Diagnostics in Warm Dense Matter experiments

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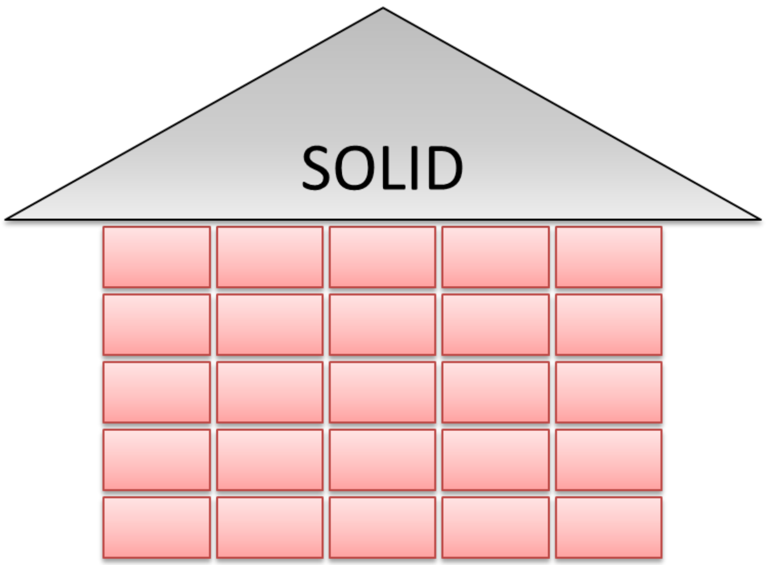
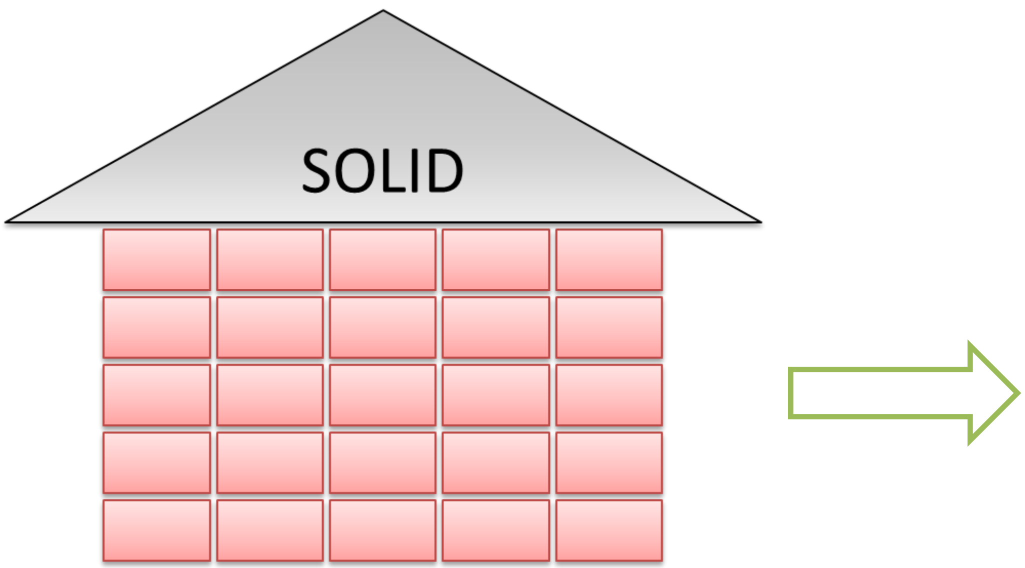

