DE LA RECHERCHE À L'INDUSTRIE

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Dynamical compression studies

at CEA Gramat

on going experimental and numerical work

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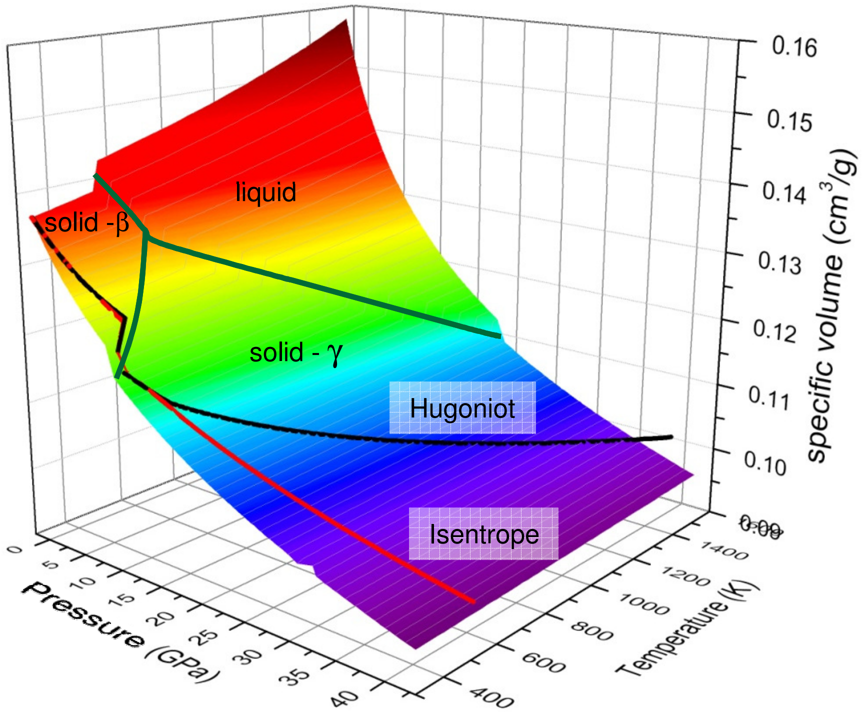
ESRF - Dynamic compression studies with X-rays Workshop

Objectives

→ EOS
→ Phase transition kinetics
→ Damaging / shear



Tin phase-diagram

Experimental facilities

→ Gas guns for planar impact shock compression
→ HPP drivers for magnetic ramp loading or flyer plate experiments
  → Planar and cylindrical loading geometries

Diagnostics

→ Laser Doppler interferometry velocimeters
→ Pyrometry for temperature measurements
→ Piezoelectric stress gauges
→ X-ray sources under development for *in situ* diffraction and density measurements

Numerical tools

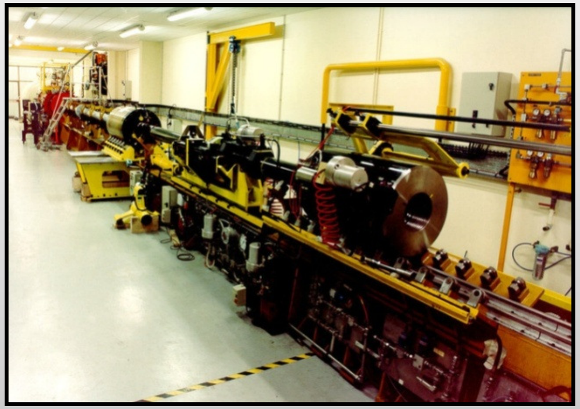
→ 1D Lagrangian code UNIDIM
→ 3D MHD code GORGON

Launchers for Plate Impact Experiments

Single or double stage gas gun

PYRENE
150 m/s < V < 750 m/s
35 g < m < 60 g
bore ϕ32 mm

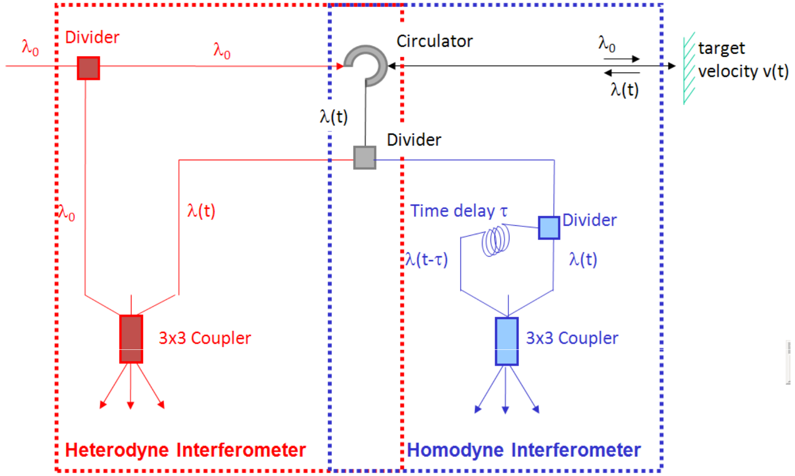
DEMETER
50 m/s < V < 1000 m/s
400 g < m < 4000 g
bore ϕ110mm



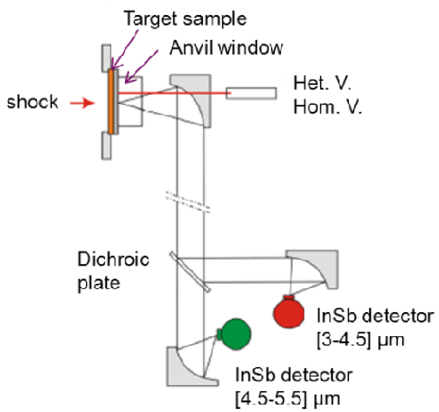
PERSEPHONE
V< 4000 m/s
m = 150 g
bore ϕ52 mm

