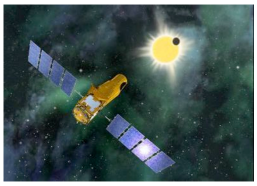
Laser and Z pinch experiments to reveal plasma properties of seismic probes through the HR diagram



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Abstract: Helio and asteroseismic measurements are convincing probes of the stellar internal dynamics, but the interpretation of the acoustic mode characteristics is largely based on the microscopic description of the stellar plasmas. The precise determination of the helioseismic frequencies has put in evidence some specific signatures which contribute to check the validity of the plasma physics introduced in the stellar structure equations (position of the solar BCZ, subsurface helium content, maxwellian distribution of reactant velocities, screening in nuclear reaction rates) but the present discrepancy in the solar radiative zone justifies the need to separate the different processes and to check some of them in laboratory.

This need expands to most of the pulsating stars for which the mechanism of excitation is connected to the κ mechanism and for which the labelling of the observed modes (already numerous with COROT) is more puzzling.

In the stellar envelops, noticeable differences between OPAL and OP opacities have direct impact on modelling and frequency predictions.

In order to facilitate the interpretation of COROT, KEPLER, PLATO and on ground observations, we are developing a laboratory program dedicated to the identification of some plasma properties in stellar conditions: measurement of ionization states, absorption coefficients, turbulence, equation of state on large laser or on Z-pinch facilities.

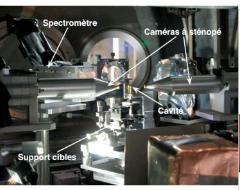
We present here the context and our perspectives.

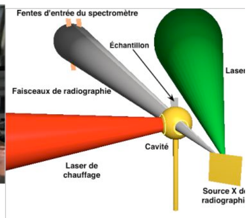
This work will be done in collaboration with CEA/DAM, LLNL and Z-pinch teams

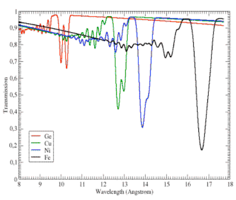
Opacity coefficients are fundamental ingredients of stellar evolution but they were up to recently inaccessible to laboratory measurements for stellar interiors. The first quantitative measurement of photoabsorption in the region corresponding to envelop of stars has been obtained by Springer et al. (1992) with an accuracy of about 15%. This measurement has confirmed the need for an increased conribution of iron by a factor 2 in the envelop of Cepheid around 4 10^5 °K to understand properly the mass of these stars (Moskalik et al. 1992). Today we notice still real differences in the opacity calculations (OPAL and OP) for such conditions which lead to very different radiative forces (Badnell et al.2005) up to 50% for Fe. Such discrepancies are also visible for C, N, O, S, Si… so looking to the opacity spectra and measuring its characteristics are very useful for the development of asteroseismology for pulsating stars like beta cepheids which are excited by κ mechanism at temperature where iron produces an opacity bump (near 20 eV). Here we consider two kinds of installations and show what is already done and what we are preparing for the envelop of pulsating star and the interior of low mass or solar type stars.

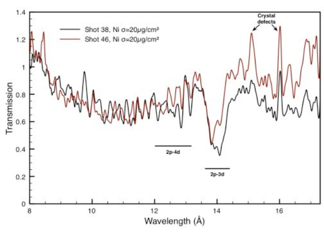
Checking the opacity of the envelop of pulsating stars for κ mechanism

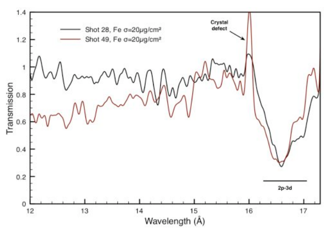
- A first experiment has been performed in 2008 at LULI 2000 Palaiseau France (Loisel et al. RPHDM2009) to measure the absorption spectroscopy of mid and of neighbouring Z around iron to check the evolution of the spin orbit splitting 2p-3d transitions for 4 elements in some conditions which are not far from astrophysical conditions (20eV, about 5 mg/cm³) found in the envelop of beta cepheids stars.
- The experiment used a laser to heat a cavity Φ1200 μm on which the sample is fixed of 100 to 200 J, impulsion 500 ps, 0,54 μm and a picosec laser (10 to 20 J, impulsion 10 ps,1.05 μm, delayed by 1.5 ns illuminates the sample to examine the sample properties. The spectrum is obtained thanks to an X ray spectrometer especially designed for this purpose.
- The sample is composed by a sandwich of foals C/Z/C ~0.1 μm to avoid a too quick expansion of the analysed sample.
- Experimental setup and theoretical predictions of the waited transmission phenomenon using an opacity code SCO (Blenski et al. 2000) for the four elements are shown here.