SOLID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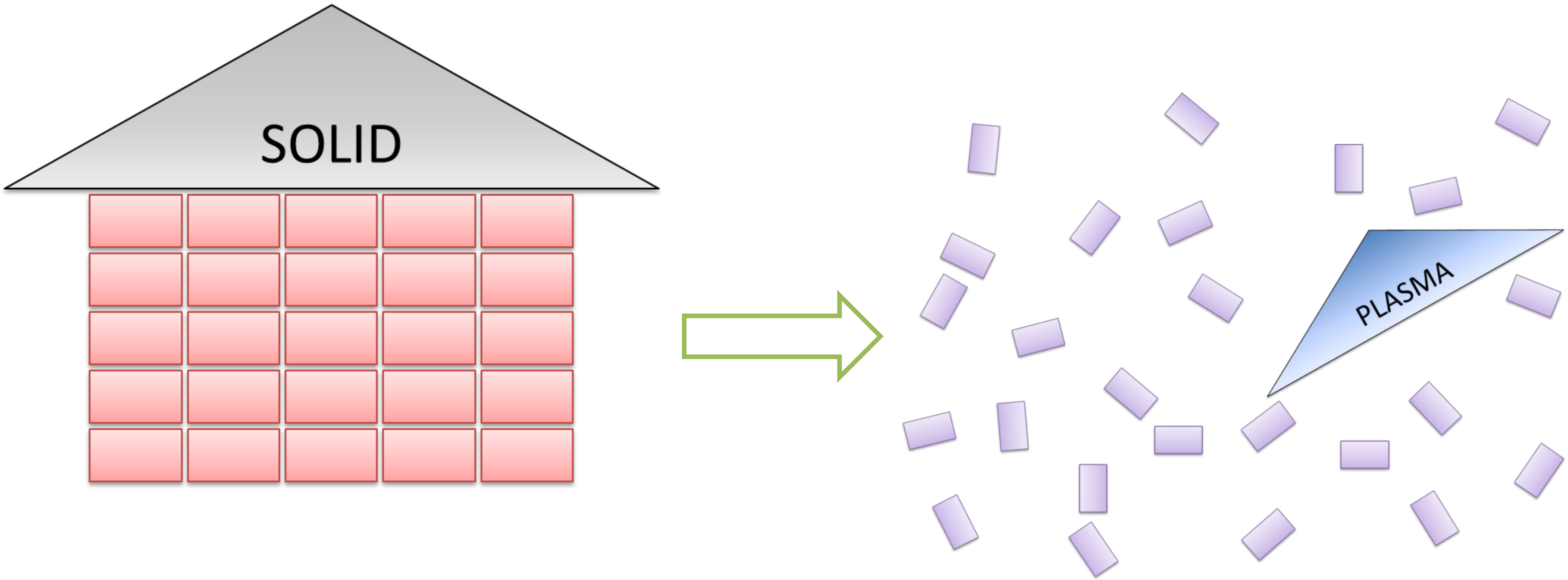
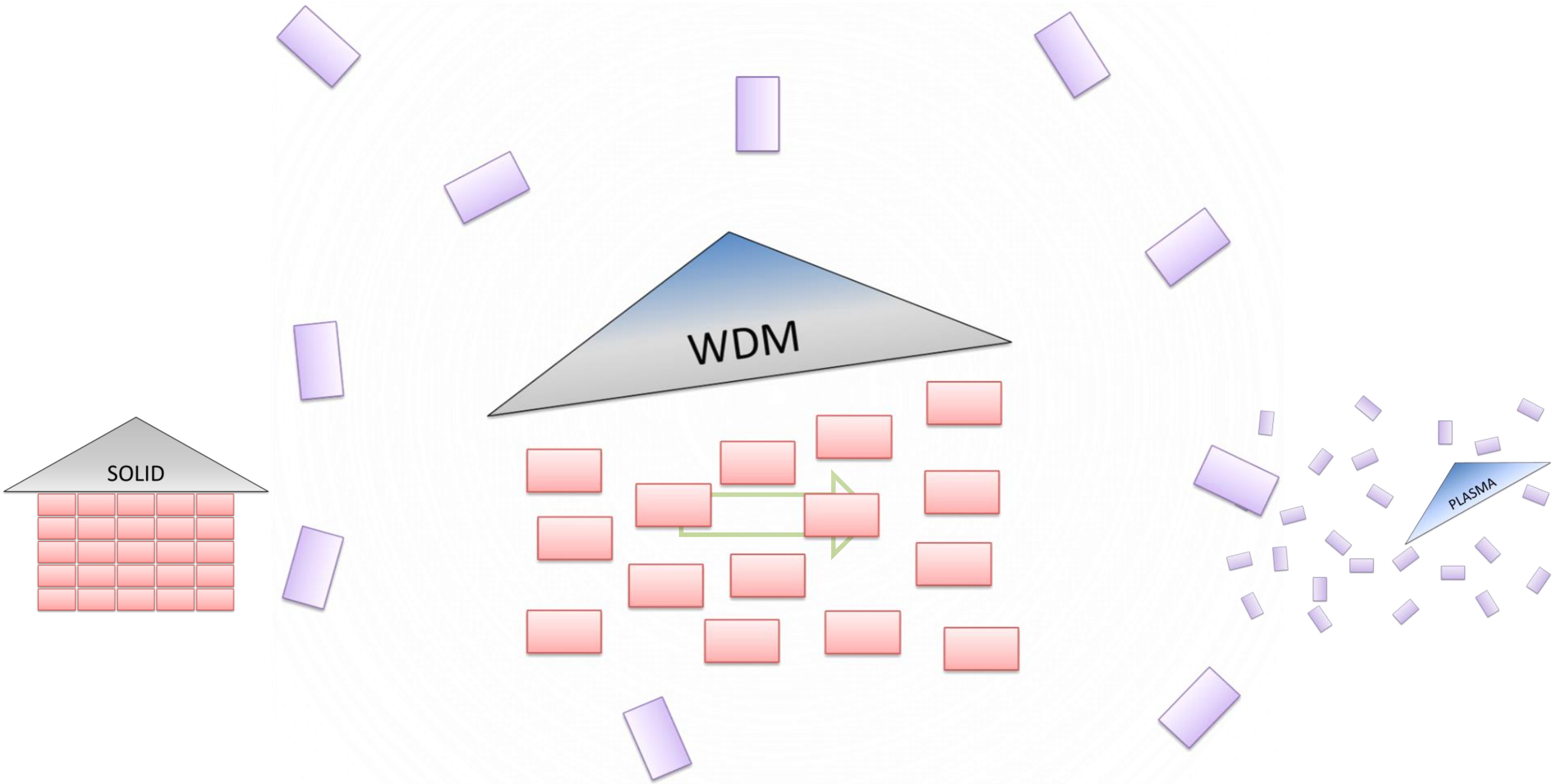
