STUDIES OF THE ECR PLASMA IN THE VISIBLE LIGHT RANGE

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Abstract

High resolution visible light (VL) plasma photographs were taken at the ATOMKI-ECRIS by an 8 megapixel digital camera. Plasmas were generated from gases of He, methane, N, O, Ne, Ar, Kr, Xe and from their mixtures. The analysis of the photo series gave many qualitative and numerous valuable physical information on the nature of ECR plasmas. It is a further challenging task to understand the colors of this special type of plasmas. The colors can be determined by the VL electron transitions of the plasma atoms and ions. Through the examples of He and Xe we analyze the physical processes which effect the characteristic colors of these plasmas.

INTRODUCTION

ECR plasmas can experimentally be investigated by two significantly different ways. Small-size electrostatic electrodes (Langmuir-probes) give local information on certain plasma parameters (density, potential) [1]. The other method is based on the fact that the plasma emits radiation in the infra-red (IR), visible light (VL), ultra-violet (UV) and X-ray (XR) regions of the electromagnetic spectrum. The main drawback of this method is that the recorded information always corresponds to integration or superposition over a specific line-of-sight in the plasma volume. In spite of this, the analysis of photos and spectra in any of these regions has shown that spatial imaging gives important and new insight into the plasma structure. XR-photons come from the walls of the plasma chamber or from the highly charged plasma ions. VL-photons however dominantly originate from atoms and low-charged ions excited by the cold electrons. Thus studying VL plasma photographs transforms information mainly on the spatial position and density distribution of the cold electrons.

As a continuation or supplement of our earlier successful X-ray studies [2] we made series of high-resolution VL plasma photos and movies in the ATOMKI ECRIS Laboratory. In [3] the effect of the basic setting parameters (gas pressure, magnetic field, microwave power) to the shape, color and structure of Ne, Ar and Kr plasmas were studied. In [4] the shape and intensity distribution of the VL-plasmas are compared with computer simulations and with XR-photos. The results and information presented in these two papers improve the understanding the ECRIS plasma. In the present paper a study is given on the colors of the ECR plasmas.

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EXPERIMENTAL SETUP

The technical details and the application fields of the ECR ion source of ATOMKI are shown elsewhere [5, 6]. The homepage of the ECR Laboratory [7] stores also lots of information and photos. The ATOMKI-ECRIS had to be partly re-constructed in order to take direct photos from the injection side. The extraction optical system was removed. The beamline was closed with a quartz vacuum window to observe the plasma in-situ. A mirror was placed at a distance of 100 cm from the plasma chamber in 45° angle in order to set the observers and the camera at a safe perpendicular 40 cm distance from the mirror and from the axes of the ion source. Two microwave amplifiers (14.3 GHz klystron and 8-12 GHz TWT) were connected to be used simultaneously or individually. The axial magnetic field was usually set 80% of its maximum value in order to form closed resonance zones in a wide range of frequencies so the typical peak values of the magnetic field were 0.88 Tesla. The pressure (measured in the injection box) was (2…5)*10^{-5} mbar when only one gas was injected. This pressure value is more than one order of magnitude higher than the optimal one for the production of highly charged ions, but corresponds to produce high current, singly charged beams by this ion source.

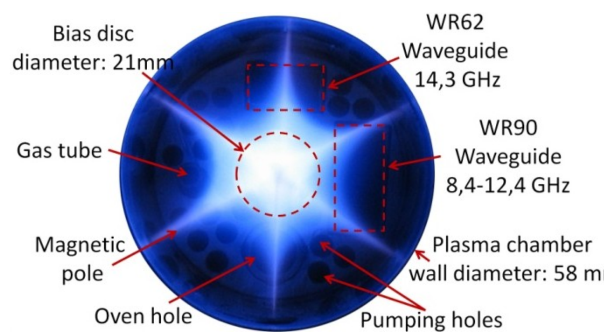

Figure 1. Typical axial image of the plasma. (Kr gas, microwave: 8.4 GHz, 10Wr, 2*10^{-5} mbar pressure) Plasma chamber, waveguides, bias disc, gas tube, oven hole, pumping hole can be seen.

When looking in the plasma chamber of an ECRIS the axial image of the plasma (Fig. 1.) in conformity with experimental setup can be seen. The photographs were taken by an 8 megapixel Canon digital camera. The ECR plasma is not an ideal photo model: its longitudinal length is about 20 cm, it is partly transparent and diffuse. To take systematically photo series we had to set manually the camera parameters. The typical exposure time was between 0.8 and 4 sec. Iris value was set to the maximum

R = 8 value. The minimum ISO value (80) was set to record the images with minimal noise.