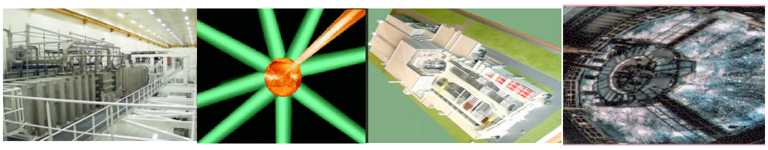




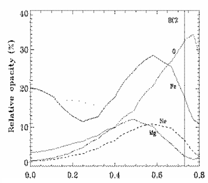


The quality of the measurements is significatively improved in comparison with previous experiments due to the use of a petawatt laser to probe the sample keeping the measurement as LTE as possible. In fact the temperature seems to be determined at ±2 eV. Nevertheless we hope to improve the experiment in using a higher energy for the ns laser at LULI 2000 and consequently a greater cavity on which the sample is placed. For the campaign 2009, the experimental objective will be also to try to measure some mixture of elements. In 2010 we intend to perform an astrophysical experiment with iron around 20 eV but for this experiment we would like to look to the spectrum in the range of energy which corresponds to the maximum of the Rosseland opacity, this choice implies probably to develop a new XUV spectrometer in the 100 eV (100 Angstroms-200 Angstroms) range.

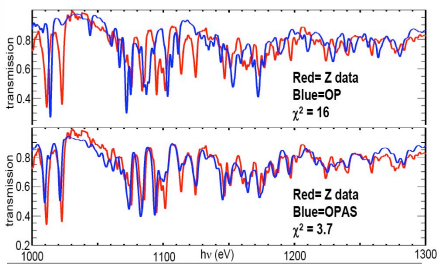
Checking the opacity of the interior of stars with LIL+PETAL, LMJ or NIF and SANDIA



New installations become available to provide interesting temperature and density conditions to check some opacity coefficients used to describe the transport of energy by radiation inside the stars. On the above figure, we show the LIL installation in Bordeaux with PETAL (picoseconde laser) which must be available in 2012, LMJ 2013 (but mainly reserved at the beginning for inertial fusion confinement FCI) and the Z pinch machine at Sandia. We (french and american teams are preparing a program to verify the degree of ionisation of typical Z element at given T, ρ and its corresponding spectrrum in the range of energy (wavelength) useful to determine the mean Rosseland opacity. Like in the case of nuclear reaction rates, which have benefit from laboratory luclear cross section, the stellar seismic development with COROT and KEPLER for low mass stars justifies to get laboratory measurements of absorption coefficients. Different techniques can be used and the accuracy of the measurements depends on a proper description of the dynamical processes which are accompagnying the measurements. Of course for the development of the program, the Sun is an interesting object to consider because the quality of the seismic probes leads to impressive results.



In this figure, we show the relative contribution to the opacity coming from the main heavy elements, it is well known that the edge of the convective zone is mainly due to the partial ionisation of oxygen, but, as it is well shown on the figure, iron plays also a crucial role, so the degree of ionisation and the opacity spectrum of these two elements need to be verified in priority. Moreover the sound speed difference between recent solar models and seismic observation (Turck-Chièze et al. 2004) encourages also to check iron contribution at higher temperature



A first experiment has been realized for iron in the Z pinch machine in La Sandia (USA) at 153 eV and density of 7 10^{21} electrons/cm³ (Bailey et al. 2007), conditions not far from those of the BCZ, which is compared to OPAL and OP calculations.

Nevertheless due to the fact that it is difficult to get LTE measurements, this first effort must be pursued in other installations to properly determine the experimental error bars and to estimate the quality of the theoretical calculations.

We are preparing a program for iron and oxygen on LIL+PETAL for 2012.

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