
Création et étude des plasmas denses avec les sources XUV fs accordables

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Plan de l'exposé

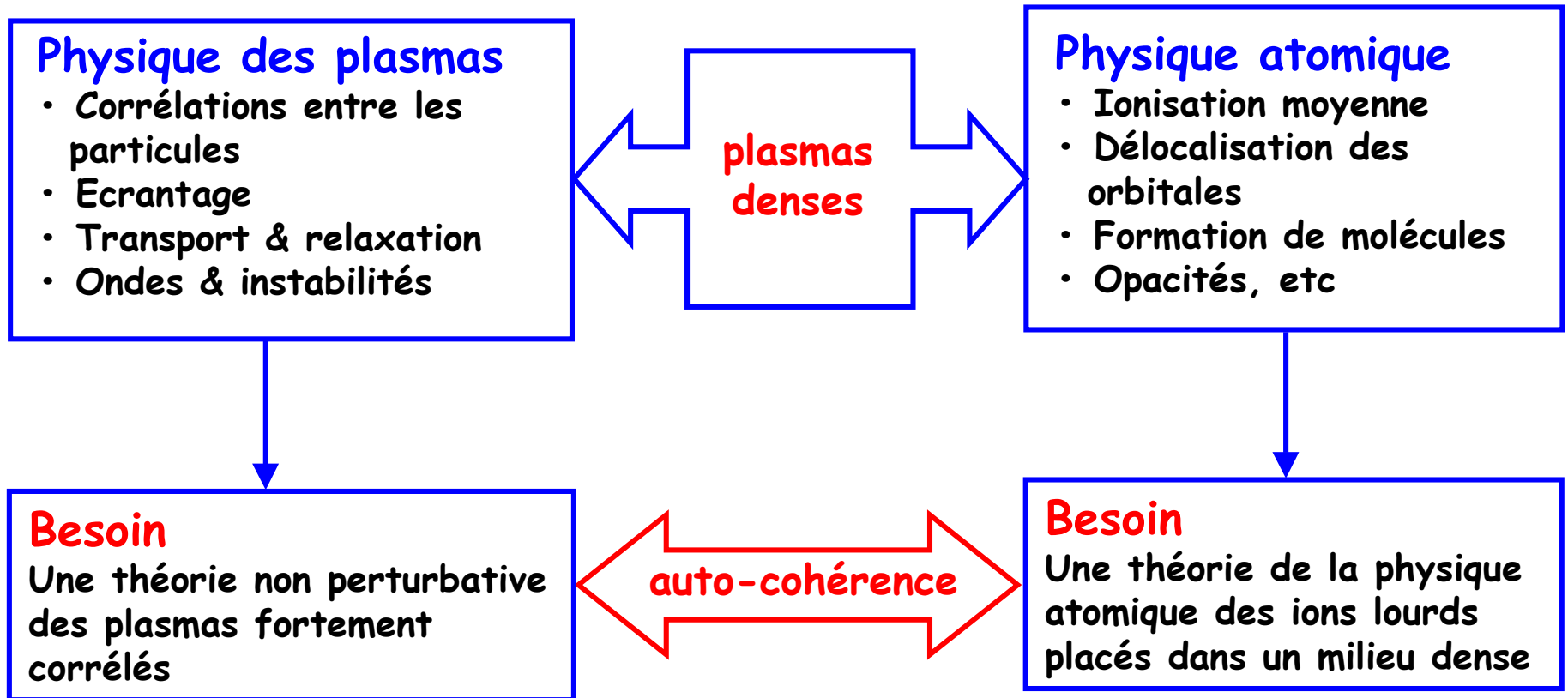


- ▶ Pourquoi étudier les plasmas denses ?
- ▶ A **quel régime thermodynamique** accède t-on avec l'interaction laser XUV fs-matière ?
- ▶ **La source AEC permettra** un chauffage isochore du solide et des mesures de données de référence
 - isentrope de détente
 - opacité
 - réflectivité optique
- ▶ **La source AEC permettra** l'étude des phénomènes transitoires qui apparaissent pendant la transition de l'état solide à l'état plasma (expériences pompe sonde)

Théorie des plasmas denses



Pourquoi est-ce difficile ?



Bibliographie



Quels types de plasmas ?

