A novel technique for X-ray multi-spectral imaging of ultraintense laser generated plasmas

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0. Abstract

A novel technique is presented enabling spectrally resolved, two-dimensional imaging of laser-produced plasmas. The technique has been tested with microplasmas produced by ultrashort relativistic laser pulses. The technique is based upon the use of a pinhole camera equipped with a CCD detector operating in the single-photon regime. The spectral resolution is about 150 eV in the 4-10 keV range and images in any selected photon energy have a spatial resolution of 5 μm. The potential of the technique to study fast electron propagation in ultraintense laser interaction with multilayer targets is discussed and some preliminary results are shown.

1. Intro: X-ray diagnostics of laser plasmas

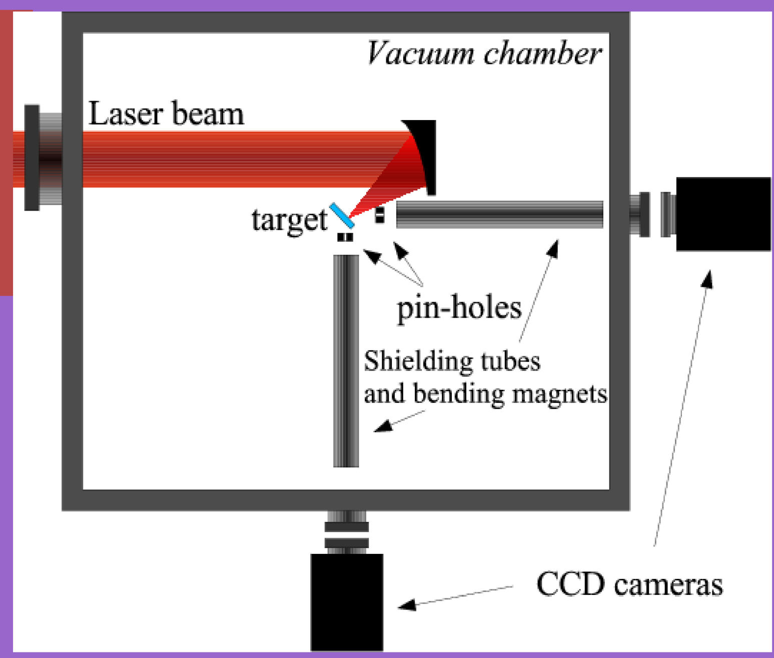
- Soft X-ray emission from laser-produced plasma is mainly studied by means of Bragg crystals. Other spectroscopic tools include, in particular at even shorter wavelengths, scintillation photomultiplier detectors coupled to K-edge filters, cooled Ge detectors in photon counting mode, etc.
- Spatial resolution can be obtained either with flat Bragg crystals coupled to narrow slits [1] or pinhole arrays [2] or with bent crystals.
- Bent crystals coupled either to X-ray films or to CCD detectors are by far the most commonly used diagnostics. Spectral resolutions down to a few eV and a simultaneous 1D spatial resolution of some microns can be reached in this way [3-6].
- The main drawbacks of using bent Bragg crystals are:
  - the efficiency can be quite low, due to the narrow rocking curve, usually smaller than the width of the spectral line of interest;
  - the reflectivity generally decreases at high energy;
  - the small Bragg angle usually needed at high photon energy can lead to strong image aberrations;
  - the contributions from different diffraction orders can overlap;
  - crystals can produce fluorescence and Compton radiation when exposed to hard X-rays, so that their use can be quite difficult in relativistic laser-plasma interaction or PW environments.
- The use of CCD detectors in single-photon regime is now more and more considered for ultrashort and ultraintense laser-plasma X-ray spectroscopy [7-9].
- When used in such a regime, CCD detectors enable the spectrum of the impinging X-ray radiation to be obtained without any additional dispersing device.
- In this work, a small pinhole was coupled to a CCD detector forced to operate in the single-photon regime. In this way, spectrally resolved, 2D images of an ultrashort laser plasma were obtained.

