J. Alvarez, M. Cotelo, A. García, F. de Dortan, P. Velarde, M. Perlado
Instituto Fusión Nuclear (DENIM) - Universidad Politécnica Madrid, Spain
jalvarezruiz@gmail.com

Synchrotron X-ray photoabsorption spectroscopy of plasmas

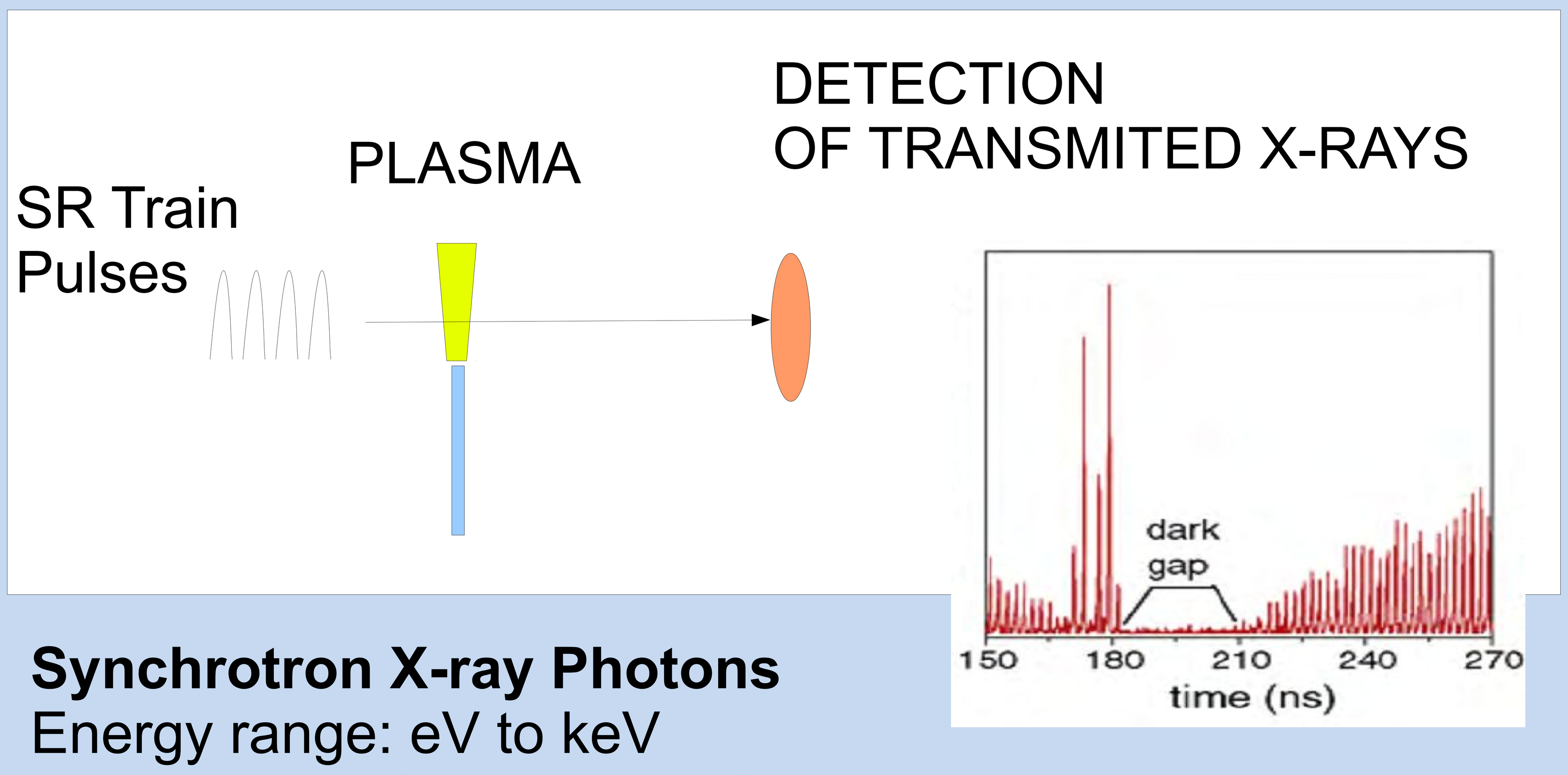
ABSTRACT

Theoretical X-ray opacities are used in numerous radiative transfer simulations of plasmas at different temperatures and densities, for example astrophysics, fusion, metrology and EUV and X-rays radiation sources. However, there are only a reduced number of laboratories working on the validation of those theoretical results empirically, in particular for high temperature plasmas (> 1eV). One of those limitations comes from the use of broad band EUV- X ray sources to illuminate the plasma which, among other issues, present low reproducibility and repetition rate [1]. Synchrotron radiation facilities are a more appropriate radiation source in that sense, since they provide tunable, reproducible and high resolution photons. Only their “low” photon intensity for these experiments has prevented researchers to use it for this purpose. However, as new synchrotron facilities improve their photon fluxes, this limitation not longer holds [2]. This work evaluates the experimental requirements to use third generation synchrotron radiation sources for the empirical measurement of opacities of plasmas, proposing a pausible experimental set-up to carry them out. Properties of the laser or discharge generated plasmas to be studied with synchrotron radiation will be discussed in terms of their maximum temperatures, densities and temporal evolution. It will be concluded that there are encouraging reasons to pursue these kind of experiments which will provide with an appropriate benchmark for theoretical opacities.

TIME RESOLVED PHOTOABSORPTION SPECTROSCOPY OF EVOLVING PLASMAS

Experimental requirements:

1. Creation of plasma.
2. Illumination with X-ray Synchrotron Radiation pulses.
3. Detection of transmited X-rays in a pulse by pulse bases.
4. Correlation of theoretical/experimental plasma parameters (temperture and density) with detected X-rays.
5. Determination of Opacities for specific plasma conditions.



Synchrotron X-ray Photons
Energy range: eV to keV
Fluence: 100-1000 photons/pulse
Time structure: 100ps pulses every few ns
Detector: Ultra Fast MCP [3]