After studying these photos and movies and observing the shape, structure and position of a high number of different kind plasmas, in one of our recent papers [3] we suggested that instead of "star" or "triangle" or "hexagon" the ECRIS-plasma would better be called "plasma-spider". Contrary to "normal" spiders this strange spider has only six legs: three at the injection side and another three at the extraction side, all originating from the middle plane region. The three arms or legs what we are seeing at both sides are fed by bunches of loss lines.

To obtain numeric information from such VL plasma pictures is possible only through the Analogue Digital Unit (ADU) values of pixels. ADUs store the color and intensity of the pixels.

THE COLOR OF THE PLASMAS

It is a challenging task to understand the color of different gas plasmas. We suppose that the plasma excitation is homogeneous throughout the VL region. The color of the plasma can be determined by visible light electron transitions (visible light energy spectrum) of plasma components (atoms and ions). According to the Schrödinger equation the excited atoms and ions emit photons with relative intensity and energy. Relative intensity of these spectral lines can be found in many handbooks. Through the example of Xenon and Helium we analyze the physical process which effects turquoise color of the Xenon plasma and pink color of the Helium plasma.

Fig. 2.a shows the VL-spectrum of the Xenon [8]. According to this spectrum we would expect violet or blue color Xenon plasma. However the human eye responds to electromagnetic radiation in the wavelength range from about 360 nm (violet) to 820 nm (red), with a peak sensitivity at near 555 nm (green). The detailed shape of this response curve depends on the individual person. Studies on representative samples of human subjects have led to adaption of a standard function relating the perceived brightness to the actual power of the spectral radiation.

This function (Fig. 2.b.) is the spectral luminous efficiency function, and it plays an important role in photometry. If we want to get real image from the color of the Helium and Xenon plasmas for the human eye, the intensity of the spectrum lines must be normalized with the spectral luminous efficiency function as it seen in Fig. 2.c.

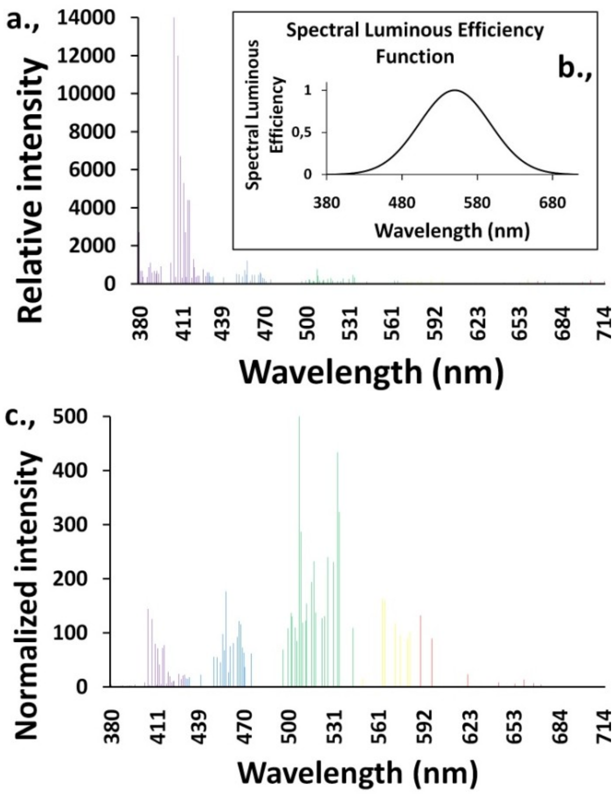

Figure 2. Xenon spectrum (a), the spectral luminous efficiency function (b) [8], Xenon spectrum normalized with spectral luminous efficiency function (c).

Any spectrum line assembly of a given gas can be decomposed to the primary colors (Red, Green, and Blue). Fig. 3.a. and 3.d. shows the decomposed spectrum [8] lines of Xenon and Helium. The normalized spectrum lines (like Fig. 2.c. in case of Xenon) were also decomposed to the primary colors and after that we got the complex light RGB values in case of Xenon and Helium (Fig. 3.b. and 3.e.). According to the Young-Maxwell-Helmholtz trichromatic theory (additive color mixing) calculated colors were created by a color mixing program using the RGB values. Fig. 3.c. and 3.f. show the Xenon and Helium plasma photos taken by us and the decomposed RGB values of these photos. There is a good visual agreement between the calculated normalised color and the real color of the plasmas and also between the RGB values of the decomposed normalized spectrum lines and of the photos. Thus this process is able to explain the color of ECR plasmas.