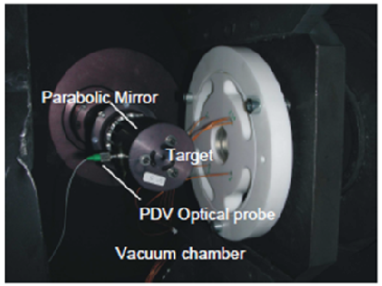
Main diagnostics

- Homodyne & heterodyne velocimetry



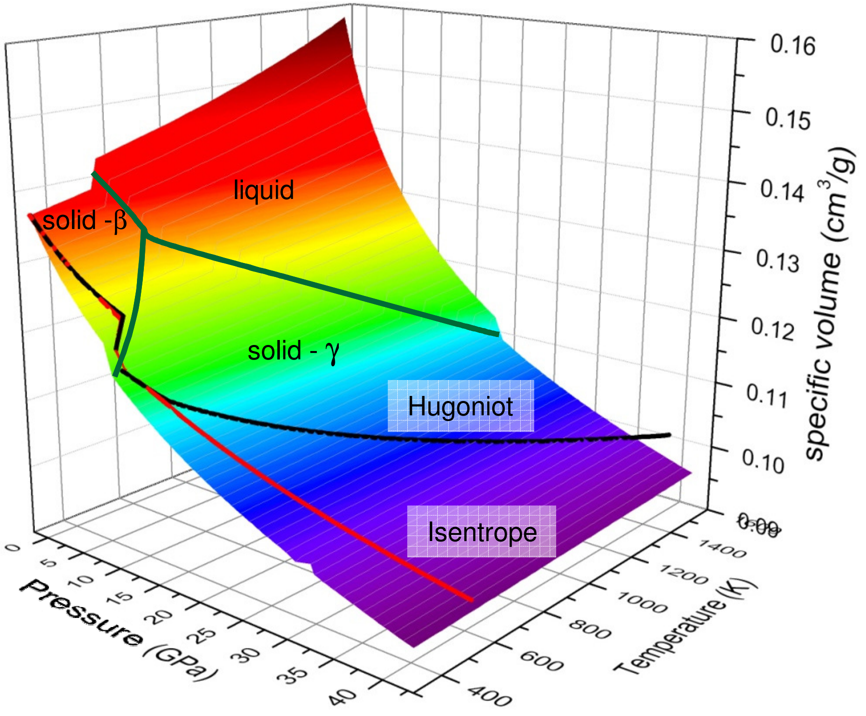
- Low temperature pyrometry





Min temperature 330 K

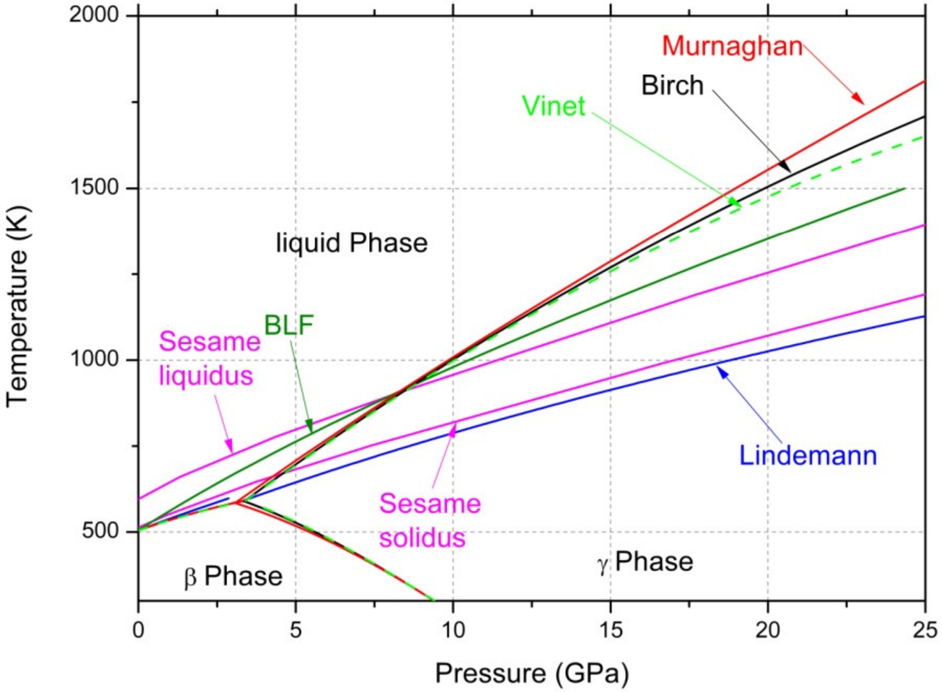
Kinetics of phase transition in Tin
on going experimental and numerical work



Reliable experimental data using **velocity and temperature measurements** of a material under dynamic loadings is of fundamental importance for

→ understanding material properties,
→ differentiating EOS,
→ investigating phase transitions (solid-solid, solid-liquid).

1D LAGRANGIAN CODE UNIDIM WITH MULTIPHASE EOS



1D Lagrangian code **UNIDIM**

- **with tabulated EOS**

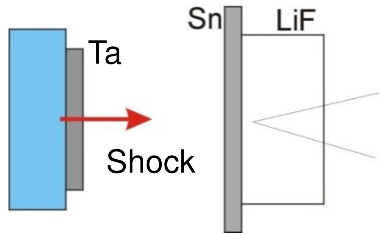
(SESAME or Bushman-Lomonosov-Fortov (BLF))

- **with Mie- Grüneisen EOS β, γ, liquid phases**
  - The parameters of the EOS are deduced from the high pressure data from Diamond Anvil Cell (DAC)