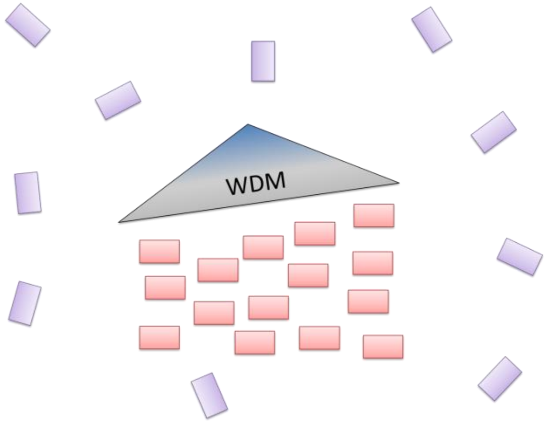
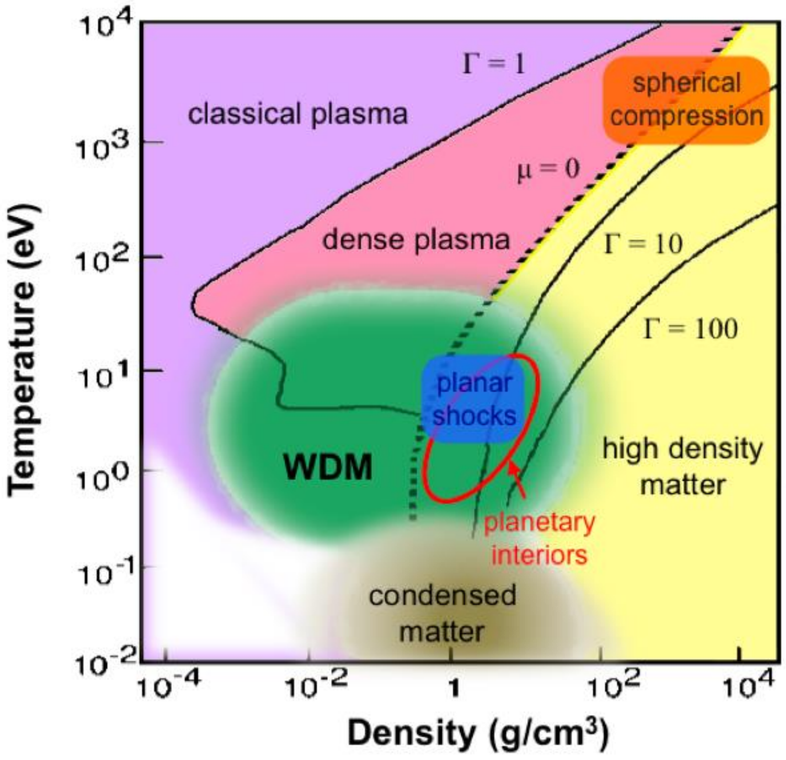
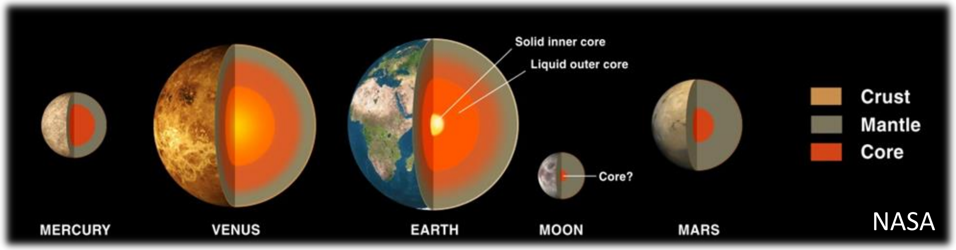