2. The first experiment: study of fast electron transport in solid targets

2a. The experimental setup

The laser system

8TW TiSa laser system JeTi @ IOQ-Jena
70fs duration, 600mJ/pulse, 10Hz rep rate
focused with an f/1.2 OAP down to a spot size 5µm²
I=5x10[19] W/cm², a_0=eA_L/mc²=4.8



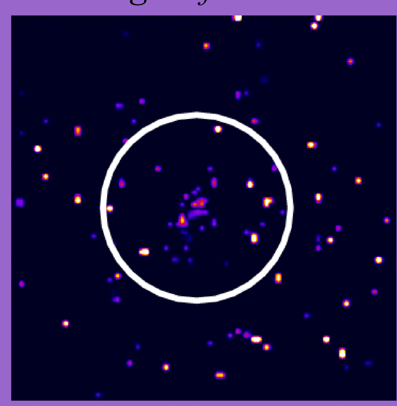
- ***Pinholes***
  5µm diameter, bored on a 25µm thick Pt substrate
- ***CCD detectors***
  Andor DX420 deep depletion, back illuminated camera
  1024x256 pixels, 26x26µm²
  cooled at -65 °C
  The CCDs were previously characterized [10]
- ***Magnification***
  10x

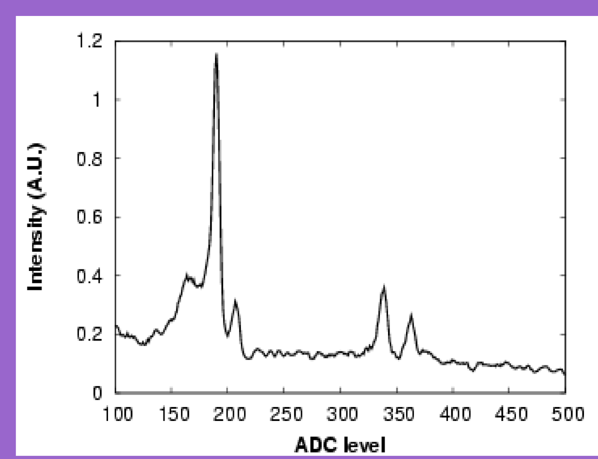
- Up to 20 mylar foils were used for each pinhole camera in order to reduce the photon flux at the single-photon level required for the technique to be effective
- Lead tubes and set of magnets were used to shield the detectors against fast electrons and fluorescence or Compton X-ray photons.

2b. Data analysis

Example: Ti-Cu target

CCD signal from each laser shot





Spectrum obtained by summing over 350 laser shots (acquisitions)

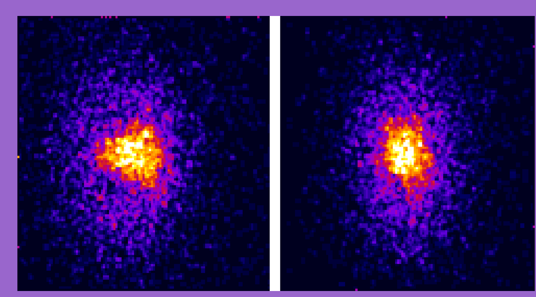
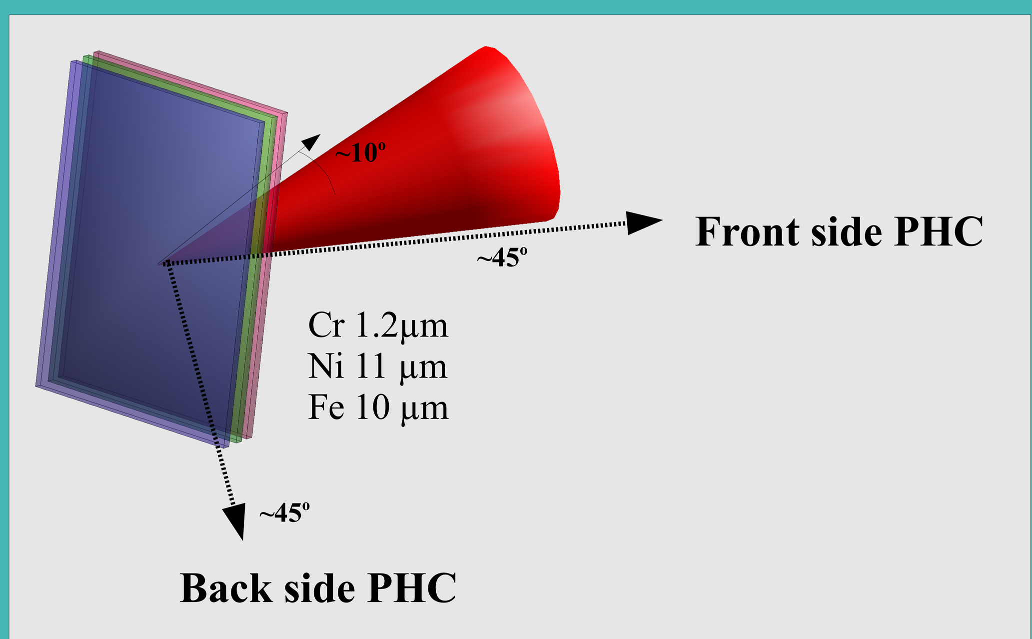


