Photoionized plasmas induced using EUV sources driven by nanosecond laser pulses

A. Bartnik, W. Skrzeczanowski, P. Wachulak, I. Saber, H. Fiedorowicz, T. Fok, Ł. Węgrzyński

Institute of Optoelectronics, Military University of Technology, Kaliskiego 2, 00-908 Warsaw, Poland

Motivations

Our main activity:

- development of laser-plasma soft X-ray and extreme ultraviolet sources
- research on interaction of intense SXR and EUV pulses with solids or gases

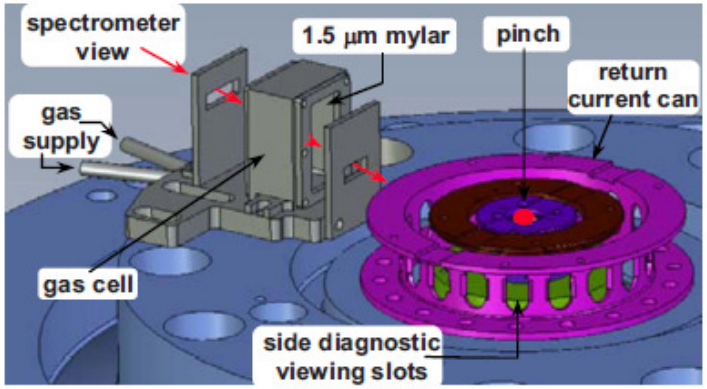
Our research interests:

- EUV and SXR imaging
- radiobiology
- micromachining and surface modification of polymers
- photoionization experiments
  - laboratory astrochemistry (planetary atmospheres)
  - laboratory astrophysics
  - warm dense matter
  - EUV + plasma surface treatment

Introduction - laboratory astrophysics

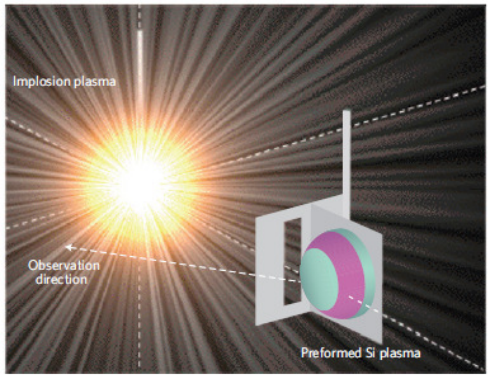
Photoionized plasmas – experiments using High Energy Density facilities (HED)