SOLID
PLASMA

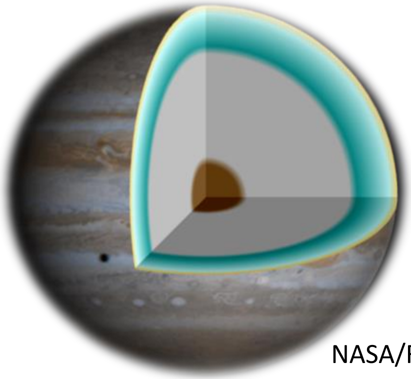

SOLID
WDM
PLASMA

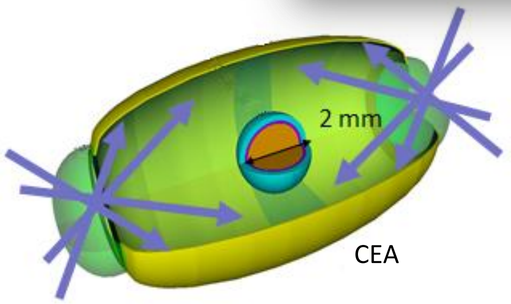
Warm Dense Matter



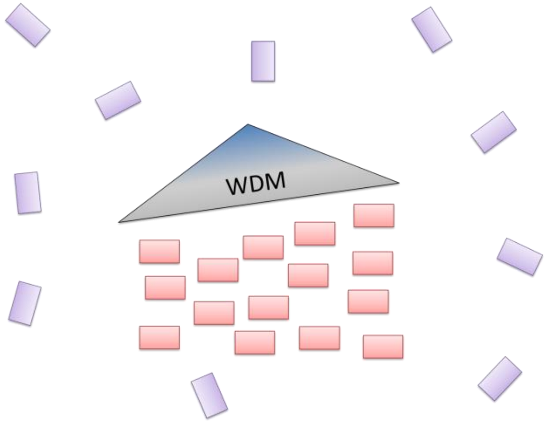




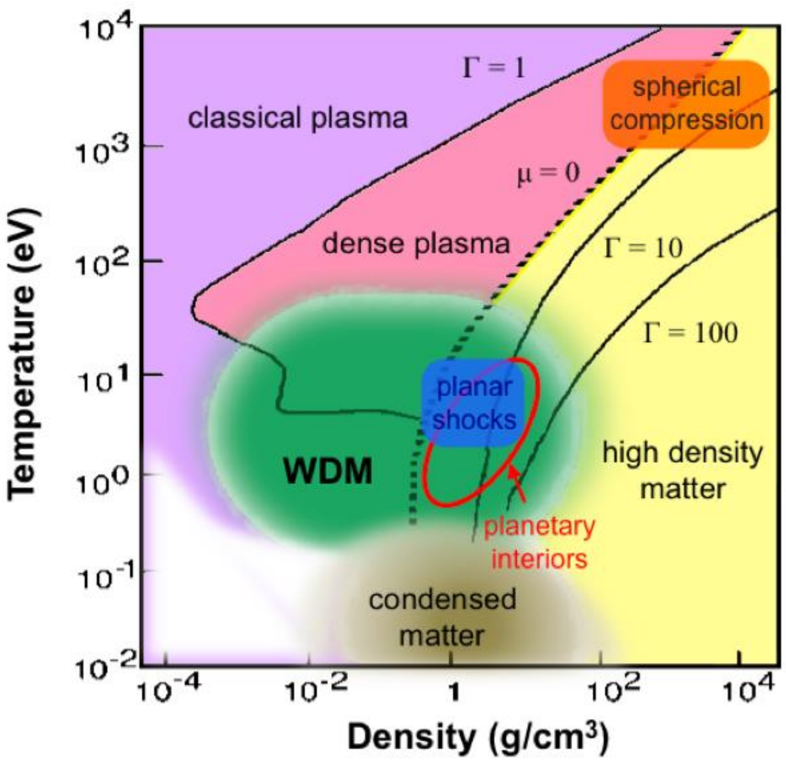

NASA/R.J. Hall



CEA



Warm Dense Matter



$T \approx 0.1 - 100\ eV$

$T \approx 1\,000 - 1\,000\,000\ K$

$\rho \approx 0.01 - 100\ g.cm^{-3}$

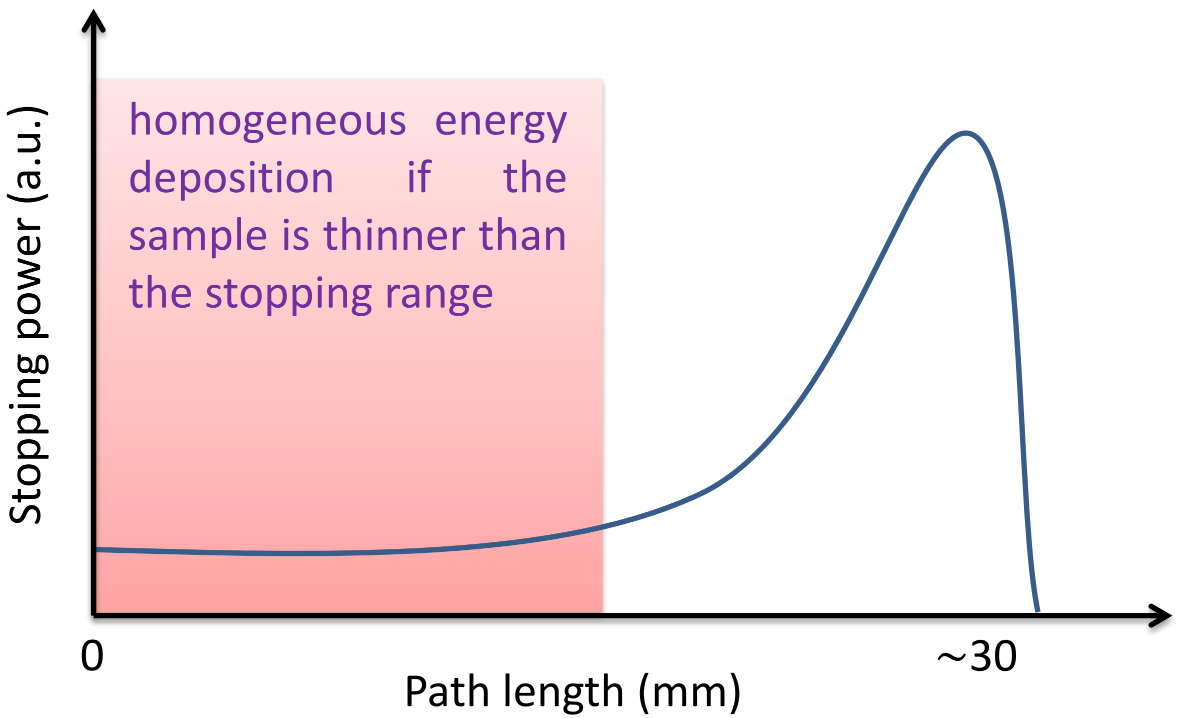
$P \approx kbar - Mbar$

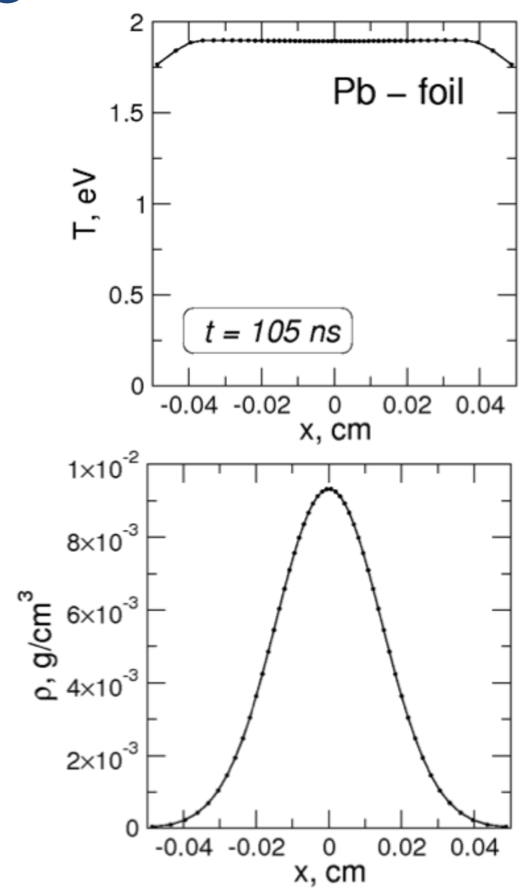
TOO DENSE
to be described by weakly coupled plasma physics
yet TOO HOT
to be described by condensed matter physics