- **with thermal, electrical conduction and MHD**

DYNAMIC β↔γ TRANSITION

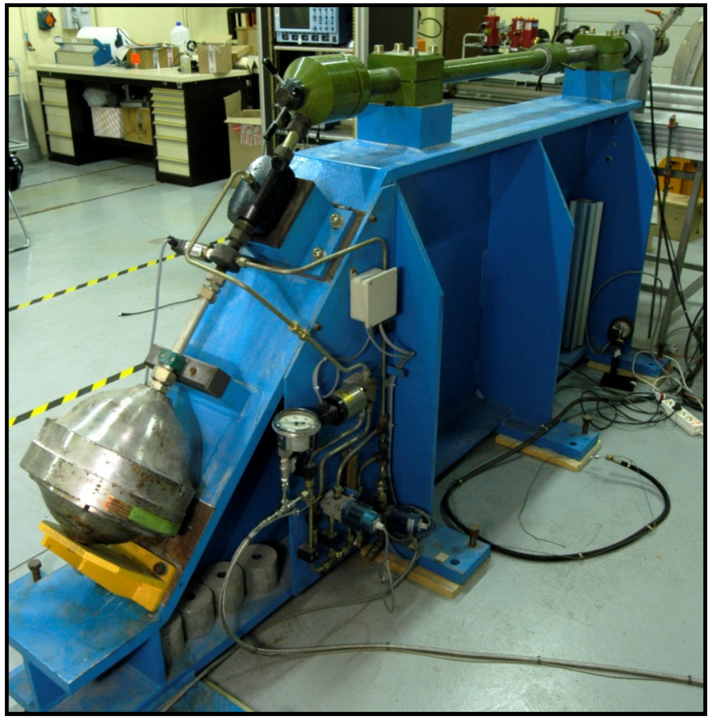
Based on velocity and temperature shock measurements at Sn/LiF interface, the β↔γ transition was studied.



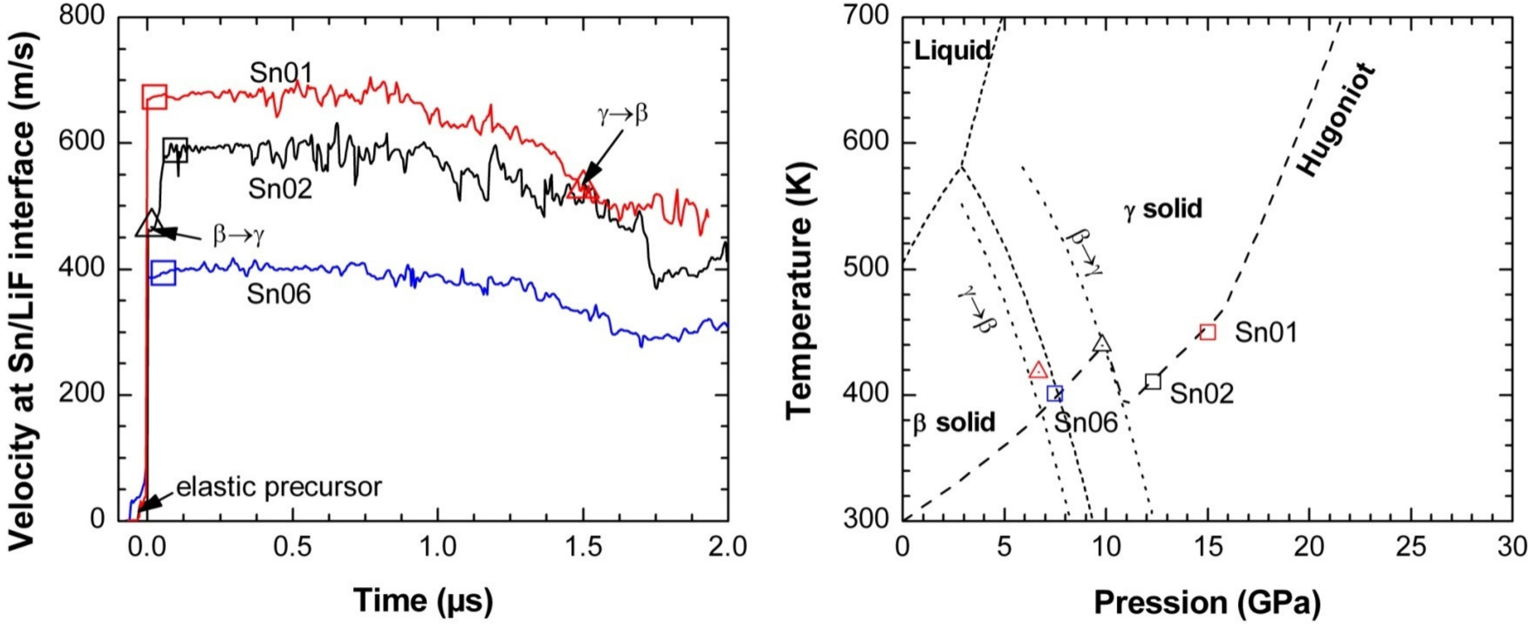
Experiments conducted on the small single stage gas (Air or He) gun **PYRENE**.
Bore ϕ32 mm; length 2.4 m.

Projectiles : 35 g to 60 g
Velocity range : 150 m/s to 750 m/s.

→ Easy-to-use
→ Transportable device
→ Diagnostic development and tests



DYNAMIC β↔γ TRANSITION: VELOCITY MEASUREMENTS



Classical features:

Shock-compression $\sigma_{\beta\text{-}\gamma} \geq$ static loading $\sigma_{\beta\text{-}\gamma}$

Shock-release $\sigma_{\gamma\text{-}\beta} \leq$ static loading $\sigma_{\gamma\text{-}\beta}$

➔Direct and reverse transition with hysteresis feature

TEMPERATURE MEASUREMENT AT CEA GRAMAT

The direct transition appears on the Hugoniot at ~ 9.1 GPa instead of 7.5 GPa

This is due to kinetic effects. The transition is too slow to be observed at the equilibrium pressure under normal shock loading conditions.

Reliable **low temperature measurement** of a material under dynamic loadings has been of fundamental importance to investigate its phase-diagram (solid-solid), and to display the kinetics of the $\beta \leftrightarrow \gamma$ transition in Tin.