PLASMA REQUIREMENTS

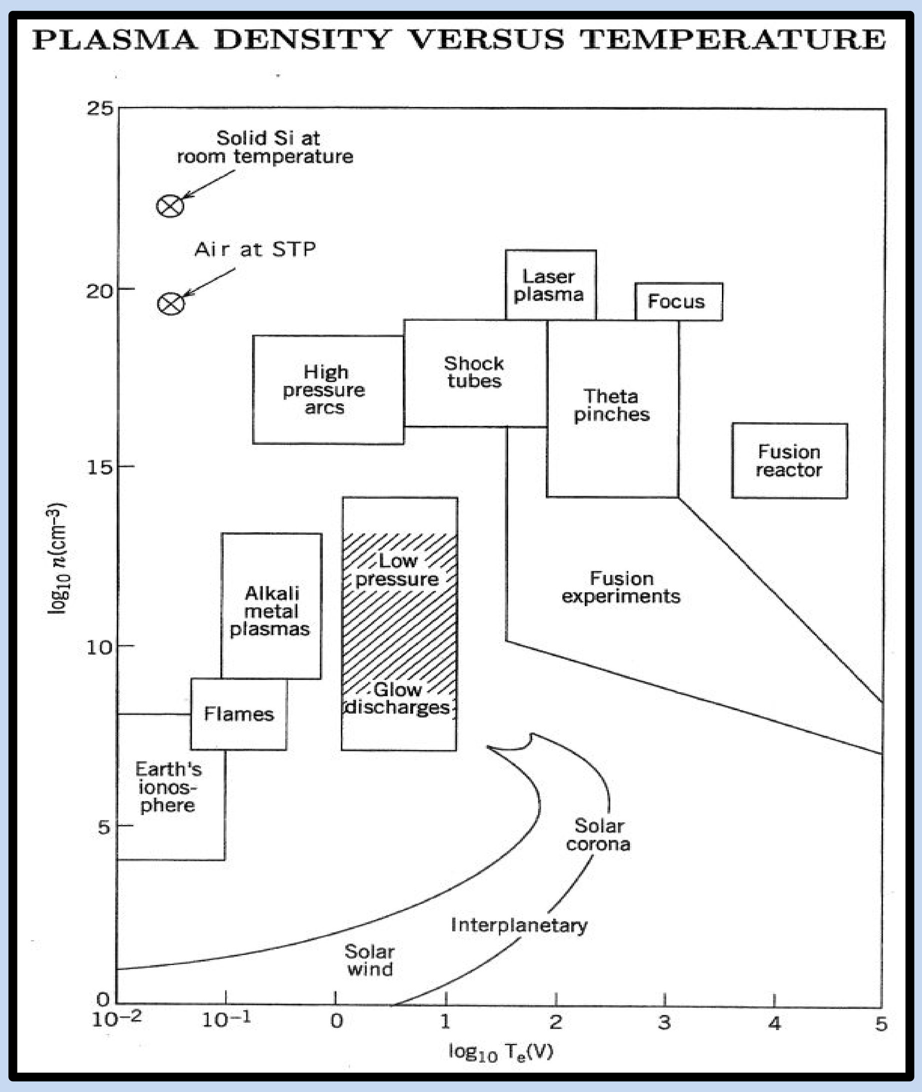
In order to be able to experimentally observe changes in the transmited X-ray pulses it is reasonable to absorb a 10-20% of the intensity. According to Beer-Lambert's law and a typical absorption cross-sections of about 1Mb(10^{-18}cm^{-2}), densities of 10^{19}/cm^3 and lenghts of 1mm are required.

$$I = Io \exp(-k)$$
$$k = \sigma \rho l$$

Io, *initial intensity*
I, *transmited intensity*
σ, *cross section*
ρ, *plasma density*
l, *plasma length*

PLASMA GENERATED BY DISCHARGE

Dense and high temperature plasmas can be generated with Z-pinch [4] (10^{17}-10^{19}/cm^3; temp <10 eV; duration of μs). Other lower density plasmas but of longer time duration could also be explored [5,6].
Figure on the right places different plasma sources according to the plasma tempertaura and density [7].

