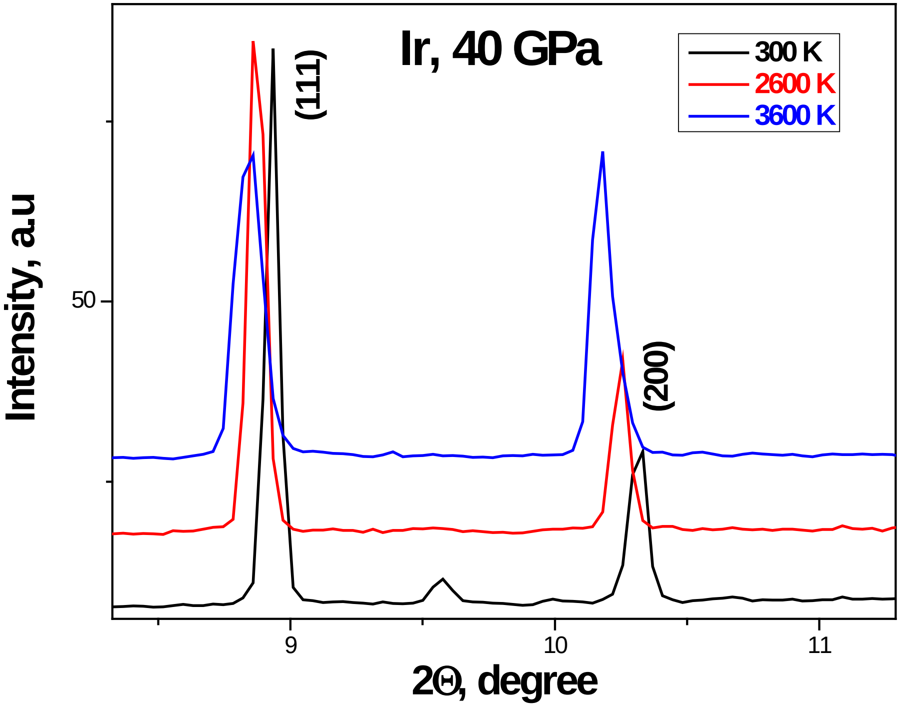
The time-resolved radiometric measurements of temperature



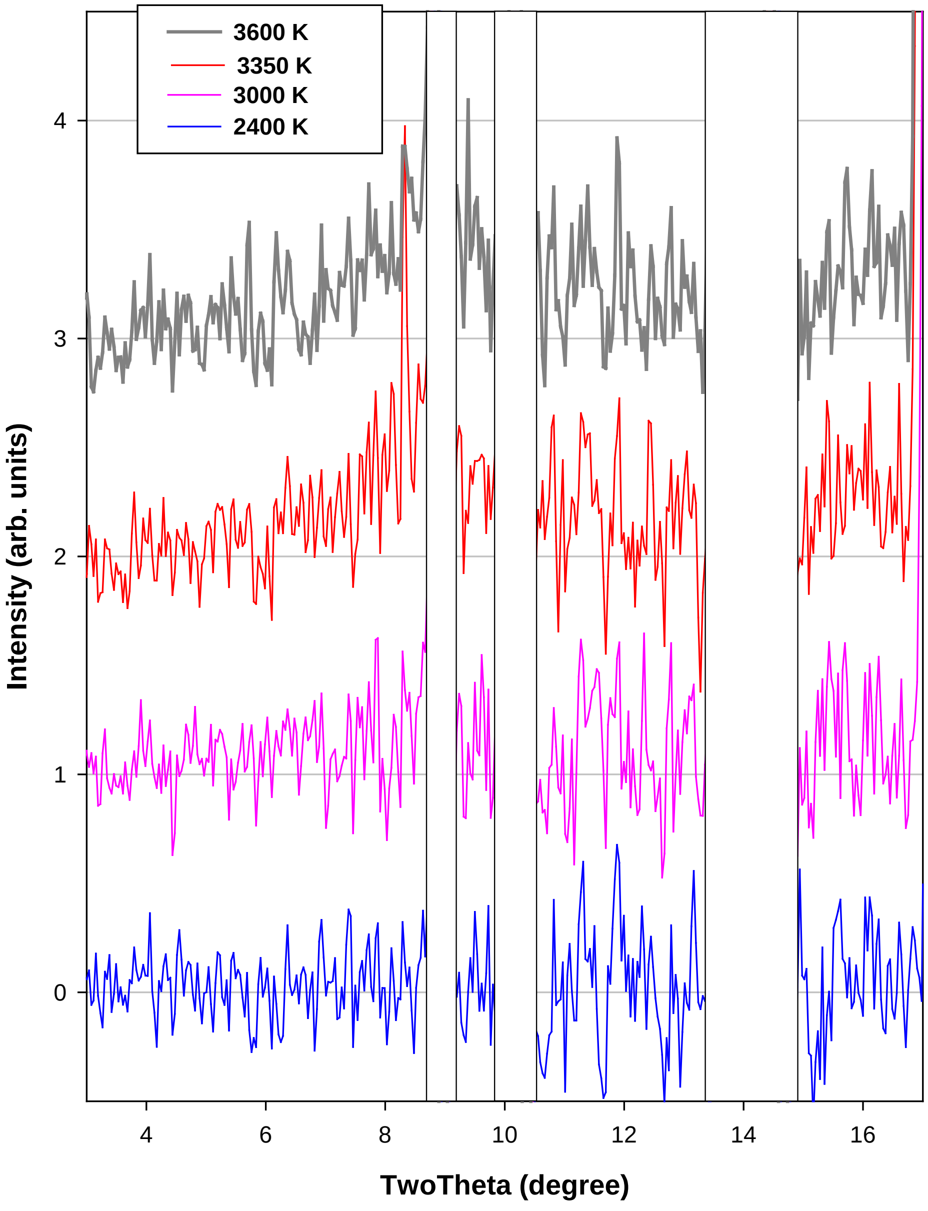
Goncharov, Prakapenka et al, Rev. Sci. Instrum. 81, 113902 (2010)