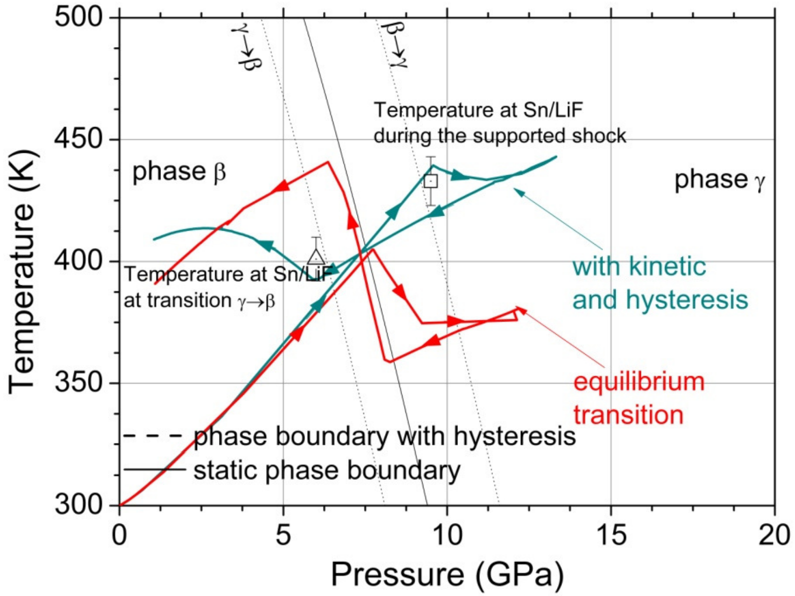
DYNAMIC β↔γ TRANSITION: TEMPERATURE MEASUREMENTS

Shock-compression $\sigma_{\beta\text{-}\gamma} \geq$ static loading $\sigma_{\beta\text{-}\gamma}$

➔ Direct transition with kinetic effects and mixture phase

Shock-compression $\sigma_{\gamma\text{-}\beta} \leq$ static loading $\sigma_{\gamma\text{-}\beta}$

➔ Reverse transition with kinetic effects and mixture phase



In our multiphase EOS an empirical kinetic model has been added.
Even though the kinetic model seems to correctly describe our experimental results, nucleation and growth will be developped to improve the model.

DYNAMIC β↔γ TRANSITION: TEMPERATURE MEASUREMENTS

Shock-compression $\sigma_{\beta\text{-}\gamma} \geq$ static loading $\sigma_{\beta\text{-}\gamma}$

➔ Direct transition with kinetic effects and mixture phase

Shock-compression $\sigma_{\gamma\text{-}\beta} \leq$ static loading $\sigma_{\gamma\text{-}\beta}$

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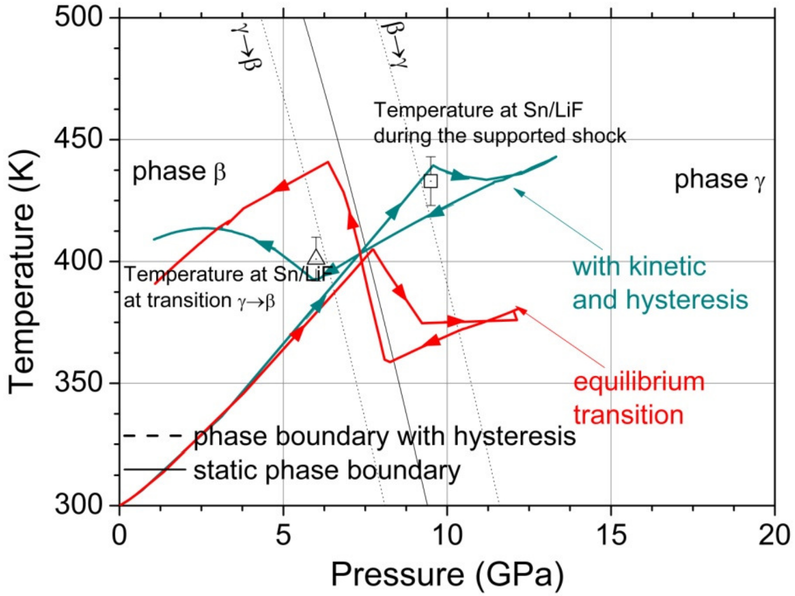

In our multiphase EOS an empirical kinetic model has been added.

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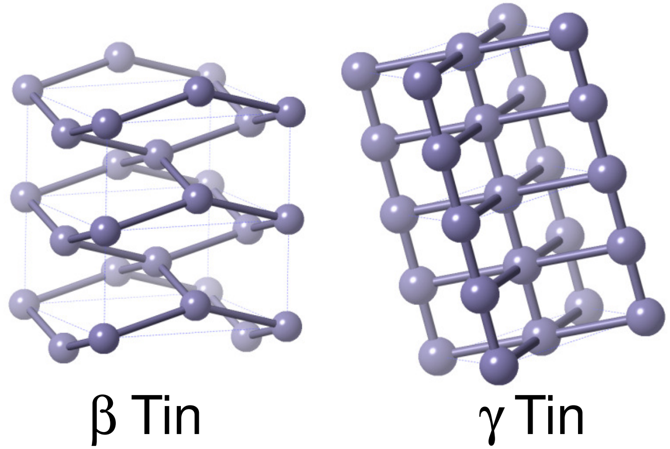
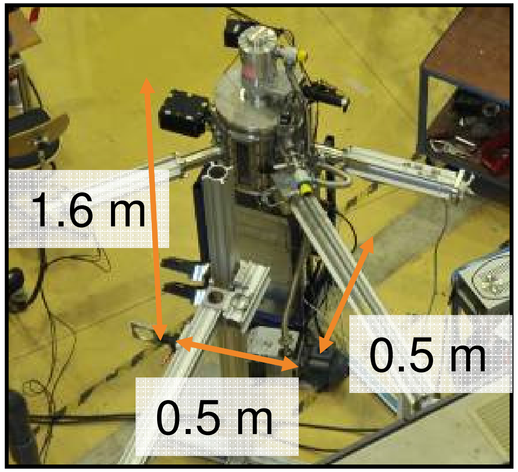
We need to analyse the cristallographic structure changes under shock loading with time resolved X-ray diffraction.