Image of the source at the Ti Kα/β line energy without (LEFT) and with (RIGHT) image-to-image alignment procedure [10]

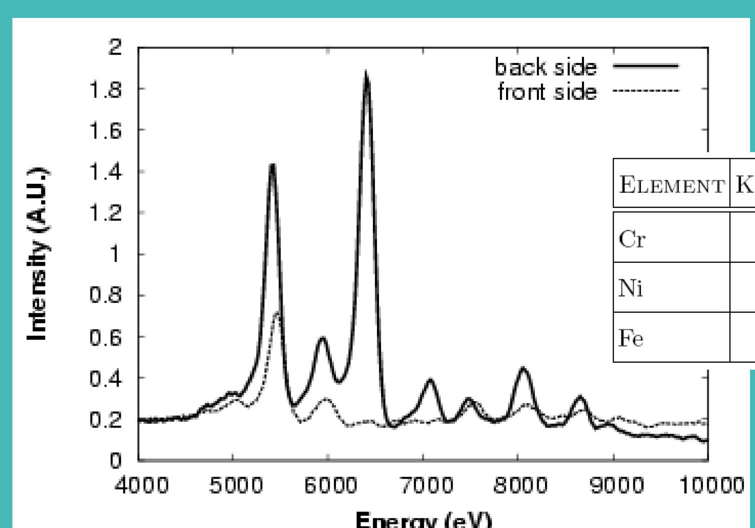
Spectral resolution: ~150eV
Spatial resolution: ~5µm

3. The first experiment: some results with multi-layer targets

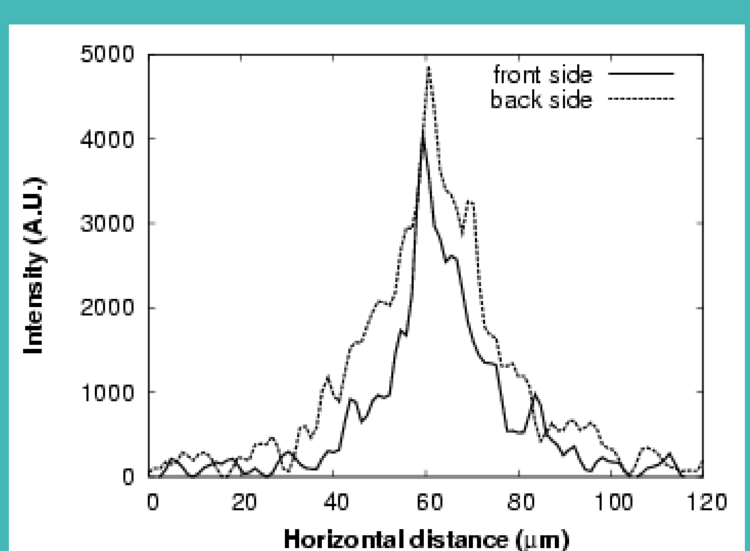
- In order to diagnose the fast electron propagation in solid targets, multi-layer targets were used
- The Kα/β emission from each layer provides informations about the fast electron propagation across that layer