Pulsed laser heating Ir at 40 GPa

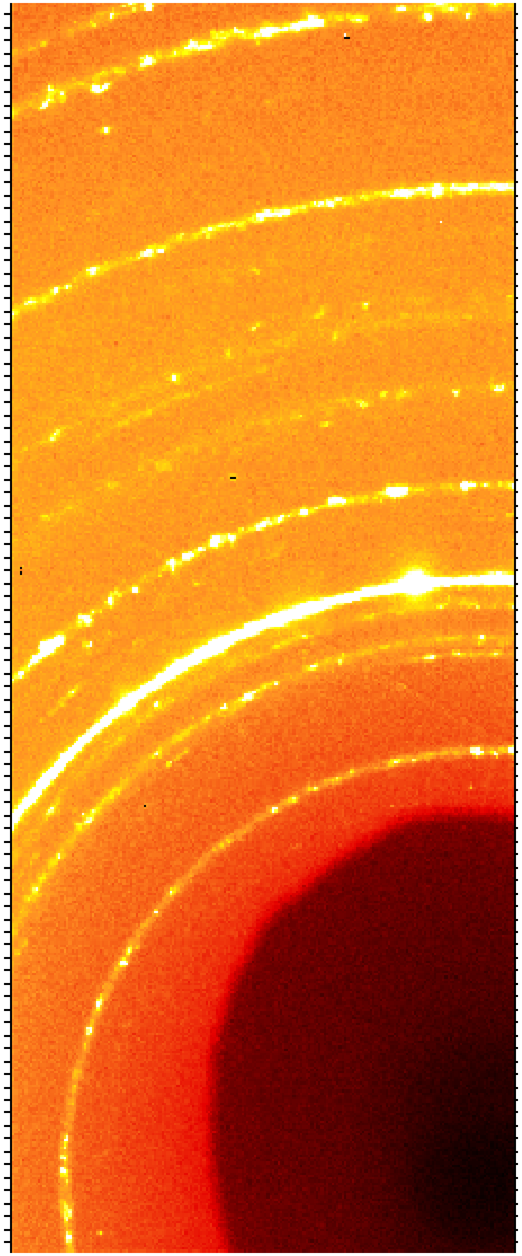


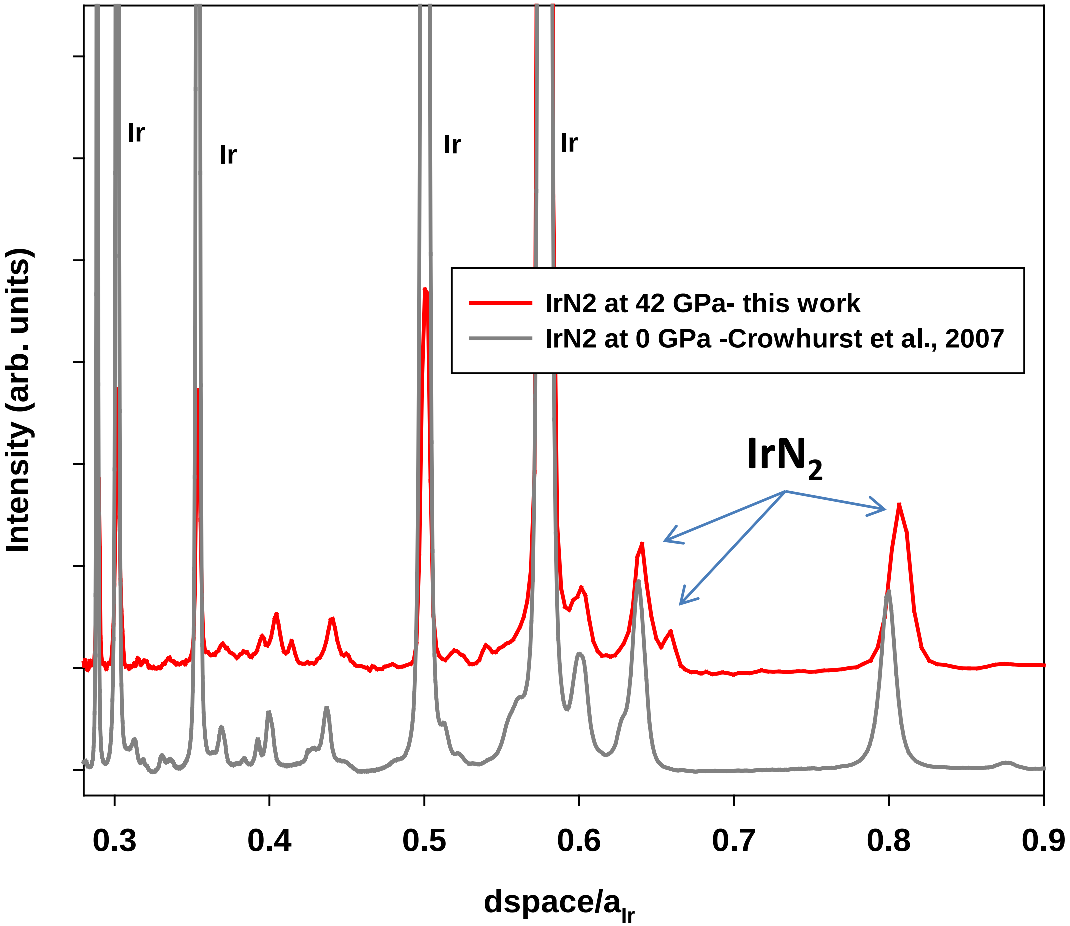


• Melting can be detected by observing a diffuse diffraction ring