- Planètes joviennes et extra-solaires
- Naines brunes
- Etoiles de faible masse
- Z-pinch
- Enceinte à plasma isochore
- Fusion par confinement inertiel
- Plasmas créés par laser ultra-court

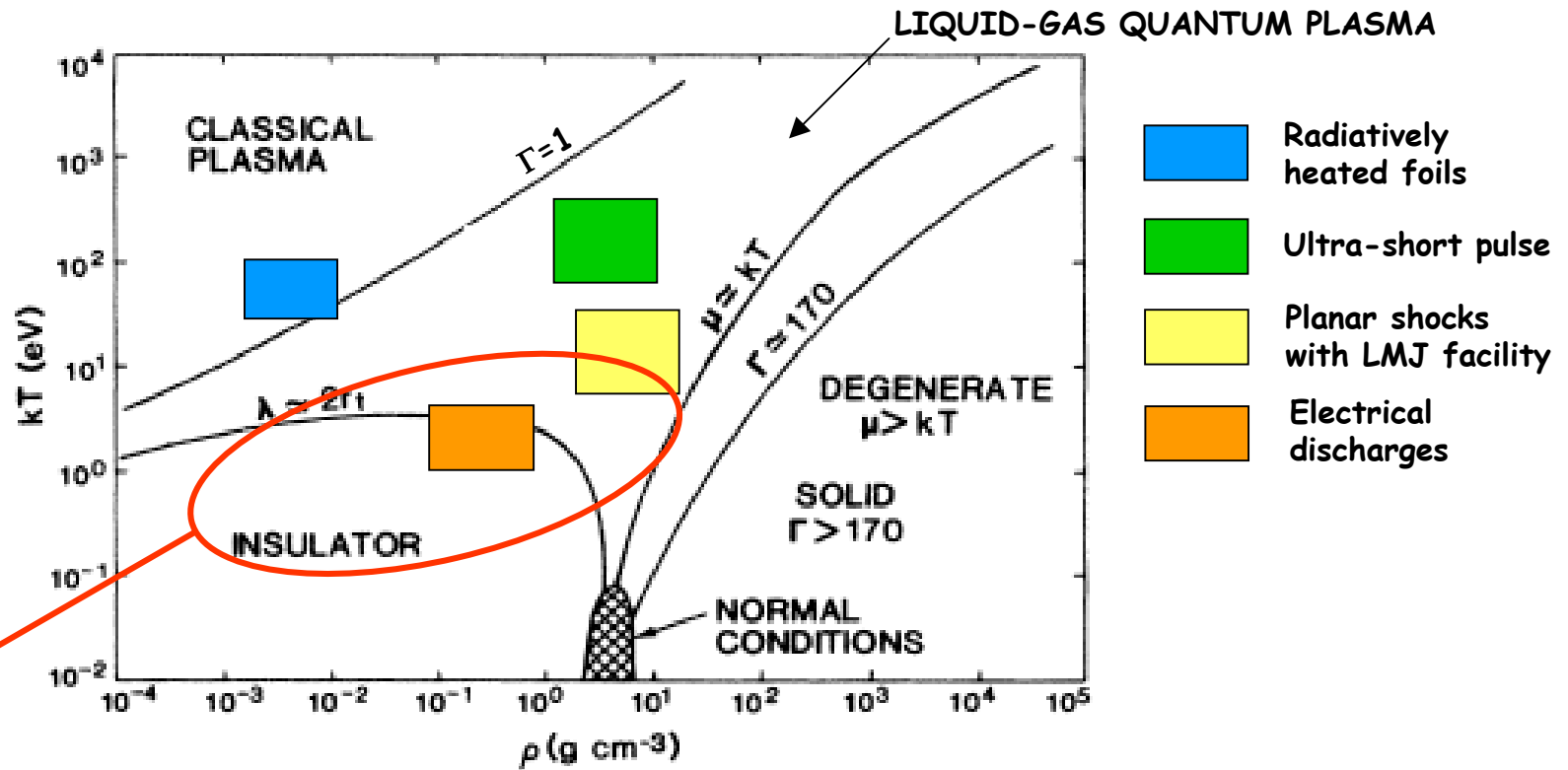
Guillot, *Science* 286 (1999)
Saumon et al., *Ap. J.* 460 (1996)
Van Horn, *Science* 252 (1991)
Saumon et al., *A.J.* 391 (1992)
Chabrier et al., *A.A.* 327 (1997)
Benage et al., *PRL* 83 (1999)
Renaudin et al., *PRL* 88 (2002)
Renaudin et al., *PRL* 91 (2003)
Lindl, *Phys. of Plasmas* 2 (1995)
Audebert et al., *PRL* 89 (2002)
Yoneda et al., *PRL* 91 (2003)

Quels types de calculs théoriques ?