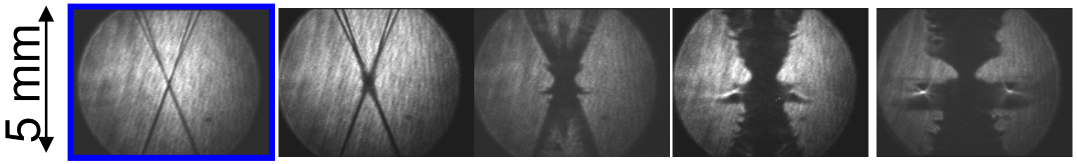


ON GOING X-RAY DIFFRACTION DEVELOPMENTS WITH A HPP DRIVER

Compact HPP driver
300 kA, 400ns

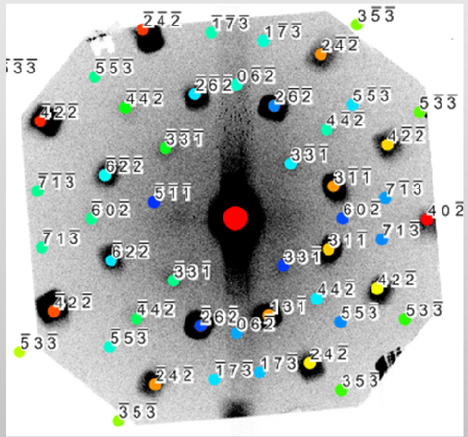


X-ray source : X-pinch



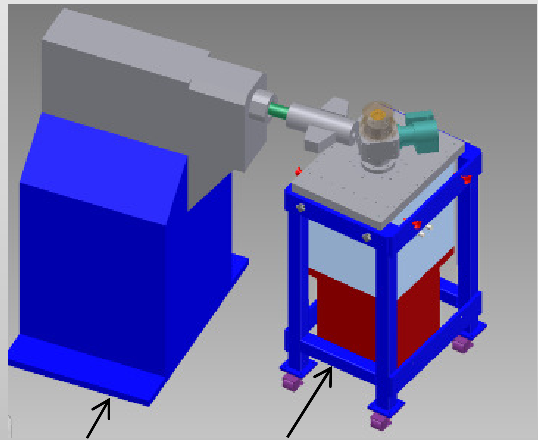
- Soft X-ray component by pinching process **< 10 keV**
- Hard X-ray component by e- beam process **> 10 keV**

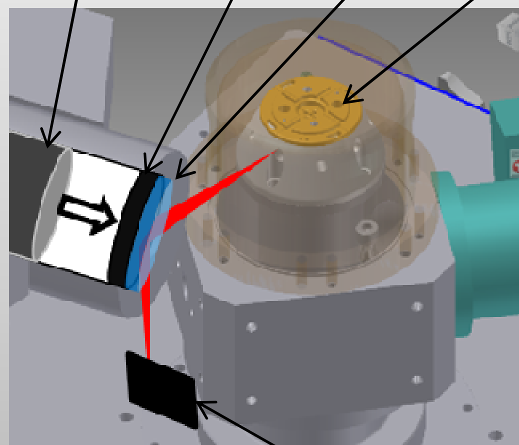
Static XRD result



LiF diffraction pattern overlaid with simulation
Probing radiation 15-35 keV

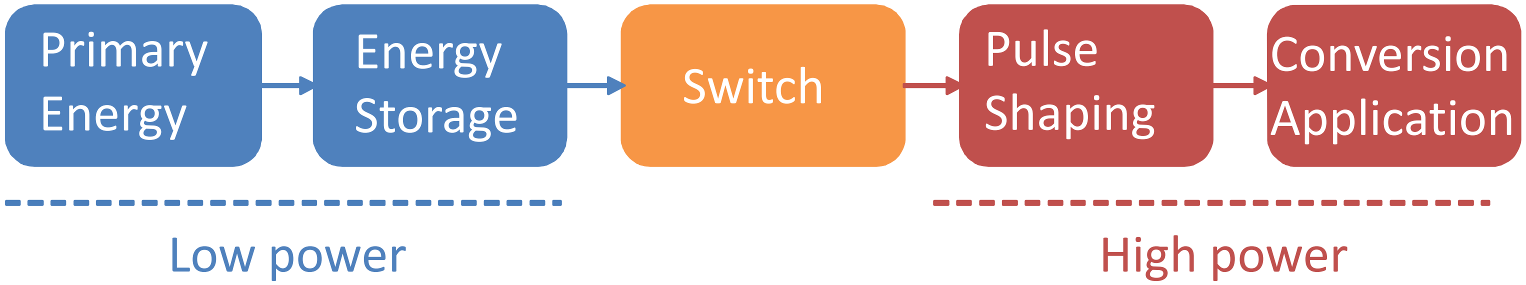
Future dynamic XRD experiments





High Pulse Power (HPP) development at CEA Gramat

HIGH PULSED POWER RESEARCH AND DEVELOPMENT AT CEA GRAMAT



Since several decades CEA Gramat has developped the **capability to design, realize and operate HPP driver** (high current or high voltage) for various applications.

It also includes the **load design** …

- Wire Array loads ; ICE loads ; HV diodes

…the **diagnostic development** …

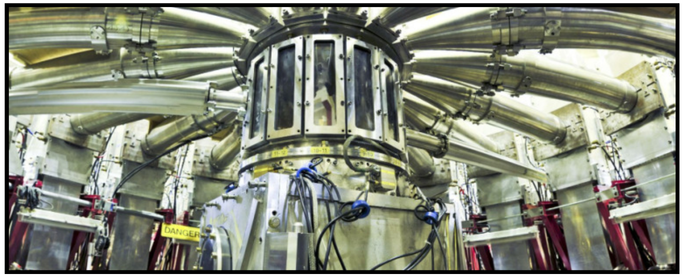
- electrical, plasma and X-ray diagnostics

… and the **effect studies**

- radiation effects, material compression, instabilities

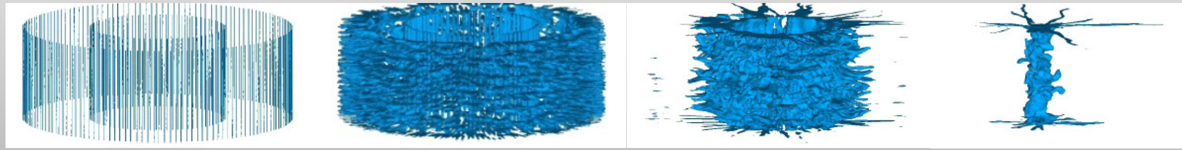
High Current Generators : SPHINX 8MA, 1.2µs