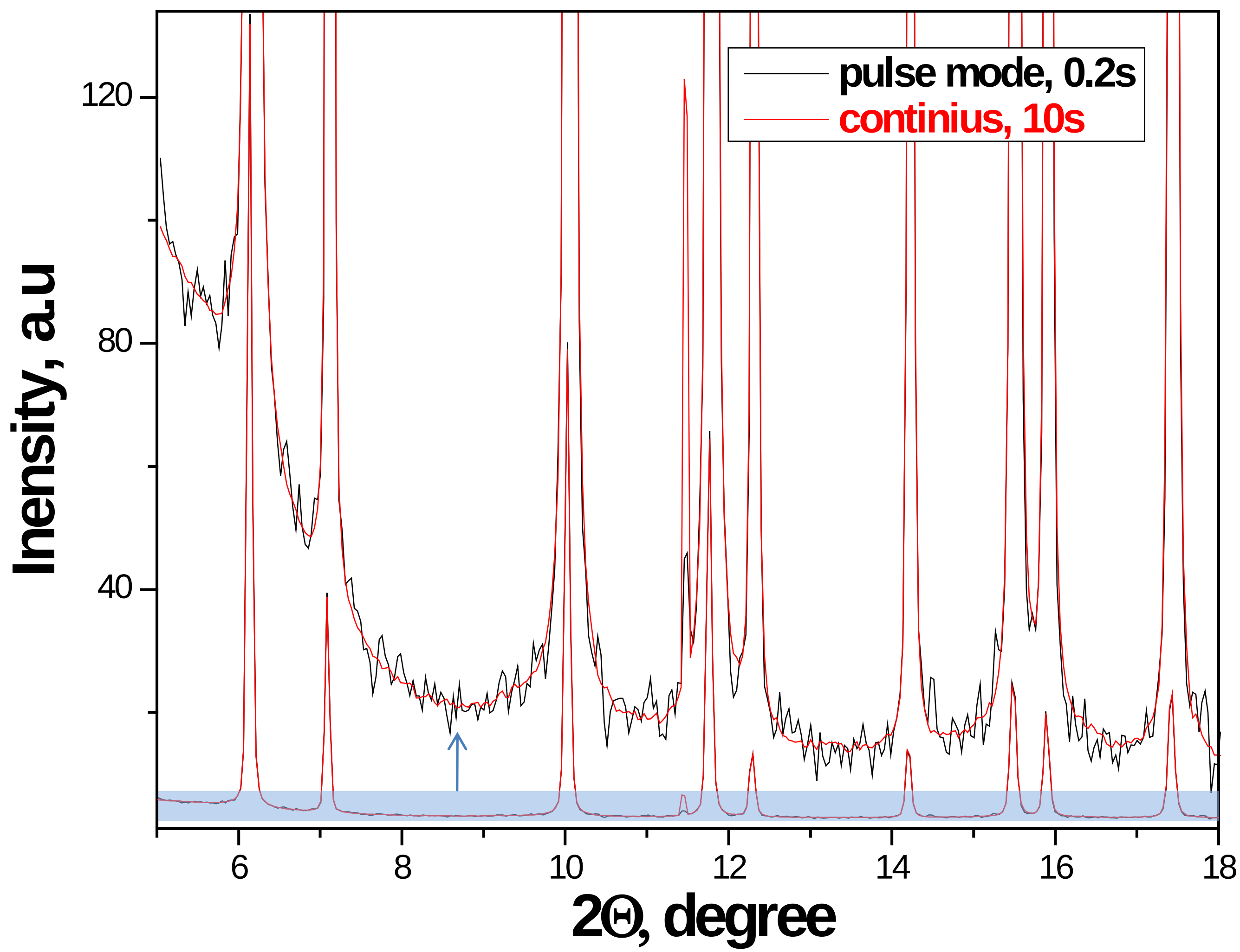


- ***Chemical reactivity is very fast in pulsed heating experiments***
- ***New possibilities for studying of chemical reactions***