Z accelerator at Sandia National Laboratories
X-ray pulse - 1.5 MJ/5 ns

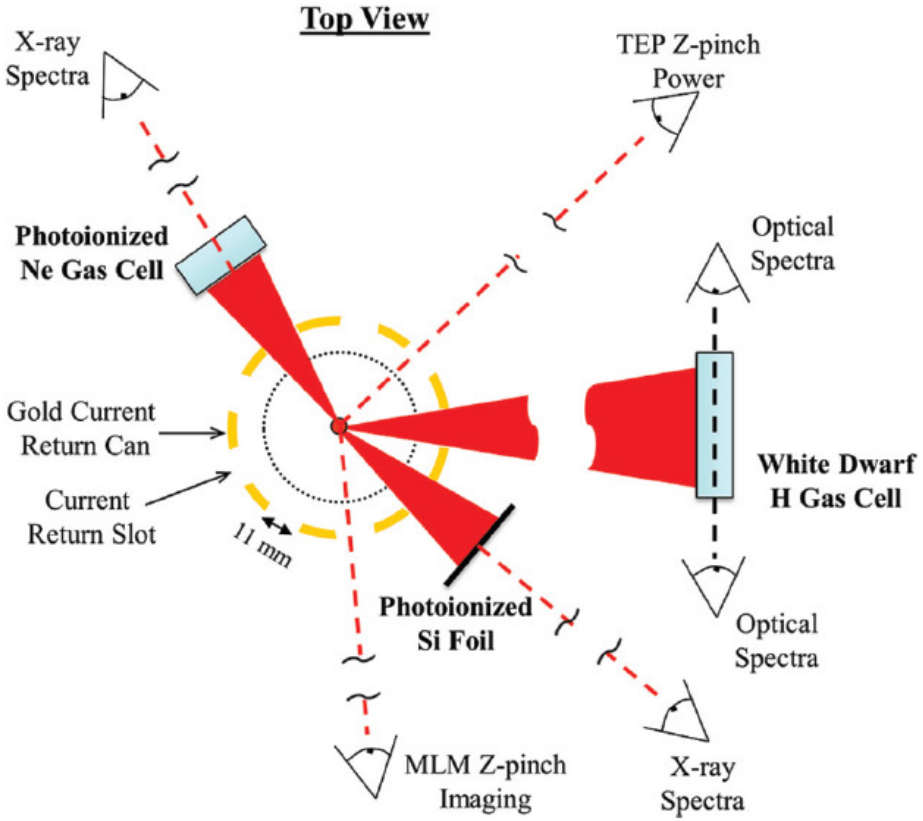


Mancini, R.C. et al. Phys. Plasmas 16, 041001 (2009)

12 beams from the GEKKO-XII
4 kJ of total energy at 1.2 ns

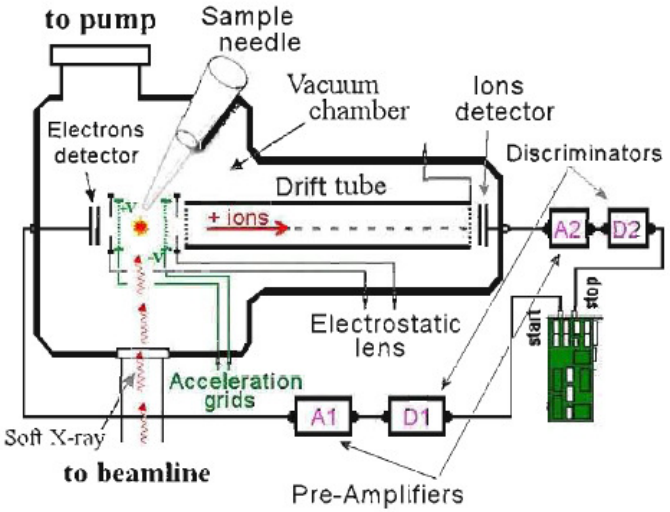


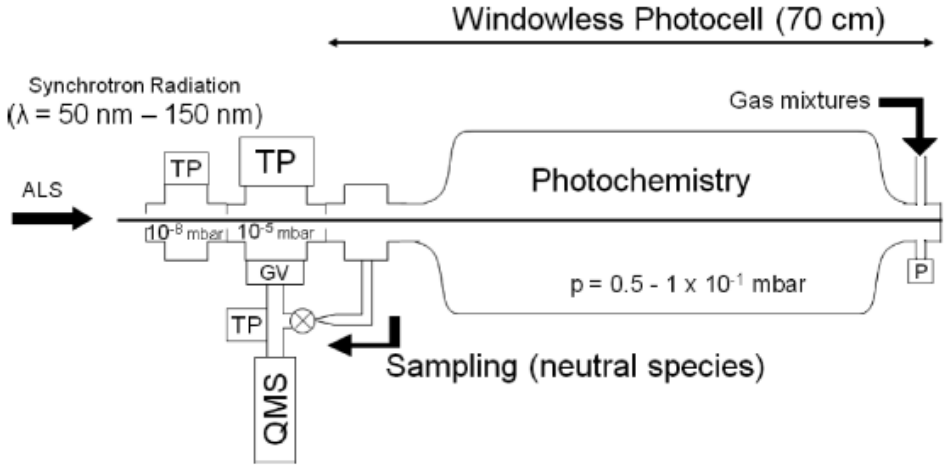
Fujioka, S. et al. Nature Phys. 5 (2009) 821-825