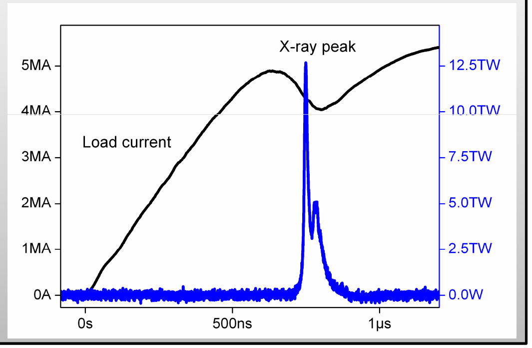
Microsecond LTD driver
- ∅13m Height 3m
- 16 branches of 10 LTD stages
- Stored energy 2.2MJ



Wire Array loads (WA)

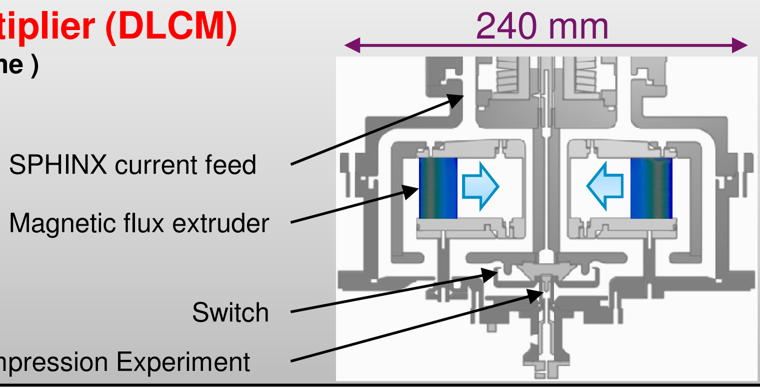
→ **Z-pinch WA for radiation effects studies**
→ **also conical WA for LabAstro jets, radial WA as compact sources, Z-pinch experiments for opacity measurements …**

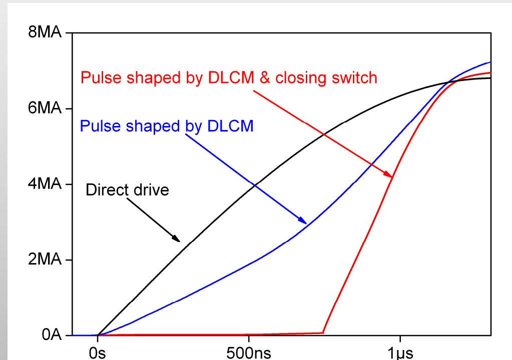




Dynamic Load Current Multiplier (DLCM)

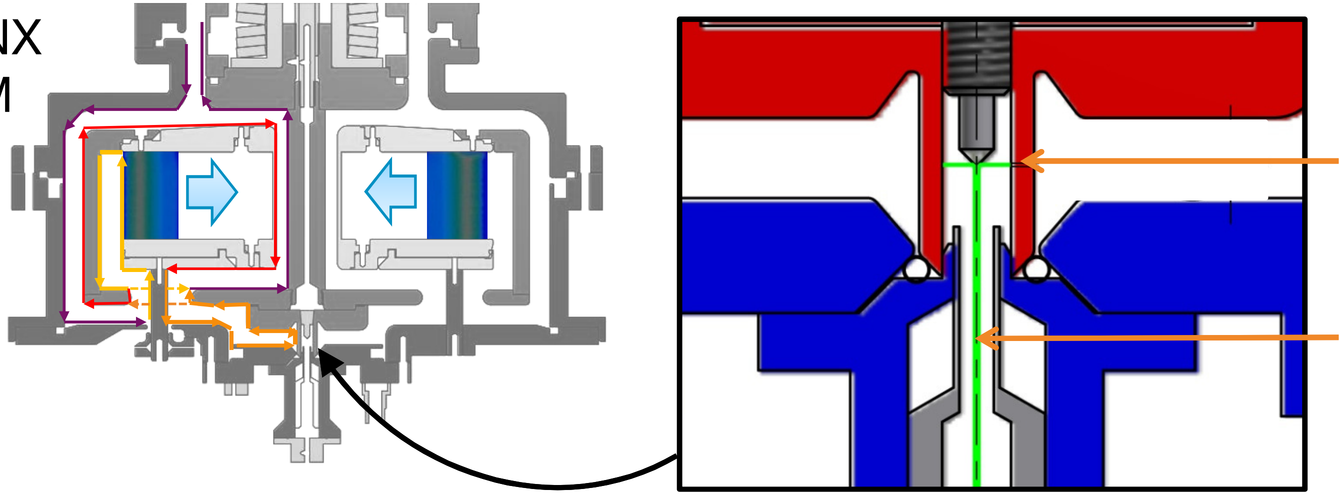
→ **pulse shaping (µs and sub-µs regime)**
- **Cylindrical ICE**
- **Z-pinch experiment**





CYLINDRICAL ISENTROPIC COMPRESSION EXPERIMENT

SPHINX
DLCM

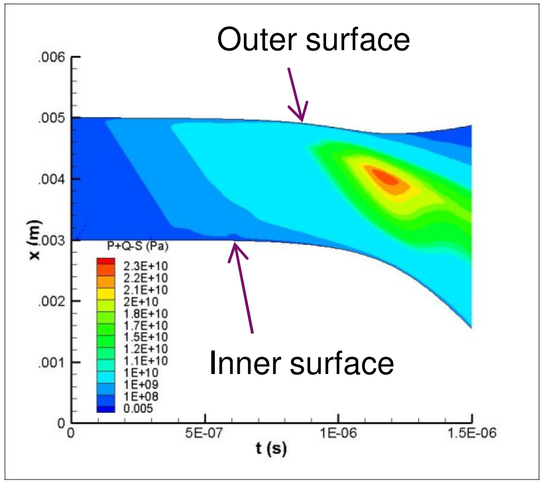


Cylindrical ICE load with vacuum insulation

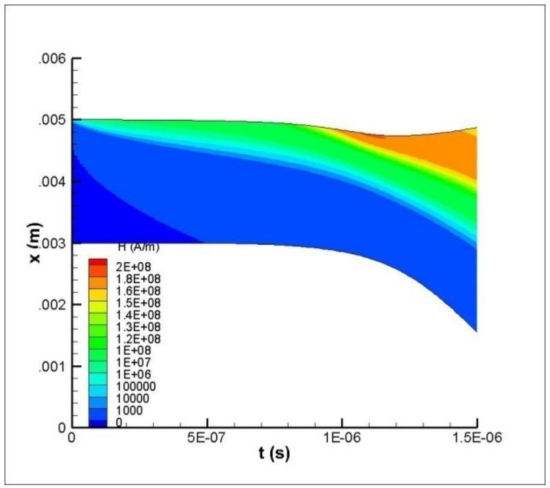
Aluminum cylinder (red)
R_{in} 3mm R_{out} 5mm