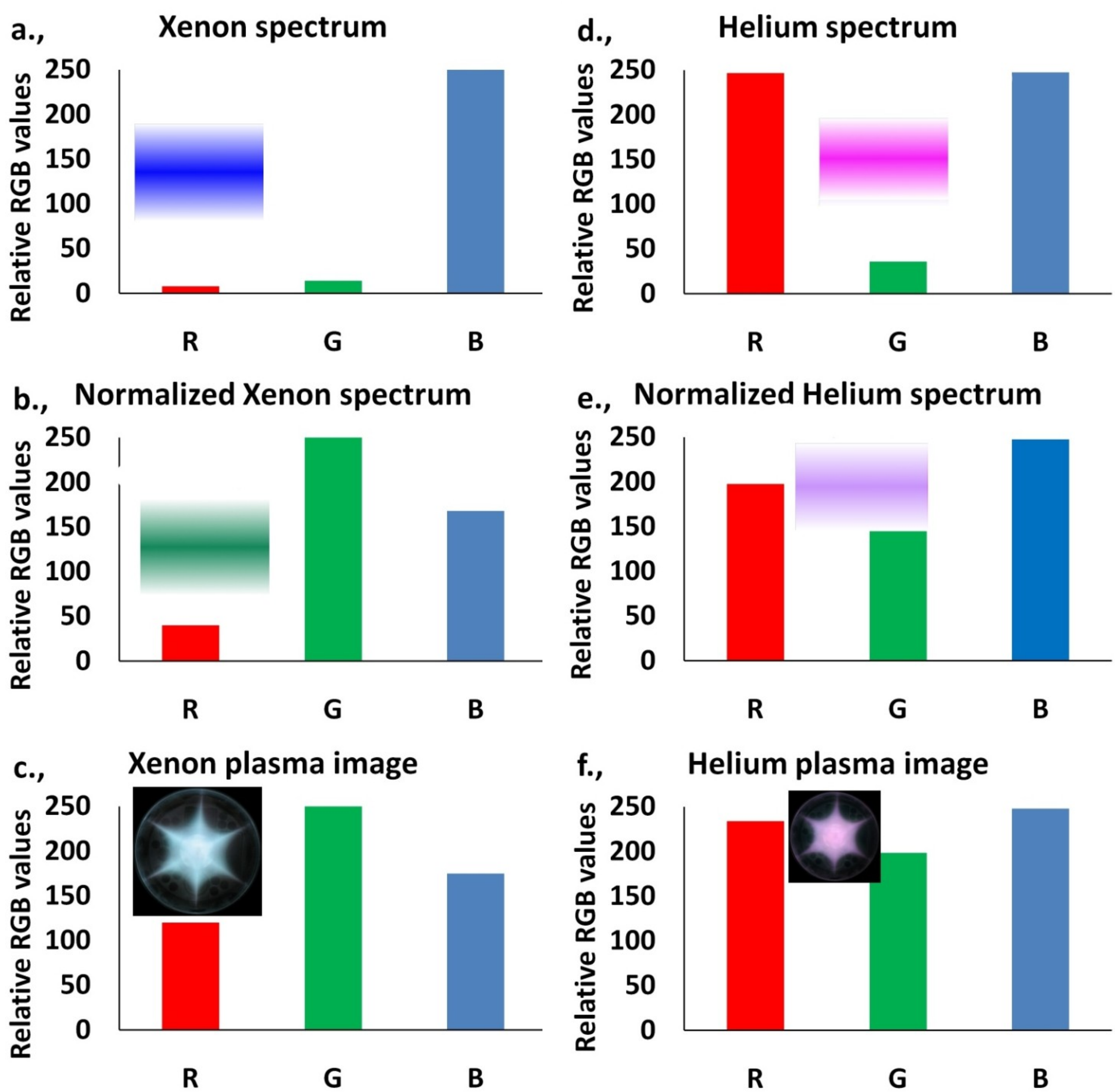

Figure 3.The original spectrum lines of Xenon (a) and Helium (d) and the normalized lines were decomposed to the primary colors (b, e) to get the RGB values. The insections show the superposition of the RGB values (a, d, b, e). 3.c. and 3.f. show the original Xenon and Helium plasma photos and the RGB values of these photos.

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