Warm Dense Matter at FAIR

Beam parameters: U^{28+}
1.5 GeV/u
10^{10} ions/pulse

$\longrightarrow$ $w \sim MJ.kg^{-1}$

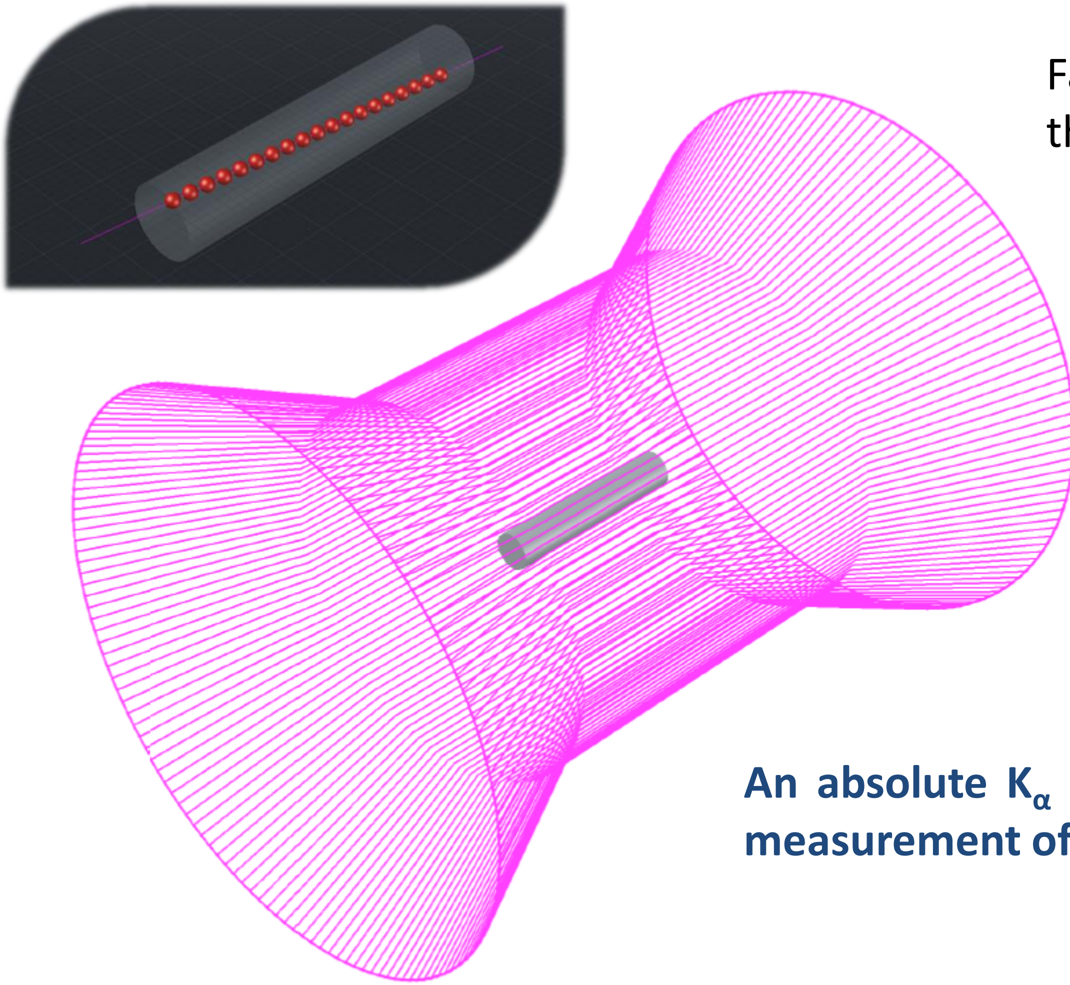




An. Tauschwitz et al.,
Appl. Phys. B **95**, 13 (2009)

In foco beam diagnostic: Energy deposition

A thin wire (Ø ≈ 50 µm) is locally in an **homogeneous** ion beam.



Fast ions **deposit energy** all along their path:

- material heating
- K-shell holes

→ **K_α line emission**

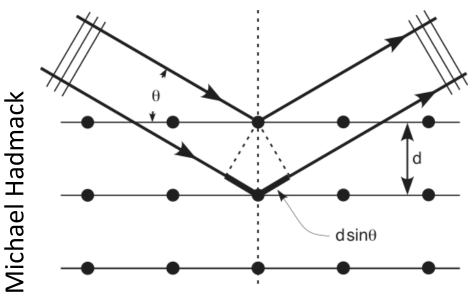
Total deposited energy and K_α yield are linked by ions cross section.

An absolute K_α emission measurement is a direct measurement of energy deposition.

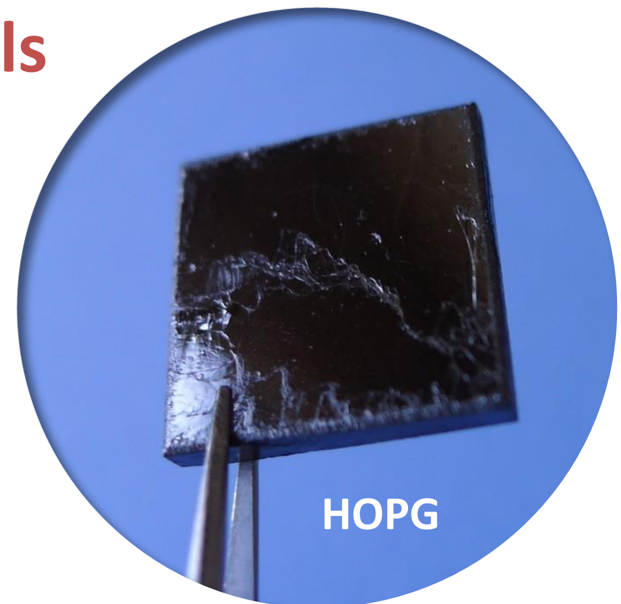
In foco beam diagnostic: Energy deposition

A thin wire (Ø ≈ 50 µm) is locally in an **homogeneous** ion beam.

○ Bragg crystals



$$2d.\sin\theta = n.\lambda$$



Fast ions **deposit energy** all along their path:

- material heating
- K-shell holes

→ K_α line emission

Total deposited energy and K_α yield are linked by ions cross section.