1550 nm Optical probe for velocity measurement

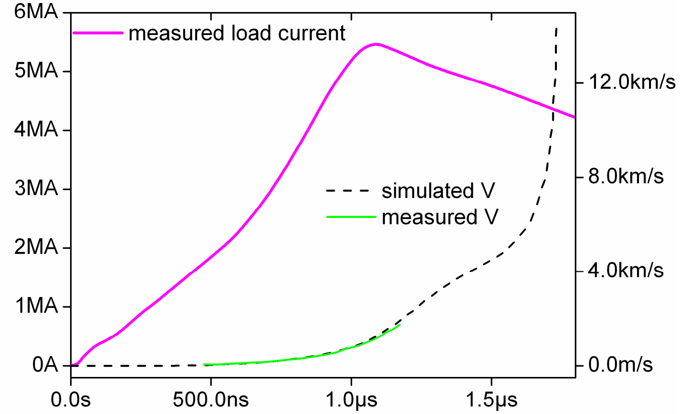
Simulated pressure (x-t diagram)



Simulated magnetic diffusion (x-t diagram)

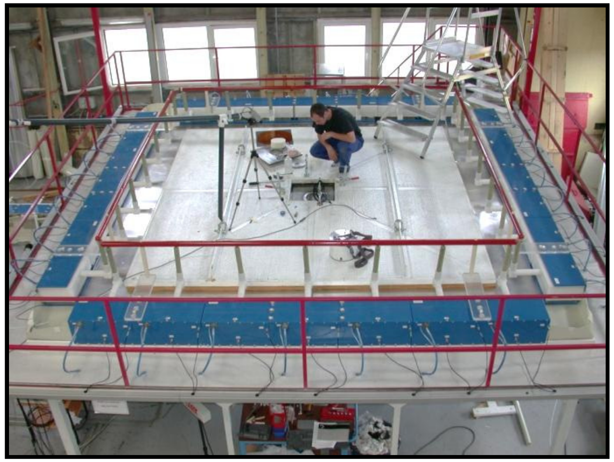


Measured and simulated free surface velocity



High Current Generators : GEPI 3.3MA, 500 ns

GEPI : Electric Generator for Intense Pressure

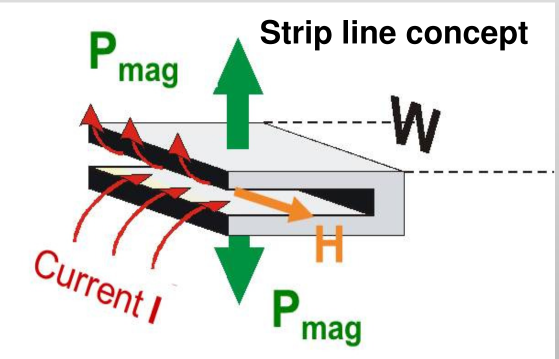


- 6m x 6m
- 28 stages in parallel
- Stored energy 70 kJ
- Peak current from <1 to 3.3 MA with 500 ns risetime
- ICE load with solid dielectric insulation

Isentropic Compression Experiments (ICE)

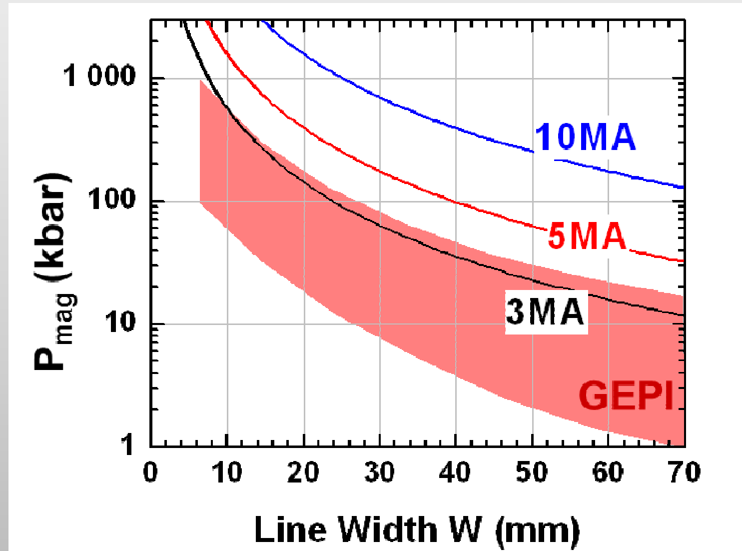
→ **material behavior under quasi-isentropic compression**
  - **pressure range : 0.1 GPa to 80 GPa**

→ **launch of non-shocked flyer plates**
  - **velocity range : 1 $km.s^{-1}$ to 8 $km.s^{-1}$**



$$P_{mag} = k_p \cdot \frac{1}{2} \cdot \mu_0 \cdot \left(\frac{I}{W} \right)^2$$

