Pinhole X-ray camera photos of an ECR ion source plasma

Sándor Biri, Endre Takács, Richárd Rácz, Larry T. Hudson and József Pálinkás

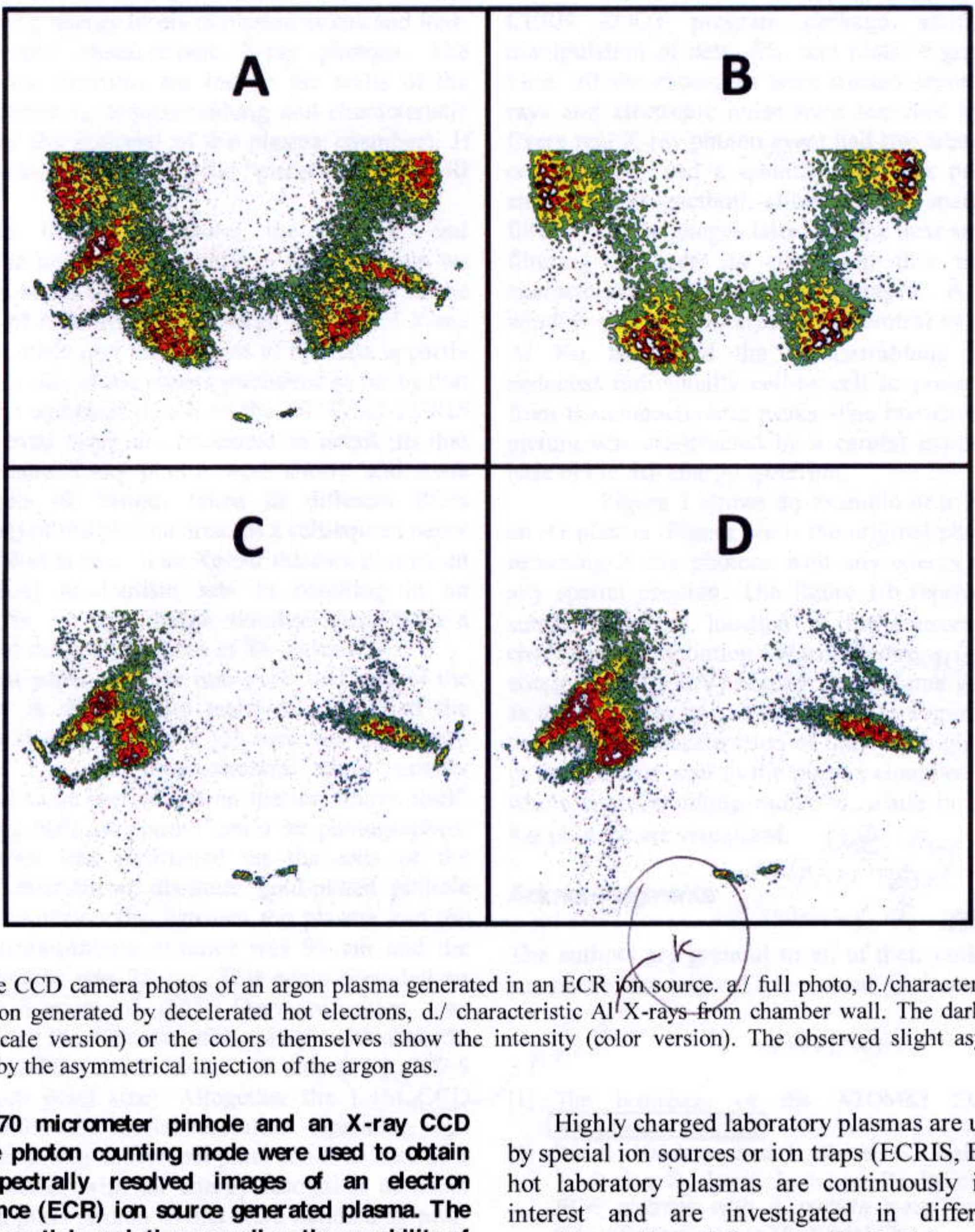

Fig. 1. X-ray pinhole CCD camera photos of an argon plasma generated in an ECR ion source. a./ full photo, b./characteristic Ar Kα X-rays, c/ Bremstrahlung radiation generated by decelerated hot electrons, d./ characteristic Al X-rays from chamber wall. The darker tone means higher photon density (grayscale version) or the colors themselves show the intensity (color version). The observed slight asymmetry of the X-ray distribution is caused by the asymmetrical injection of the argon gas.