- Monte-Carlo Quantique
- Dynamique Moléculaire Quantique
- Modèle d'atome moyen

Ceperley, *RMP* 67 (1995)
Desjarlais et al., *PRE* 66 (2002)
Recoules et al., *PRE* 66 (2002)
Perrot et al., *PRE* 52 (1995)
Blancard et al., *PRE* (2004)

Physical regions for iron in the temperature-density plane



**WARM
DENSE
MATTER**

Validity of standard theories of condensed matter (T=0) and/or plasma statistical physics is questionable

Arc-en-Ciel can both create and probe high-density finite-temperature matter



To create WDM requires rapid uniform heating

- High photon numbers, high photon energy, and short-pulse length

To pump/probe HDM requires an impulsive source of high-energy photons

- No laser source has such efficient flux (even laboratory X-ray lasers)

To measure plasma properties requires short pulses with signal > plasma emission

- No existing source can probe HDM or create WDM to probe

Arc-en-Ciel peak brightness
allows access to new
thermodynamic regimes

Possible experiments in the high-density finite-temperature regime with Arc-en-Ciel



Creating Warm Dense Matter

- Generate 10 eV solid density matter

Studying Warm Dense Matter

- Measure equation of state data and highlights the microscopic understanding of matter (**release isentropes**)
- Measure electronic properties in the time domain (**optical reflectivity**)
- Measure near-edge X-ray absorption (**XANES**) as probe of electronic structure (**liquid-like experiments**)

Probing bound-bound transitions in Hot Dense Matter

- Measure kinetic processes, frequency redistribution rates, kinetic models, and plasma formation

Probing dense matter

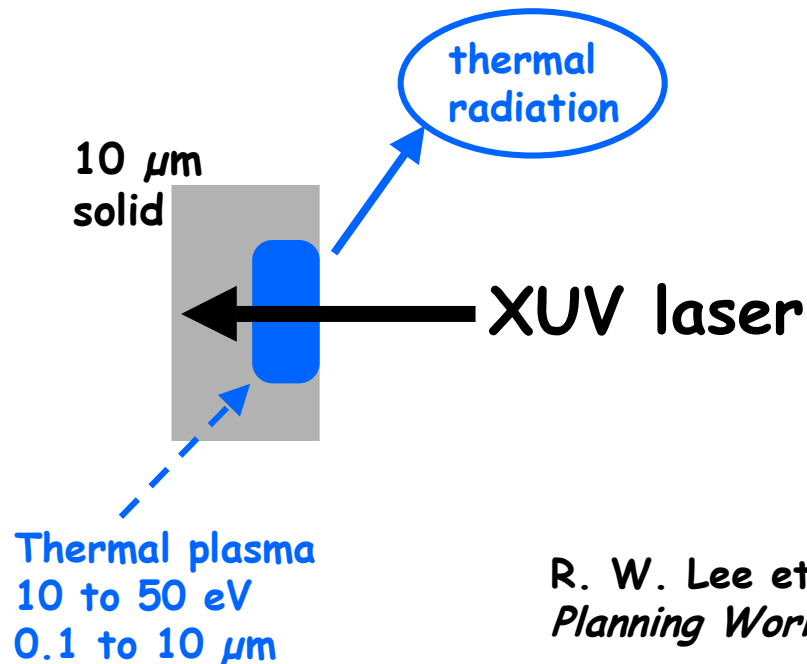
- Scattering from solid density matter
- Measure N_e , T_e , $\langle Z \rangle$, and $S(k)$

P. Zeitoun
*"caractérisation
de plasmas à la
densité du solide"*

AEC can heat matter rapidly and uniformly to create isochores

Creates a 10 eV solid density plasma

- Ensures sample uniform heating
- Energy balance: absorbing energy = total kinetic + ionization energy