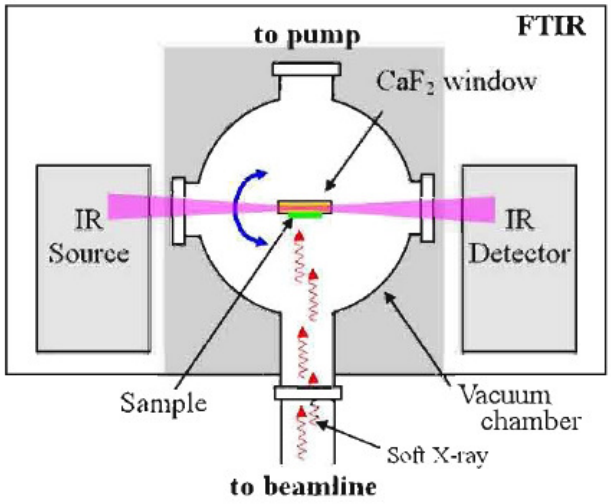
G. A. Rochau et al. The Z Astrophysical Plasma Properties collaboration, Phys. Plasmas 21, 056308 (2014)

Introduction - laboratory astrochemistry

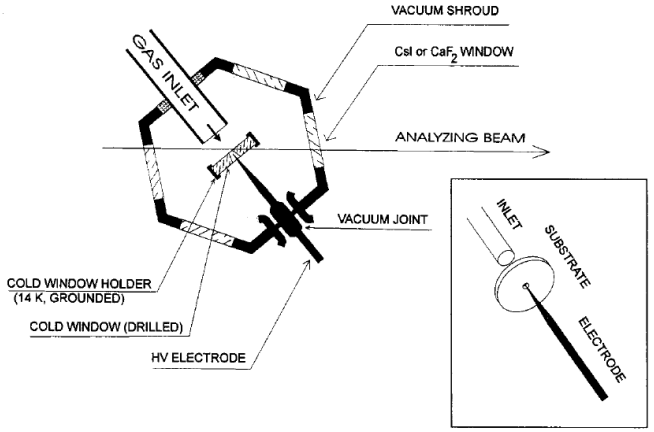




S.I. Ramirez et al. Organic chemistry induced by corona discharges in Titan's troposphere: Laboratory simulations, Advances in Space Research 36 (2005) 274–280



S. Pilling et al., Photostability of gas- and solid-phase biomolecules within dense molecular clouds due to soft X-rays Mon. Not. R. Astron. Soc. 411, 2214-2222 (2011)

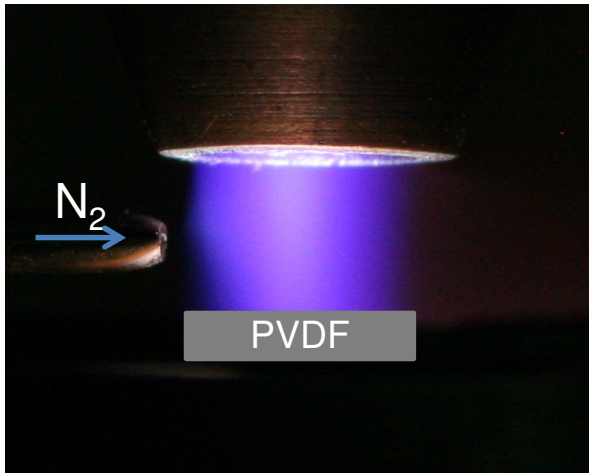


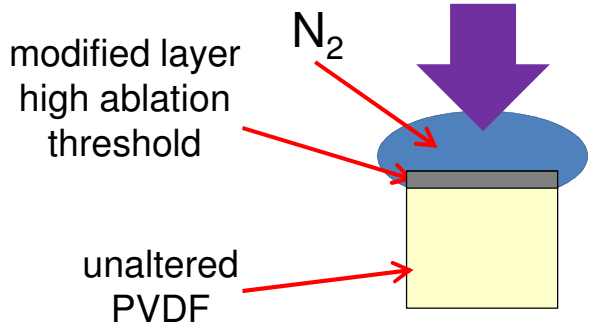
R. Kołos, A novel source of transient species for matrix isolation studies, Chemical Physics Letters 247, 289-292 (1995)