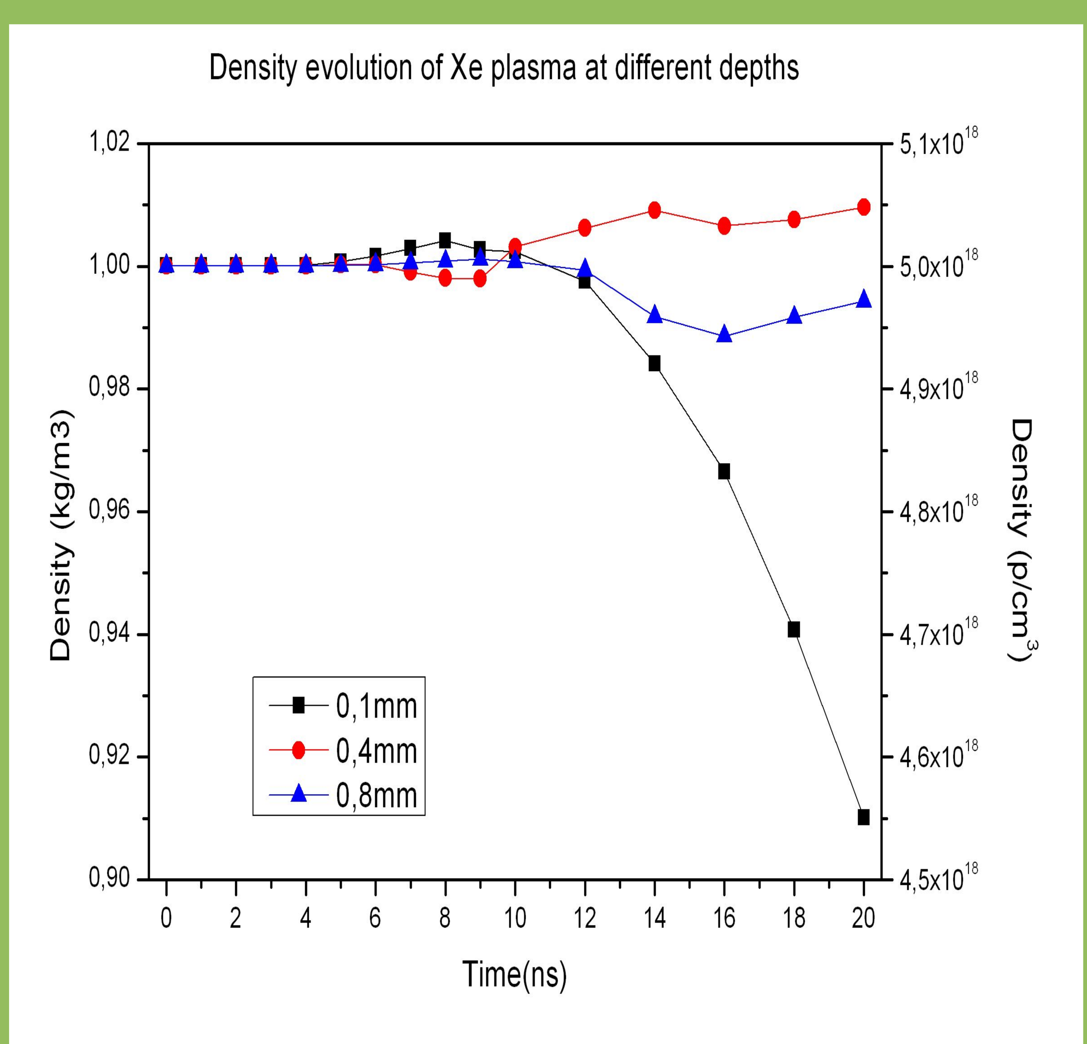


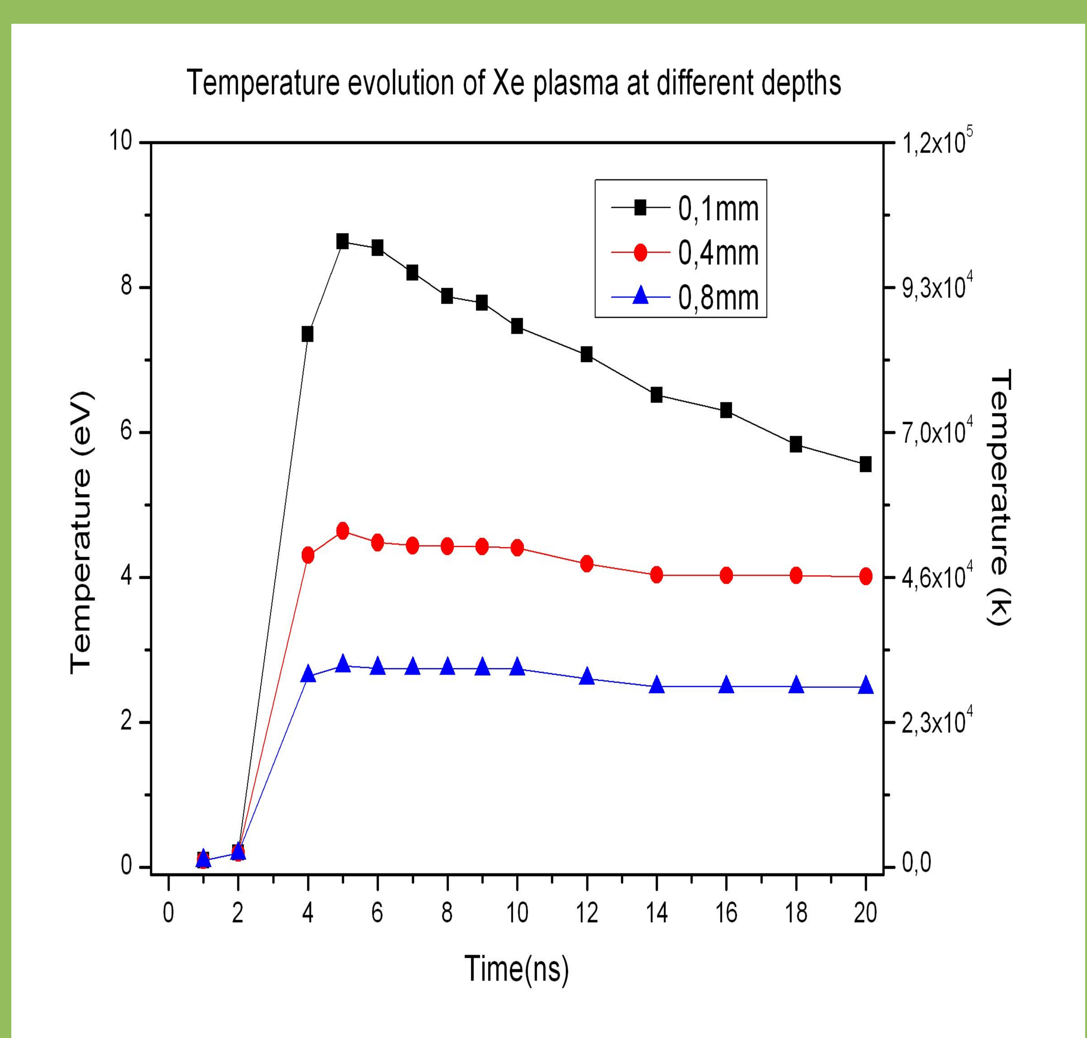
PLASMA GENERATED BY LASER

Laser generated plasmas have been used in accelerator facilities for stopping power studies since they allow higher densities and higher temperatures [8,9].
A GW laser can generate plasmas with densities up to 10^{21}/cm^3 and temperatures of tens of eV.

EVOLUTION OF A LASER INDUCED PLASMA (THEORETICAL RESULTS)

Laser parameters: λ=1064 nm; ζ=2ns; Energy=1J; Intensity= 5*10^{10}W/cm^2
Xe gas properties: density 1Kg/m^3; area=1 mm^2 ;velocity= 1μm/ns)





CONCLUSIONS

1-Current Synchrotron Sources could be used to probe plasmas and study photo-absorption behaviour at different plasma densities and temperatures.
2-Laser produced plasmas allow for higher temperatures and denser conditions.
3-Electric induced plasmas seen to be more limited but could also be employed.

REFERENCES

[1] “Absorption spectroscopy of mid and neighboring Z plasmas”. High Energy Density Physics 5 (2009) 173
[2] “Absorption spectroscopy of ions combining synchrotron radiation and laser generated plasmas” J.Elec. Spec. Rel Phen. 104 (1999) 233
[3] “Time Resolved XAS experiments at the BACH beamline of ELETTRA.” Marco Malvestuto (2011)
[4] “Density diagnostics of an argon plasma by heavy ion beams and spectroscopy” Laser Part. Beams, 14 (1996) 561
[5] “Plasma generation and plasma sources”. Plasma Sources Sci. Technol. 9 (2000) 441–454
[6] “Gas discharge plasmas and their applications” Spectrochimica Acta Part B 57 (2002) 609–658
[7]“Principles of plasma discharges and material processing” M.A. Lieberman (2001)
[8] “Frontiers of dense plasma physics with intense ion and laser beams and accelerator technology”. Phys. Scr. T123 (2006) 1–7“
[9] “Energy Loss of heavy ions in laser-produced plasmas”. Europhys. Lett. 50 28 (2000)