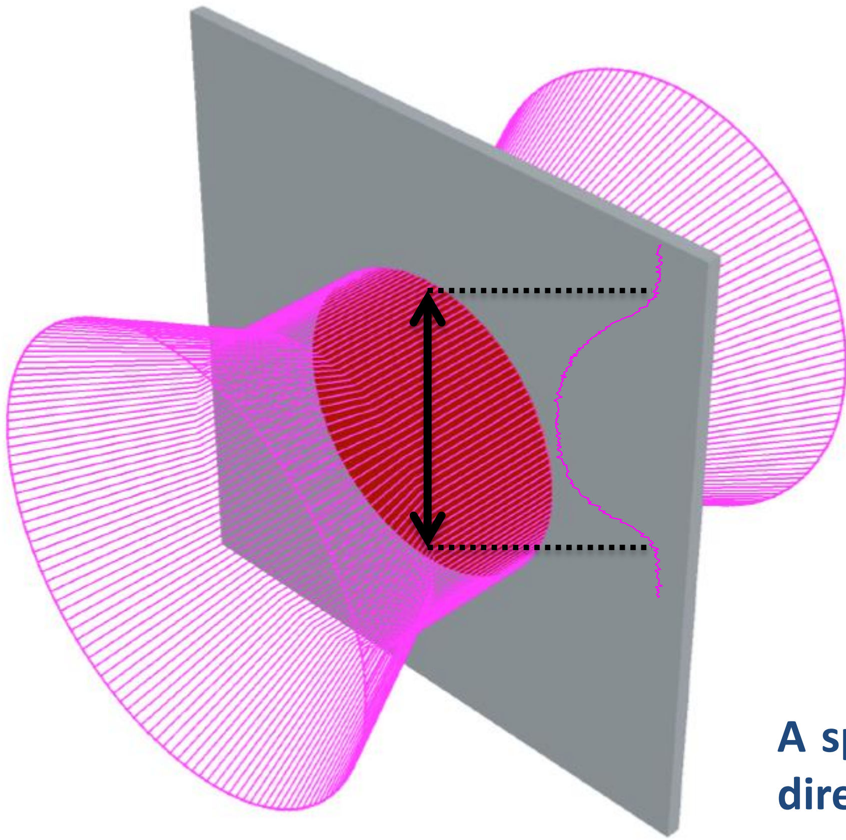
○ Single hit cameras

ANDOR

An absolute K_α emission measurement is a direct measurement of the energy deposition.

In foco beam diagnostic: Beam profile

A thin foil intersects the ion beam.



Fast ions **deposit energy** all along their path:
- material heating
- K-shell holes

→ **K_α line emission**

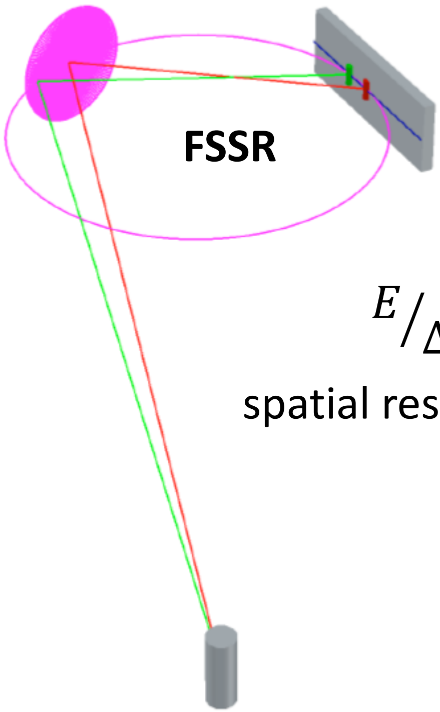
Total deposited energy and K_α yield are linked by ions cross section.

A spatially resolved K_α emission measurement is a direct measurement of the beam profile.

In foco beam diagnostic: Beam profile

A thin foil intersects the ion beam.

- **Spherically curved Bragg crystals**



$$^{E}/_{\Delta E} \approx 5000$$

spatial resolution < 100 µm

Fast ions **deposit energy** all along their path:

- material heating
- K-shell holes

→ **K_α line emission**

Total deposited energy and K_α yield are linked by ions cross section.

A spatially resolved K_α emission measurement is a direct measurement of the beam profile.

Probing WDM

Sample is prepared and well diagnosed

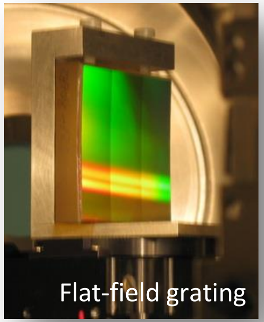
Self-emission: $\lambda_{max} = \frac{hc}{4.9651 \times k.T}$ Wien's law

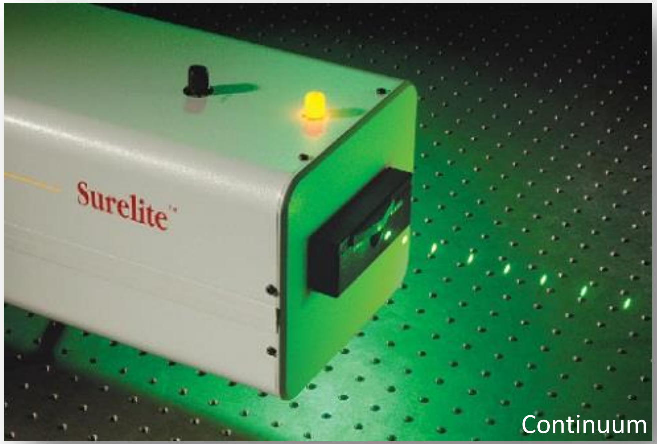
→ WDM typically emits from visible to soft X-rays

We need harder radiation:

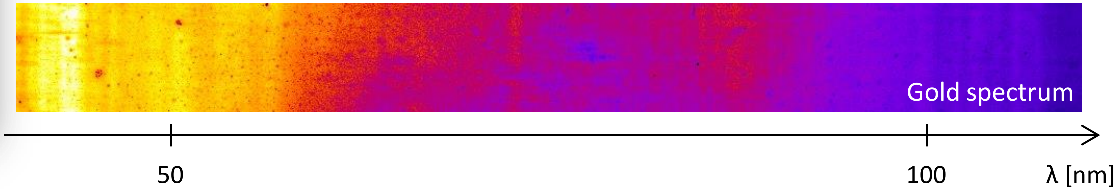
- for thick, dense, opaque samples
- **to overwhelm self-emission**

VUV – XUV opacity

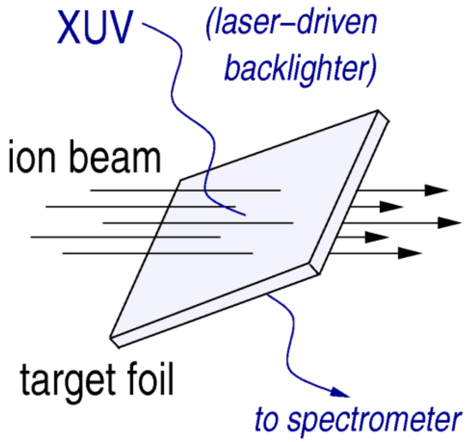




VUV-broadband sources can be driven by compact commercial lasers interacting with high-Z targets (Au, rare earth, ...)



Experimental scheme proposed by WDM



An. Tauschwitz et al.,
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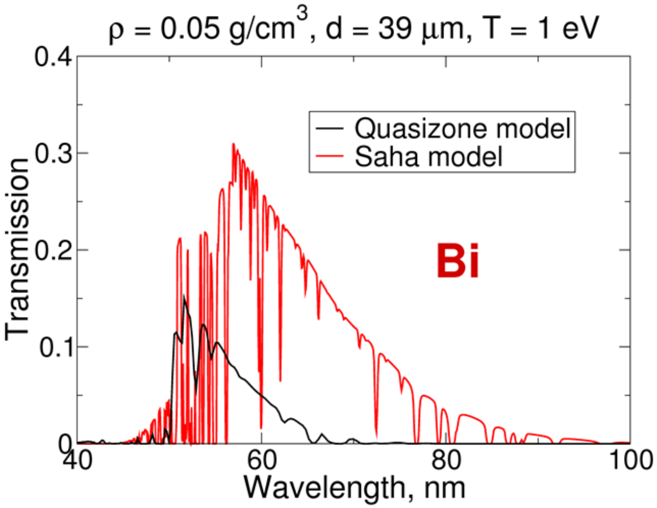
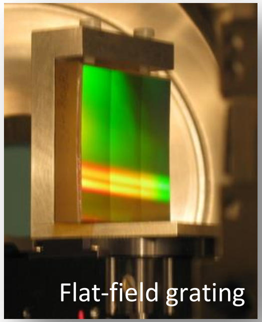
Opacity modeling in warm dense matter

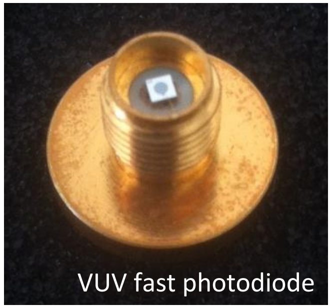


courtesy of V.G. Novikov, KIAM, Moscow, Russia

VUV – XUV opacity



Flat-field grating

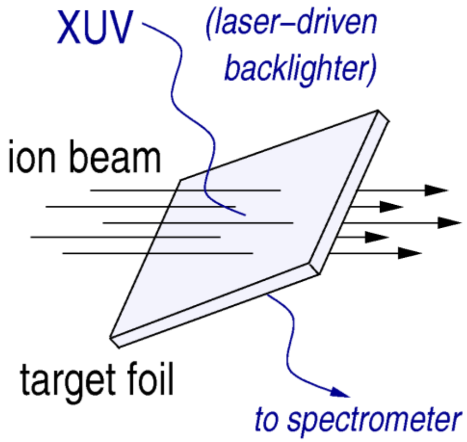


VUV fast photodiode

The same flat-field grating combined with a spherical mirror specially coated for VUV high reflectivity acts as a **focusing spectrometer**.

- higher fluence on the detector
- spatial resolution

Experimental scheme proposed by WDM



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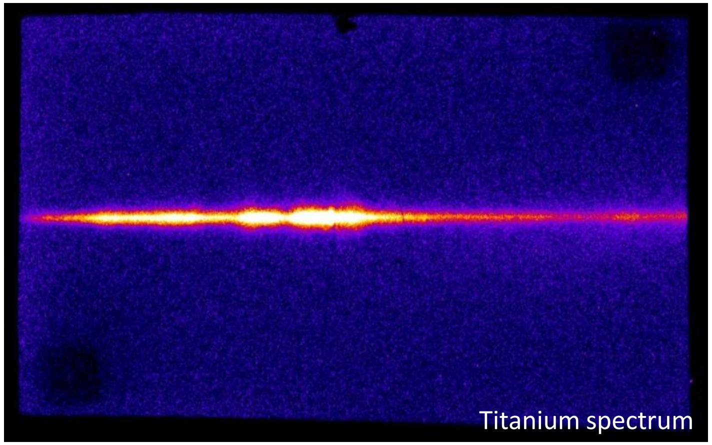
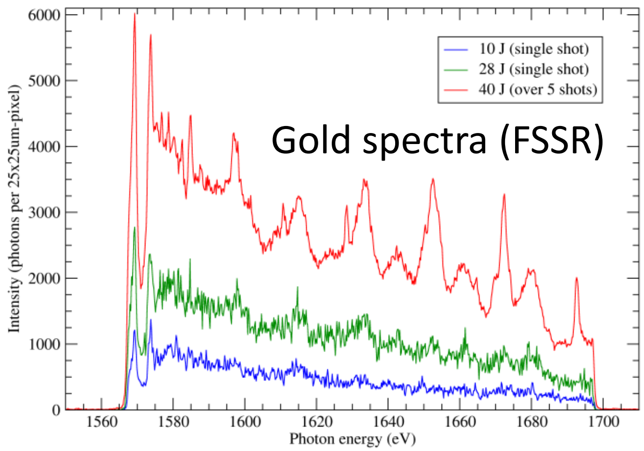