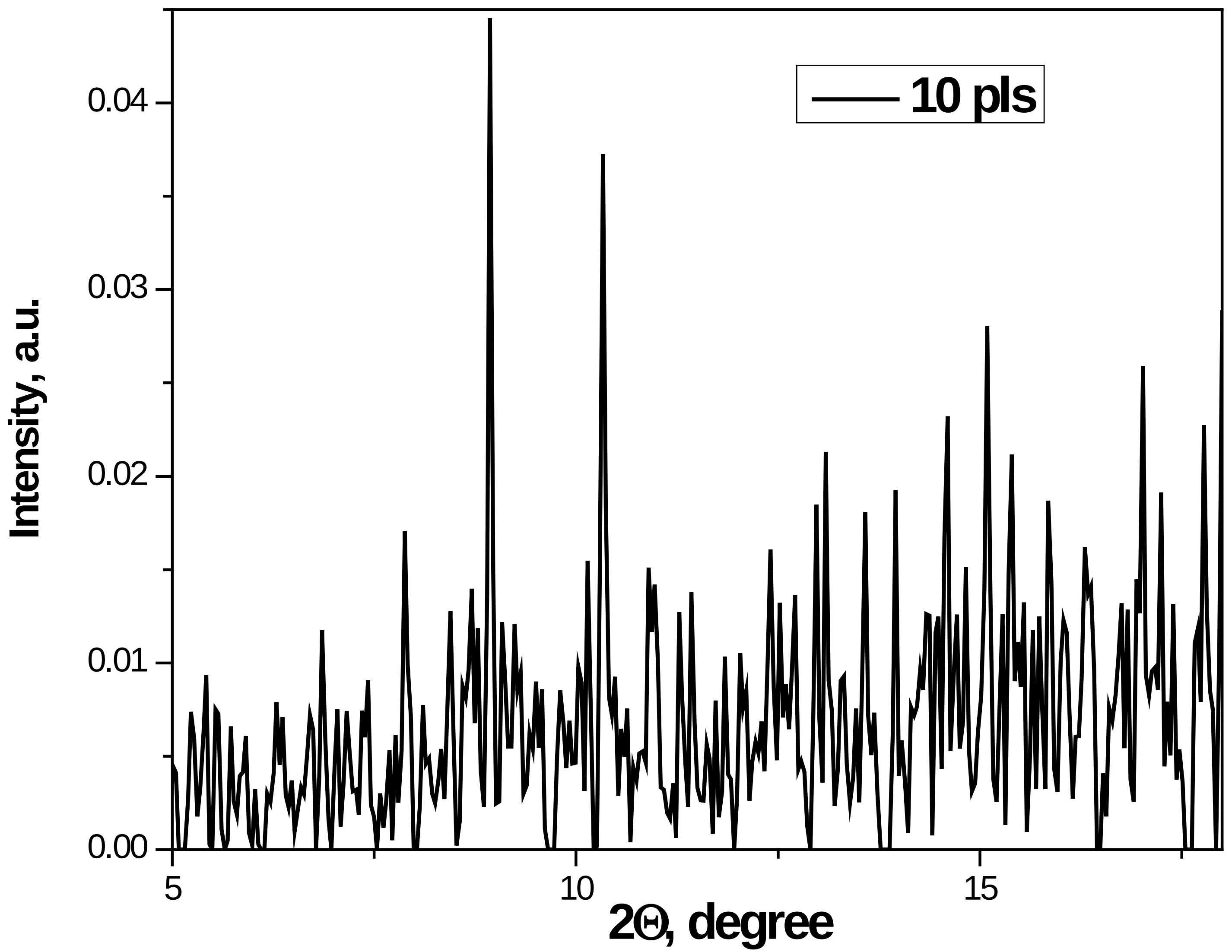


Compare XRD for CeO_2 collected with PILATUS detector
for different exposure time:
continues 10s (divided by 50) and 0.2s averaged over 10^5pls, 2us window



Standard Operating Mode, top-up: *102 mA in 24 singlets (single