Abstract **– A 70 micrometer pinhole and an X-ray CCD camera in single photon counting mode were used to obtain spatially and spectrally resolved images of an electron cyclotron resonance (ECR) ion source generated plasma. The method has good spatial resolution as well as the capability of post-processed energy filtering of the images. The X-ray images clearly show the spatial positions of different sources of the X-ray photons: bremsstrahlung, characteristic lines of the plasma ions, and X-ray emitted from the wall.**

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S. Biri [1], E. Takács [2], R. Rácz, [1,2], L. T. Hudson[3] and J. Pálinkás [2]
[1]Institute of Nuclear Research (ATOMKI), Bem tér 18/c, H-4026 Debrecen, Hungary
[2]Department of Experimental Physics, University of Debrecen, Egyetem tér 1, H-4032 Debrecen, Hungary
[3]National Institute of Standards and Technology, Gaithersburg, MD, 20899
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Highly charged laboratory plasmas are usually generated by special ion sources or ion traps (ECRIS, EBIT, etc). These hot laboratory plasmas are continuously in the center of interest and are investigated in different ways both experimentally and theoretically. In this paper we show X-ray photographs made of the plasma of an electron cyclotron resonance (ECR) ion source.

In ECR ion sources a strong magnetic trap confines the electrons, which keep together the ion component by their space charge. The electrons undergo a high energy gain through their interaction with the high intensity microwave radiation while the ions remain cold throughout the ionisation process. The energized warm electrons ionize and excite the deep lying energy levels of plasma atoms and ions, which in turn emit characteristic X-ray photons. The majority of the hot electrons are lost in the walls of the plasma chamber creating bremsstrahlung and characteristic X-ray photons (of the material of the plasma chamber). If one makes an X-ray plasma photo the "picture" at first will be very complex.

In order to better understand the creation and confinement of the ions and the details of the extraction we have performed a series of experiments in 2002/2003 in the ECR Laboratory of ATOMKI [1]. A large number of X-ray photos have been made and the analysis of the data is partly still in progress. In one of the papers published so far by that experiment [2] the technical details of the ATOMKI-ECRIS and the experimental setup are presented in detail. In that paper Xe+Ar plasma X-ray photos were shown and some additional analysis of images taken in different ROIs (region-of-interest) of the plasma area. In a subsequent paper [3] it was shown that in case of an Xe+Ar mixture plasma an evaporative cooling mechanism sets in resulting in an increase of the Xe average charge simultaneously with a slight shrinkage of the spatial extent of Xe plasma.

In the present paper a so far non-published part of the 2002 experiment is shown. The technical details of the experiment were shown elsewhere [2] here we just give a short summary. For the measurements some smaller modifications had to be carried out on the ion source itself. As a result, about 60% of plasma could be photographed. The X-ray camera was positioned on the axis of the beamline. A 70 micrometer diameter gold-plated pinhole was set on the beamline axes, between the plasma and the camera. The plasma-pinhole distance was 91 cm and the pinhole-CCD distance was 25 cm. This setup provided an average demagnification of 0.27. Demagnification was necessary because of the diameter of the plasma chamber (58 mm) and the size of the 1152x1242 CCD chip (25.9 x 27.5 mm with 22.5 μm pixel size). Altogether the 1.4M CCD camera permitted 0.1 mm spatial resolution. Operating with short exposure times, any individual pixel could be used as a single photon detector with an energy resolution of about 180 eV. Multiple pixel photon events were handled by post-experiment software analysis. The spectra were affected by window efficiency, the absorption edge of Si and above 15 keV, the fall-off of the detector sensitivity.

Argon plasmas with beam extraction were generated and axial X-ray images were taken together with extracted beam spectra. In order to be able to take full size images from the ECR-plasma that include the hot spots of the X-ray intensity the ion source had to be tuned to a low microwave power (40 W) optimizing mainly for Ar^{+} extraction. The exposure time for each image taken was 1 seconds. Altogether 1000 independent images were recorded and then summed together (resulting in a total acquisition time of 1000 x 1 s). The exposure time was experimentally adjusted such that only one (or zero) photon was allowed to hit any single pixel.

The analysis was mainly done by the well-known CERN ROOT program package, which allowed easy manipulation of data, fits, and plots of graphs and images. First, all the exposures were treated separately and cosmic rays and electronic noise were removed from each image. Every real X-ray photon event had two labels: its coordinates on the CCD and a quantity that was proportional to its energy. This method allowed easy spatial and spectral filtering of the images later on. The next step was an energy filtering in order to obtain in this case Ar and Al characteristic X-ray spatial images. A narrow energy window was applied around the central value of the Ar and Al Kα lines and the bremsstrahlung background was deducted individually cell-by-cell to preserve only photons from the characteristic peaks. The bremsstrahlung radiation picture was constructed by a careful exponential fit of the base of the full energy spectrum.

Figure 1 shows an example of a full-size image of an Ar plasma. Figure 1/a is the original photo containing all incoming X-ray photons with any energy originating from any spatial position. The figure 1/b represents the (axially summed) spatial location of the sources of the Ar Kα characteristic radiation. Warm electrons (with approximate energy of 3-10 keV) occupy nearly same geometric position as it was shown in a recent paper [4]. Figures 1/c and 1/d are the results of deceleration of the very high energy electrons in the metallic wall of the plasma chamber. In figure 1/c the whole bremsstrahlung radiation, while in figure 1/d the Al Kα photons are visualized.

Acknowledgments

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