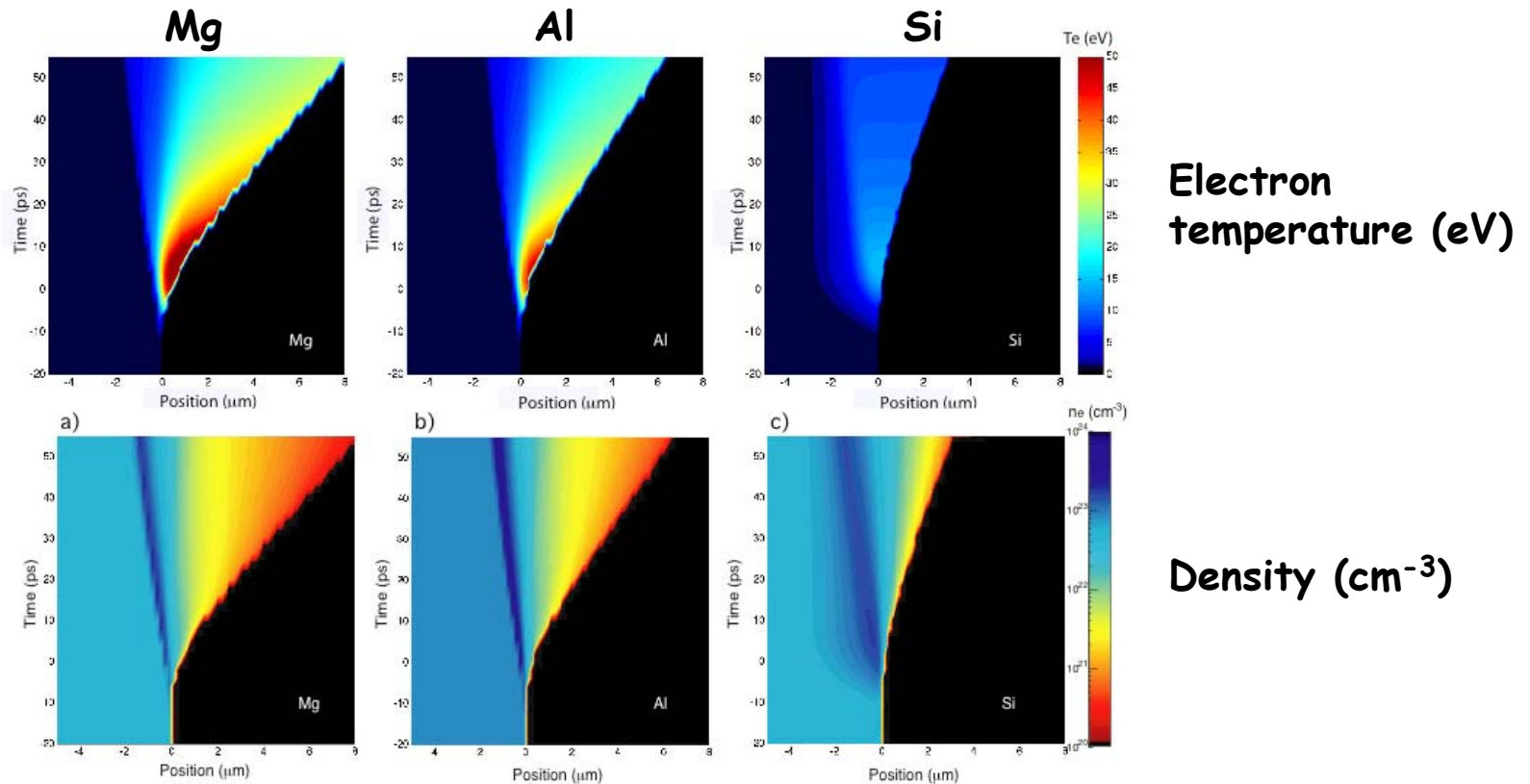
High sensitivity to the warm dense material opacity