bunches) with a nominal current of 4.25 mA and a spacing of 153 nanoseconds between 40 ps singlets*

Detector window: 2 us or ~12 single bunches or ~2x10^5 photons



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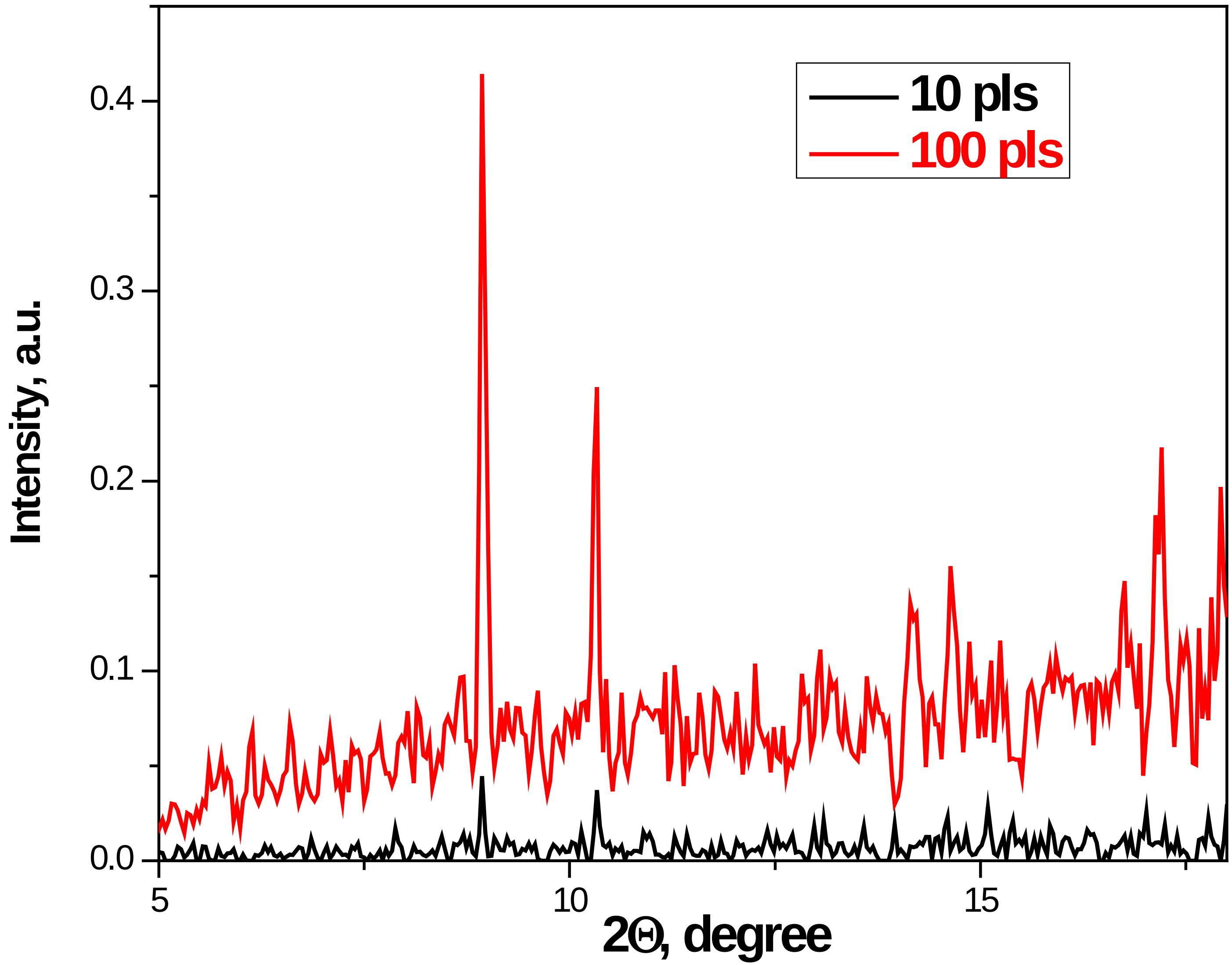