Titanium spectrum

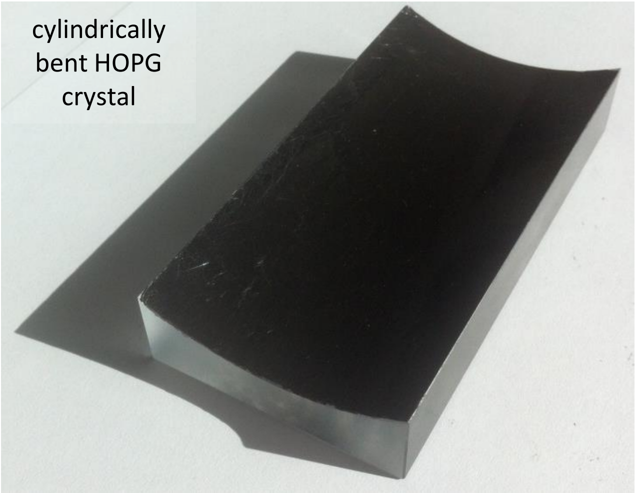
X-ray backlighting



X-ray broadband sources can be driven by moderate high-power lasers (10 J/ns) interacting with high-Z targets (Au, rare earth, ...)

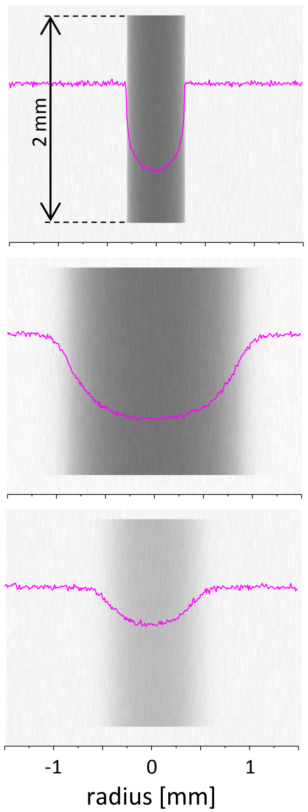
- XANES
  → mean ionization state

- X-ray opacity
  → temperature diagnostic



Laser driven X-ray radiography

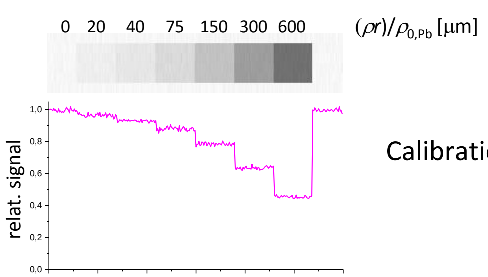
Simulated radiographs of an expanding lead cylinder



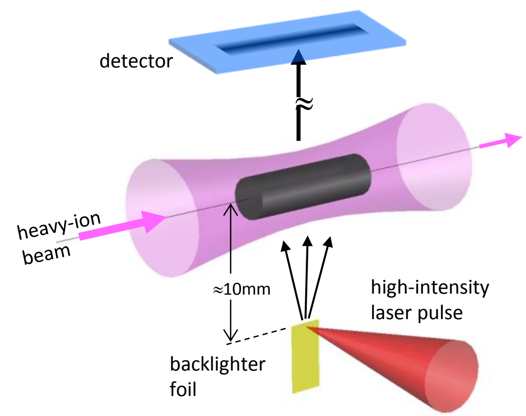
Liquid
$T\approx3400...6000K$, $\rho=\rho_0$

Critical point region
$T\approx5600K$, $\rho\approx4g/cm3$

Strongly coupled plasma
$T\approx4000K$, $\rho\approx2g/cm3 \rightarrow \Gamma\approx4$



Calibration wedge



Demonstration at

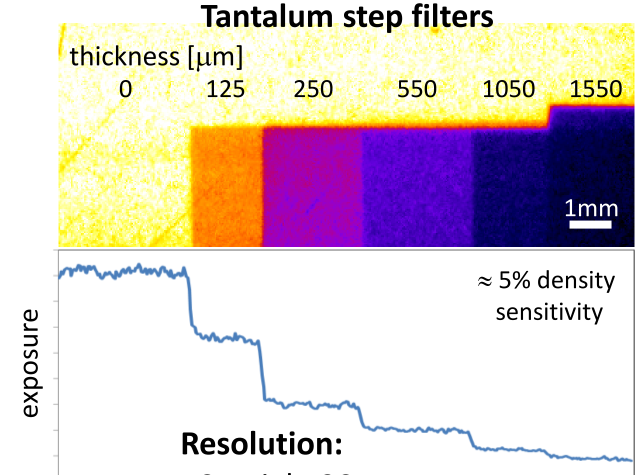
PHELIX

Laser parameters:

E_L=120 J

τ_p = 0.6 ps

Tantalum step filters



Resolution:

- Spatial <20µm
- Temporal 10-20ps

Summary

- Energy deposition diagnostics with K-shell spectroscopy

- VUV and X-ray backlighters
  - driven by moderate energy lasers
  - opacity
  - temperature

- Hard X-ray sources
  - driven by high-power lasers
  - radiography

Thank you for your attention

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- B. Borm (U. Frankfurt)
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- K. Li (SIOM, China)
- S. Wolski (U. Frankfurt)
- P. Neumayer (GSI)