R. W. Lee et al., *FEL Experiments Planning Workshop*, Hamburg, 2002

P. K. Patel et al., PRL 91 (2003) *Isochoric heating of solid-density matter with an ultrafast proton beam*

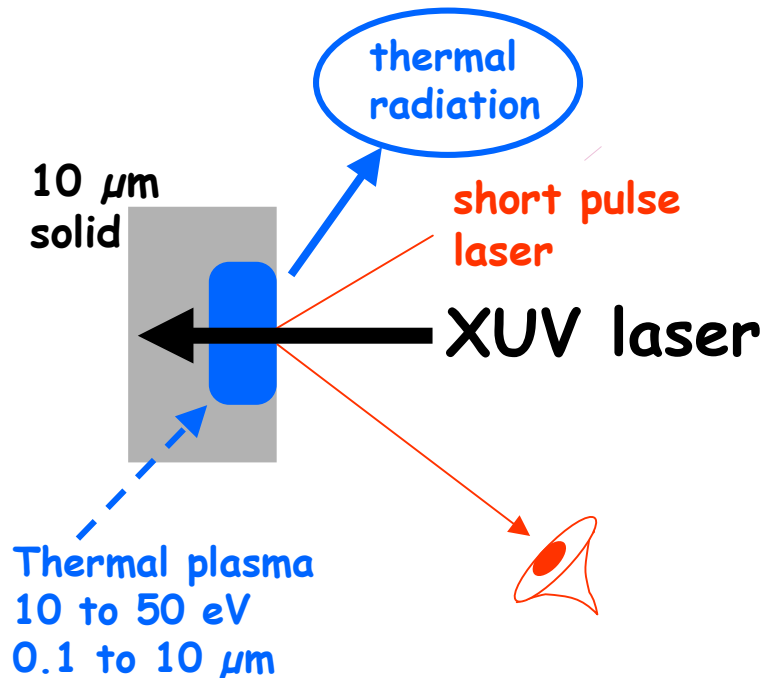
What temperature and density regimes ?

$h\nu=90$ eV, 10 ps duration, XUV laser intensity 10^{13} W/cm²



M. Fajardo, J. C. Gauthier et P. Zeitoun,
*Hydrodynamic simulation of XUV laser
produced plasmas (2003)*

1. AEC can heat matter rapidly and uniformly to create isochores and release isentropes



Material rapidly and uniformly heated releases isentropically

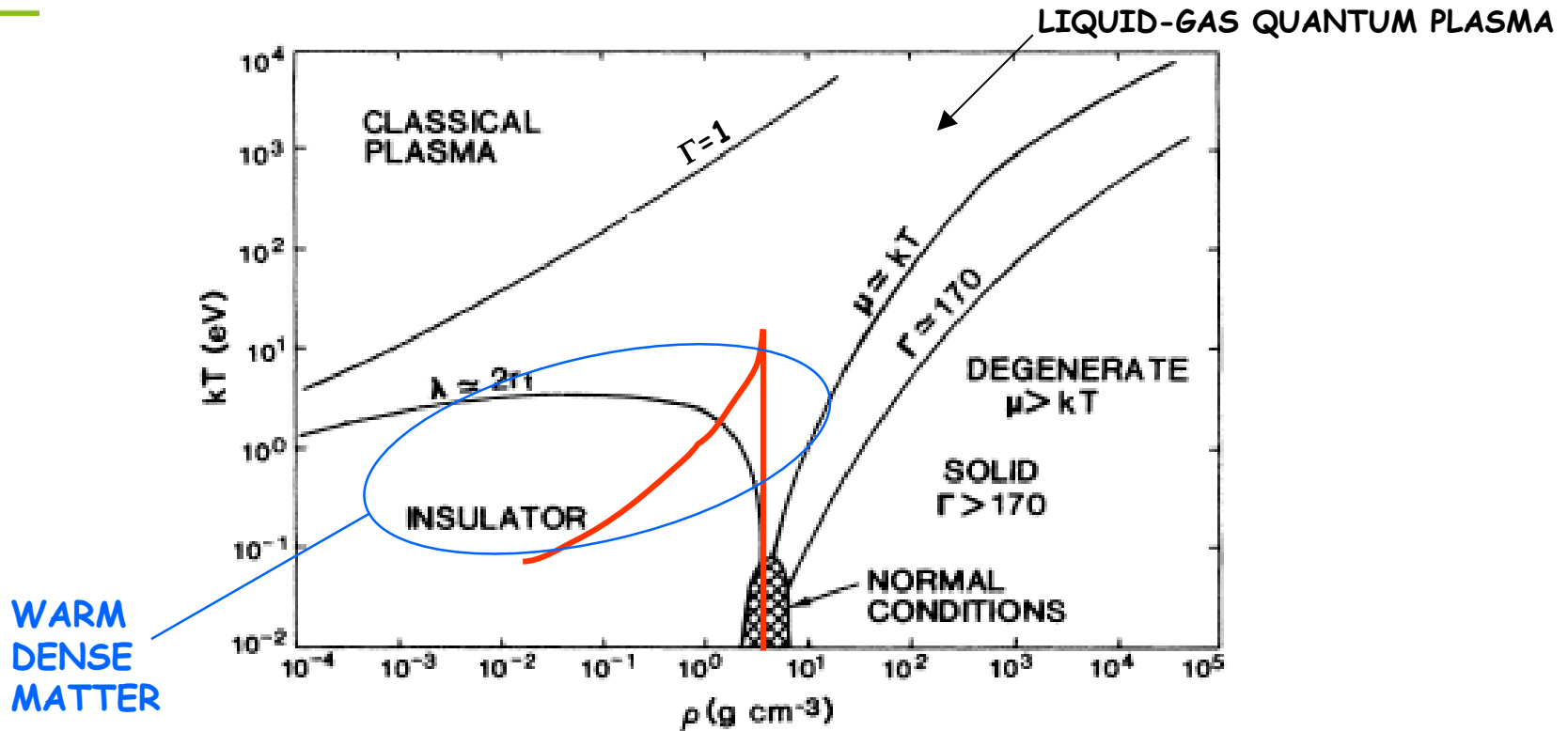
States of material on release can be measured with a short pulse laser