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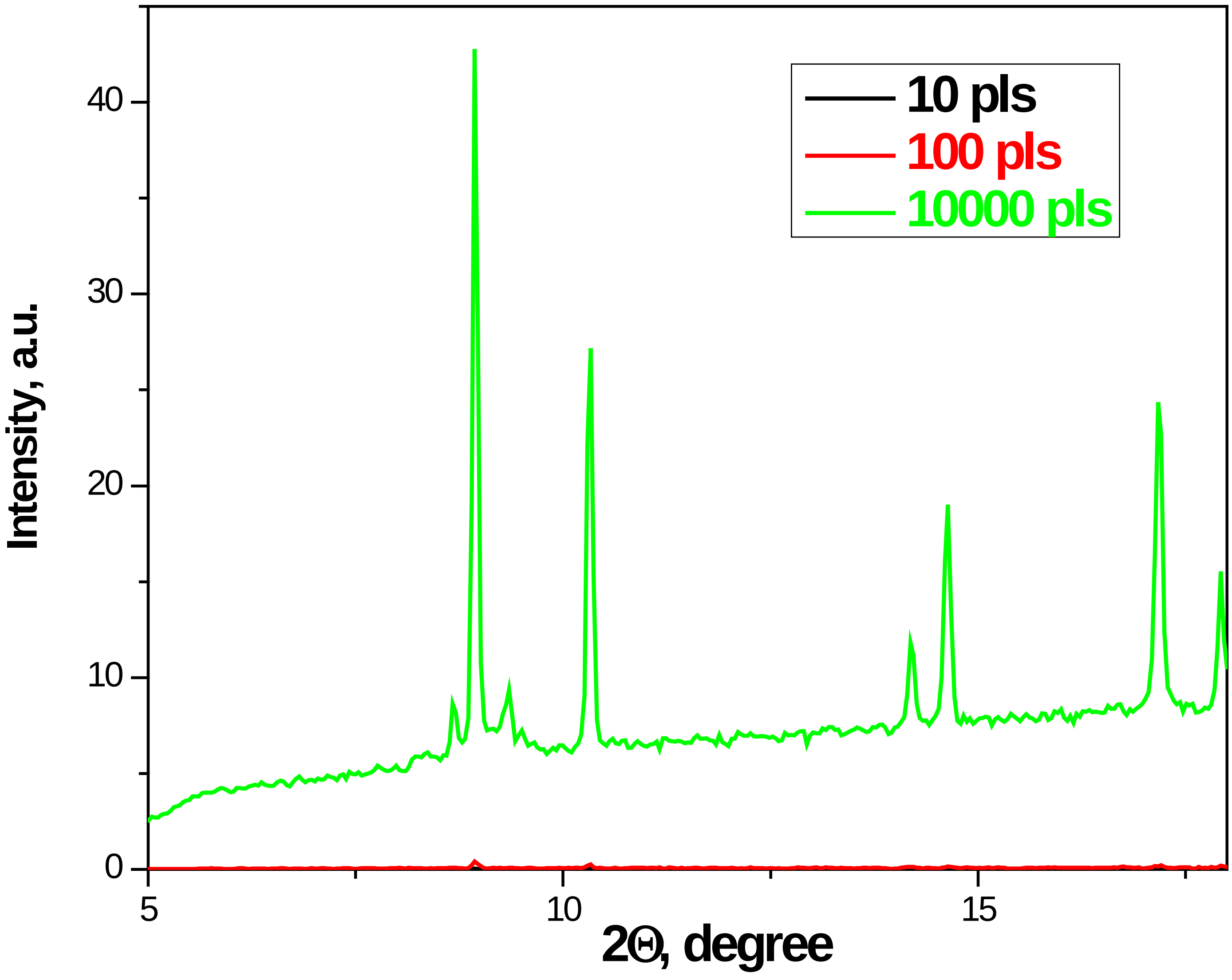
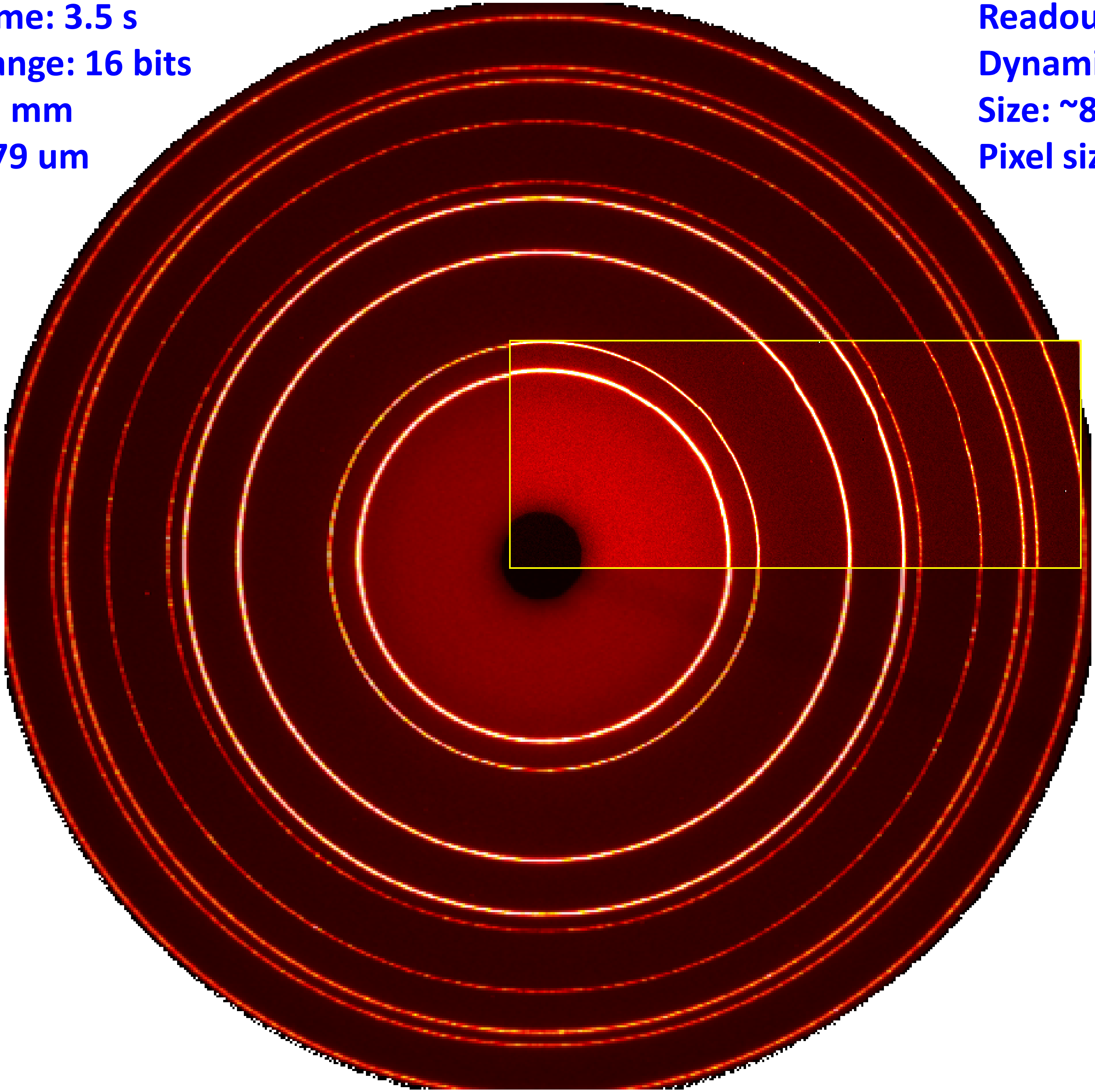