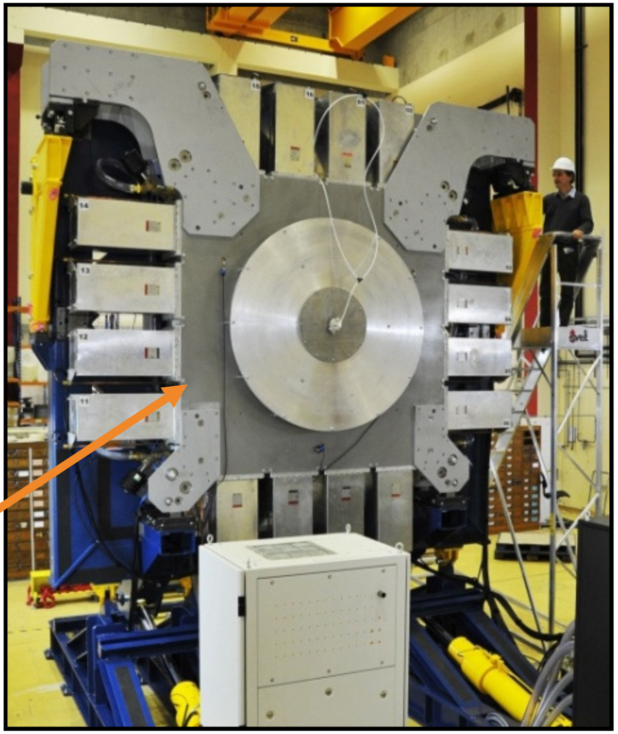
P : applied magnetic pressure
k_p : edge effect coefficient
μ_0 : free space magnetic permeability
I : load current
W : strip line width



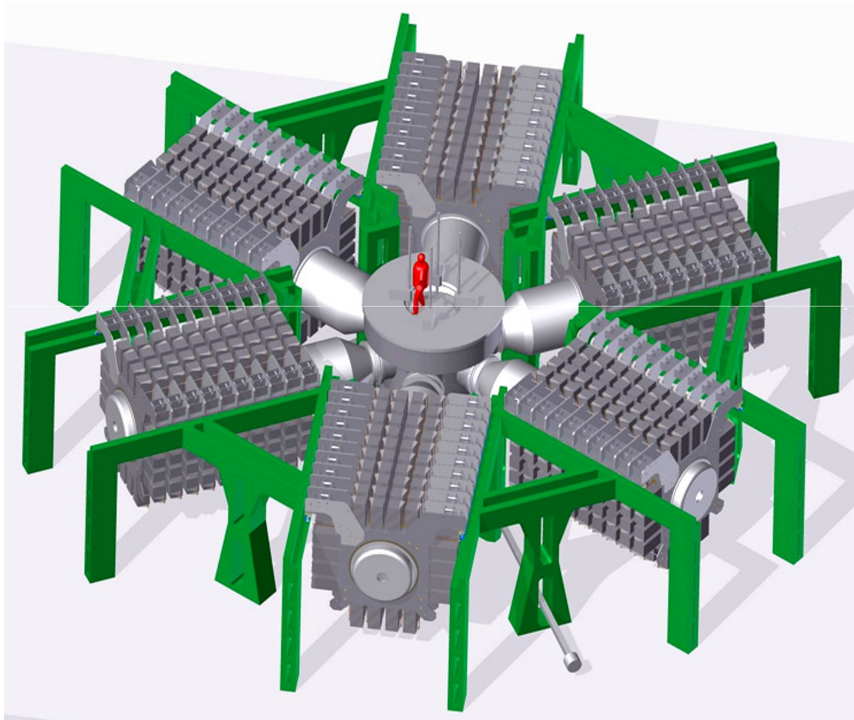
AN EXAMPLE OF HPP DEVELOPMENT : LTD16 STAGE

LTD16 stage (3.7MA-40kV-800ns) was initially developped
for an upgrade of SPHINX Z-pinch driver

Body
2.3x2.3m



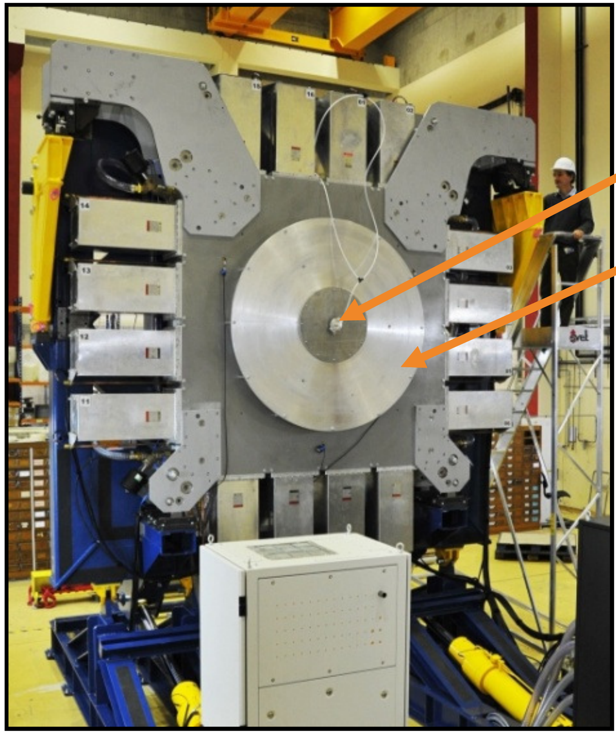
LTD16 stage
Size : 3.9m x 3.9m x 0.47m
Weight : 8 Tons



20MA 1µs LTD16 generator
Conceptual design 6 x 10 LTD16 stages
∅17.5m , 4.5m height

AN EXAMPLE OF HPP DEVELOPMENT : LTD16 STAGE → ICE-16

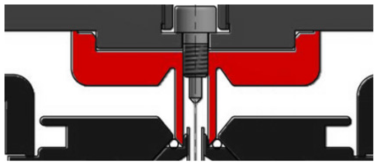
2016 : LTD16 stage will be dedicated to
Isentropic Compression Experiments

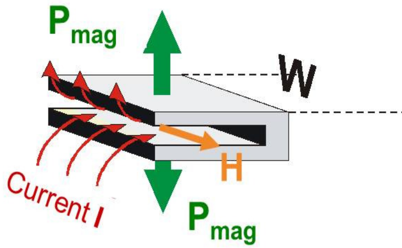


ICE load with vacuum insulation

Vacuum chamber φ1.5m

LTD16 can either work with
cylindrical load or **strip line configuration**





Diagnostic access to probe the sample with X-ray has to be considered

Is the compacity of this device compatible with synchrotron beamline operation ?

Other HPP designs are possible,
depending on specific needs at the Synchrotron