- Cooling down at a rate of few eV/ps
- Sound speed estimated to be a few of 10^6 cm/s with pressure 4 Mb
- For 500 fs get surface movement by 80 \AA

AEC allow to measure equation of state data in a thermodynamic range where electronic structure and ionic distribution have to be determined self-consistently

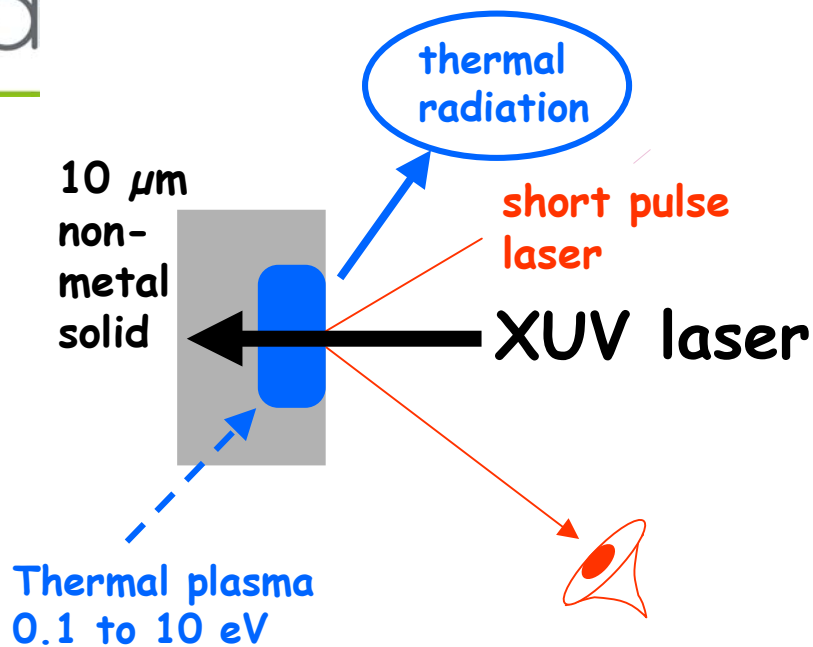
R. W. Lee et al., *FEL Experiments Planning Workshop*, Hamburg, 2002