MAR-CCD

Readout time: 3.5 s
Dynamic range: 16 bits
Size: Ø165 mm
Pixel size: 79 um

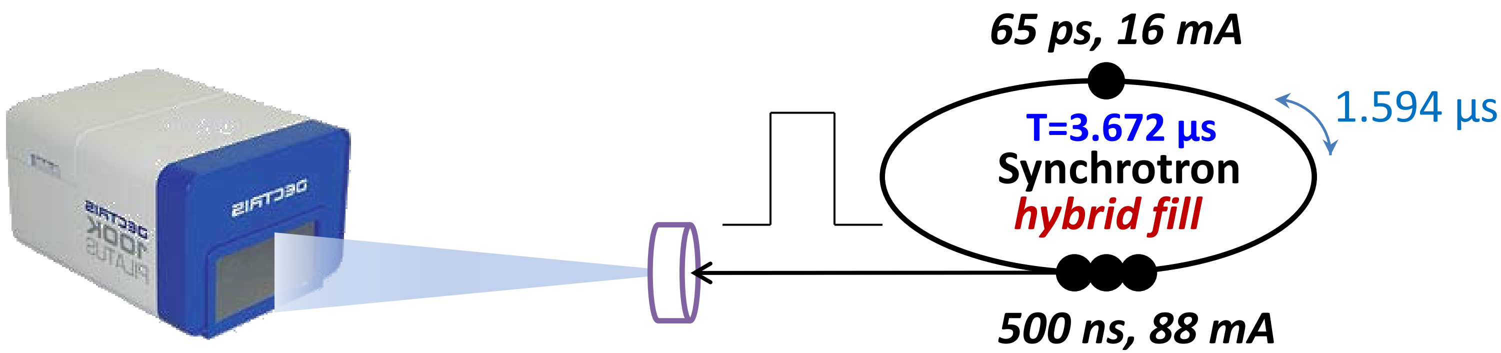
PILATUS 100K

Readout time: 2.7 ms
Dynamic range: 20 bits
Size: ~84x33 mm^2
Pixel size: 172 um

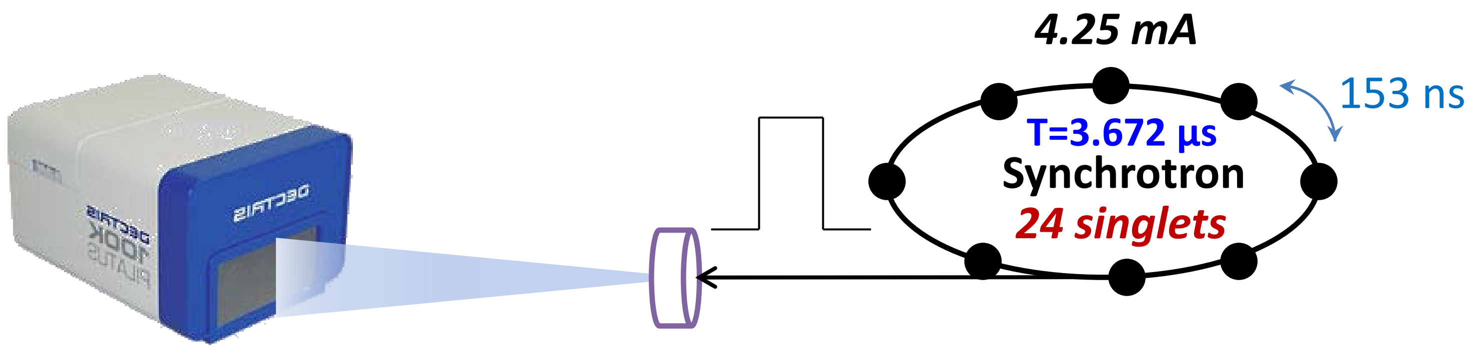


Dynamic x-ray probe optimization:

< 1 µs:



2 -100 µs:



General: *Detector: larger area, higher efficiency above 30 keV*

Sample: thick, high Z, single crystal

Pulse laser heating and optical spectroscopy combined with time-resolved x-ray probe

Reliable experimental conditions at higher then static T and P

Probing fundamental ultrafast processes

- high temperature EOS
- phase transition kinetics
- structural dynamics & deformation
- chemical reaction dynamics
- transport properties (*e.g.*, diffusion)
- electronic properties

GSECARS: Mark Rivers, Steve Sutton, Yanbin Wang, Peter Eng, Matt Newville, Przemek Dera, Nancy Lazarz, Fred Sopron

CIW :
A. Goncharov
V. Struzhkin

ESRF :
I. Kantor