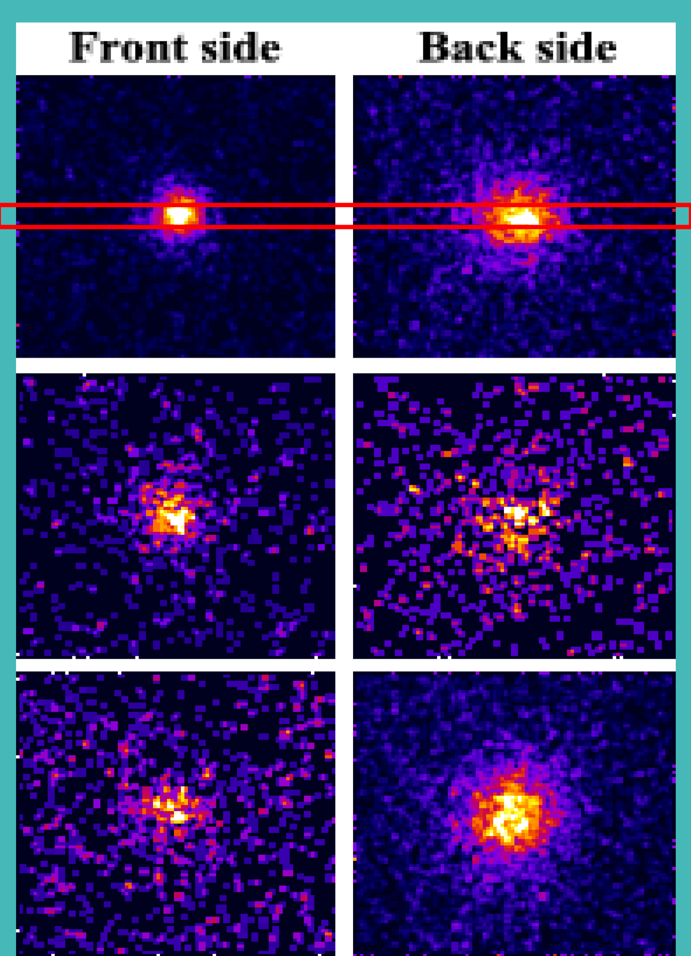


X-ray spectrum obtained from 350 laser shots irradiation of a Cr-Ni-Fe target



Element	Kα (keV)	Kβ (keV)
Cr	5.41	5.95
Ni	7.48	8.26
Fe	6.40	7.06



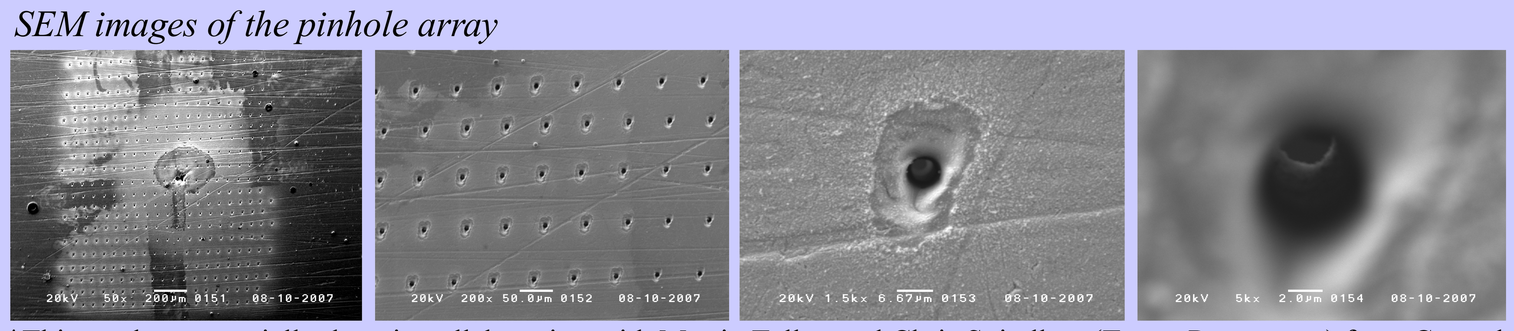


- Images of the source can be obtained at any selected photon energy, corresponding either to K-shell emission from one of the layer or to Bramsstrahlung radiation
- This is a powerful tool for the study of the fast electron propagation
- Tha data analysis is still in progress...

4. Current work and perspectives: toward a single-shot multi-spectral imaging technique*

- The technique 'as it is' has currently a multi-shot basis (about 350 laser shots were required in our case), due to the need for a statistically significant number of photons to be detected.
  Technique currently only suitable for high-repetition rate laser systems
- A possibility for going toward single-shot is to exploit large area CCDs or similar position sensitive detectors in combination with a pinhole array, in order to collect more than one 'single-photon image' on the same CCD detector.
- A 20x20 pinhole array has been prepared by the ILIL group to this purpose.
  The pinholes have been digged on a 100µm thick W substrate, by tightly focusing a 0.2 TW, 65fs duration frequency doubled TiSa laser beam.
- The pinhole array has been characterized by SEM analysis at the Rutherford Appleton Laboratory.
- Very well shaped pinholes, about 6-7µm in diameter on one side and 4-5µm on the other one, have been obtained.
- First test experiment have been carried out at the PALS lab in Prague and RAL..

SEM images of the pinhole array



*This work was partially done in collaboration with Martin Tolley and Chris Spindloe (Target Prep group) from Central Laser Facility, Rutherford Appleton Laboratory (UK)

5. Conclusions

- A novel experimental technique has been developed, enabling the 2D imaging with spectral resolution of the X-ray emission from ultrashort laser irradiated targets.
- The technique has been employed in an experiment devoted to the study of fast electron propagation in solid targets, by tracing Kα/β emission from multi-layer targets.
- A spectral resolution of 150 eV in the energy range 4-10 keV has been obtained. The spatial resolution in any selected photon energy range is of about 5µm.
- The technique 'as it is' has currently a multi-shot basis. Some methods for going toward single-shot are currently investigated.

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