1. AEC can heat matter rapidly and uniformly to create isochores and release isentropes

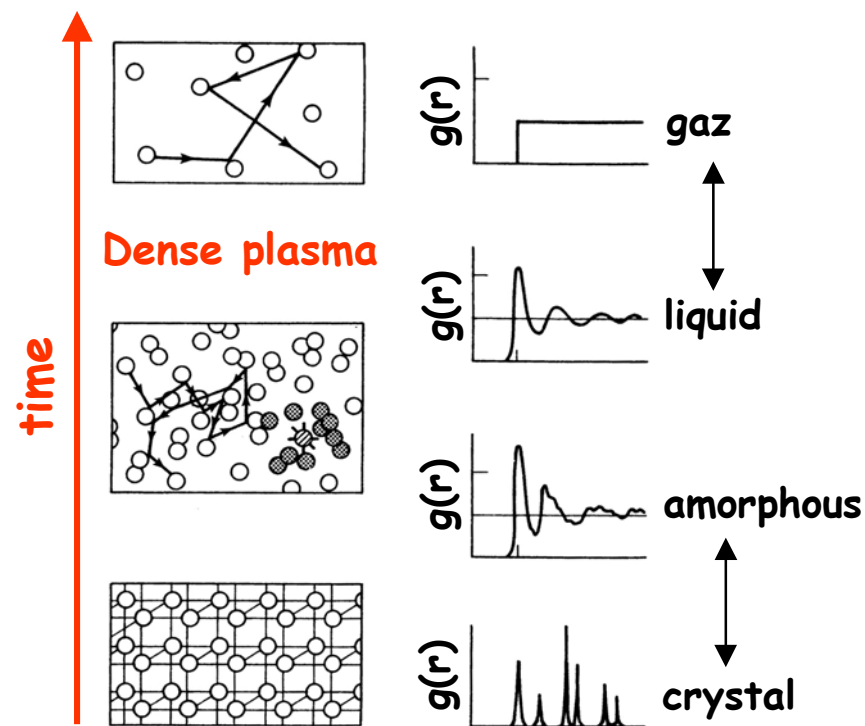


In the WDM regime, AEC will be the unique source of data

2. AEC will allow to measure optical properties of dense plasma



Optical reflectivity of material on release can be measured with a short pulse laser



- non-metallic behavior ?
- metal-non metal transition ?

La source AEC permettra l'étude du comportement dynamique des plasmas denses

Cinétique du plasma

- Mesure de la dynamique d'ionisation
- Mesure de la redistribution de fréquence (**spectroscopie active**)
- Construction et test des modèles cinétiques (**évaluation des taux**)

Couplage du plasma

- Mesure directe du facteur de structure **dynamique** $S(k, \lambda)$

Etude des transitions radiatives

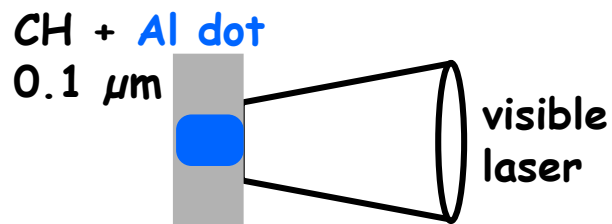
- Mesures des profils de raies, de l'ionisation et de l'abaissement du potentiel dans les milieux denses

3. TESLA can photopump a transition:

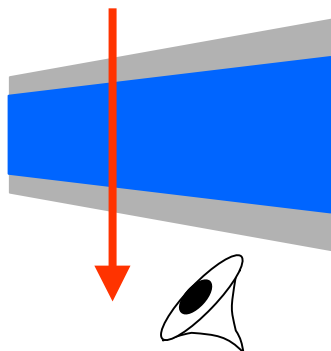
The emission provides critical tests of plasma processes

Experiment

$t=0$ a laser irradiates an Al dot

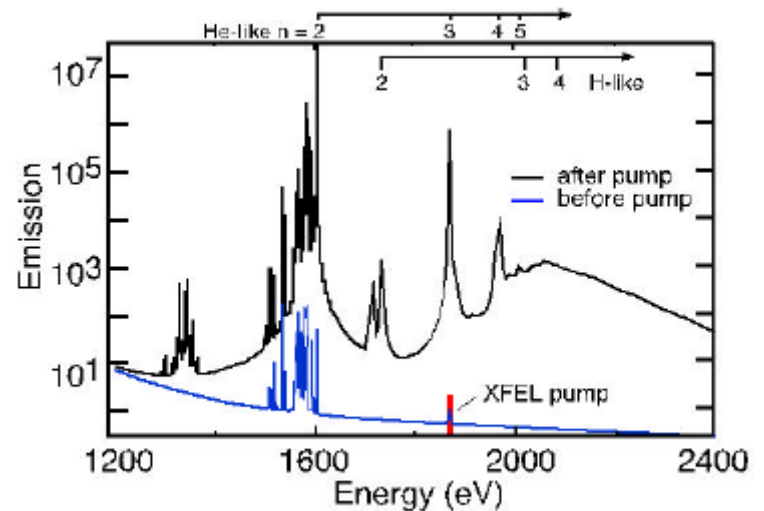


$t=0.1$ ns XRL @ 1.8 keV irradiates Al plasma



X-ray streak camera

Simulation



FEL Exp. Planning Workshop, Hamburg (2002)
R. W. Lee et al., *Creating and probing extreme states of matter with an X-ray FEL*