Introduction - photoionized plasma for surface treatment

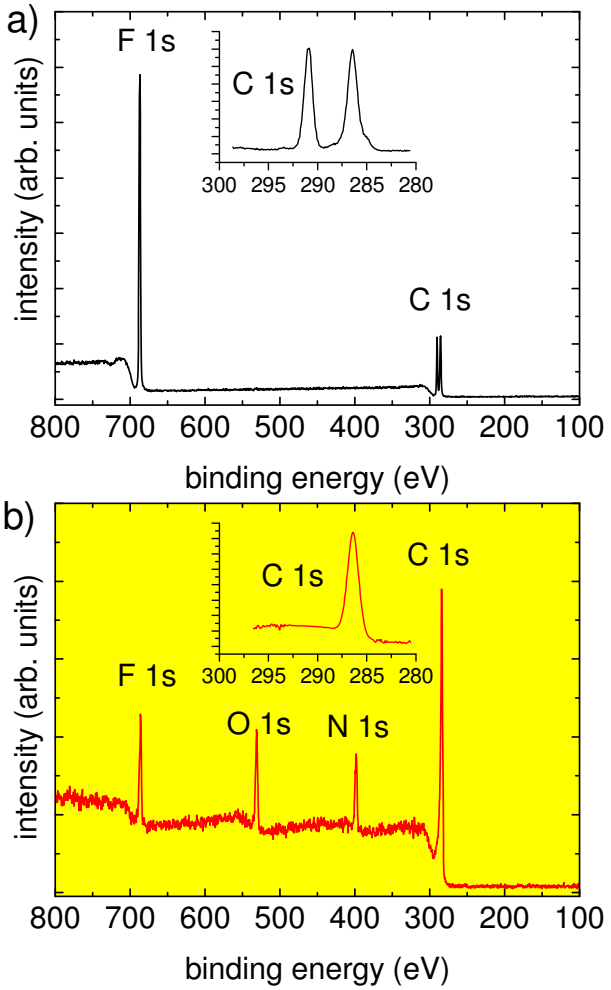
Photoionized plasma created using laser – produced plasma EUV source

EUV + photoionized
N – plasma treatment



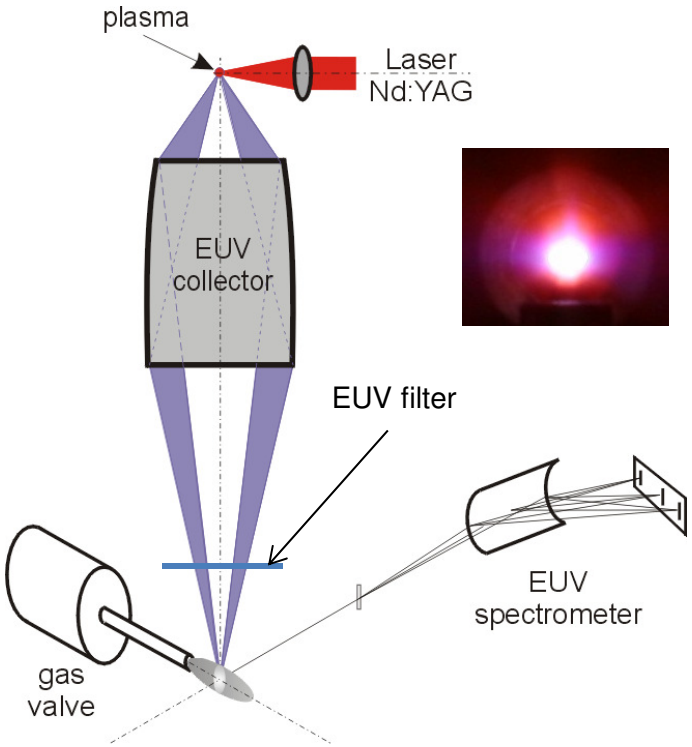


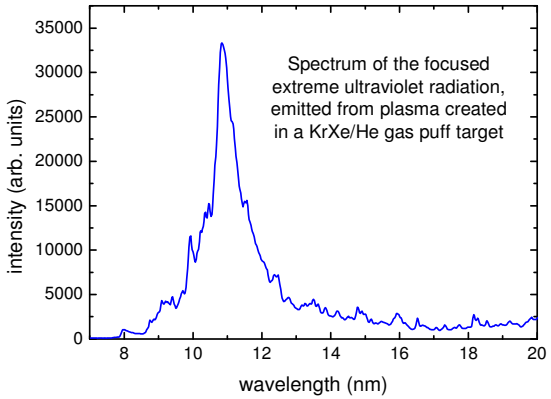
A. Bartnik et al., Appl Phys A 109, 39-43 (2012)



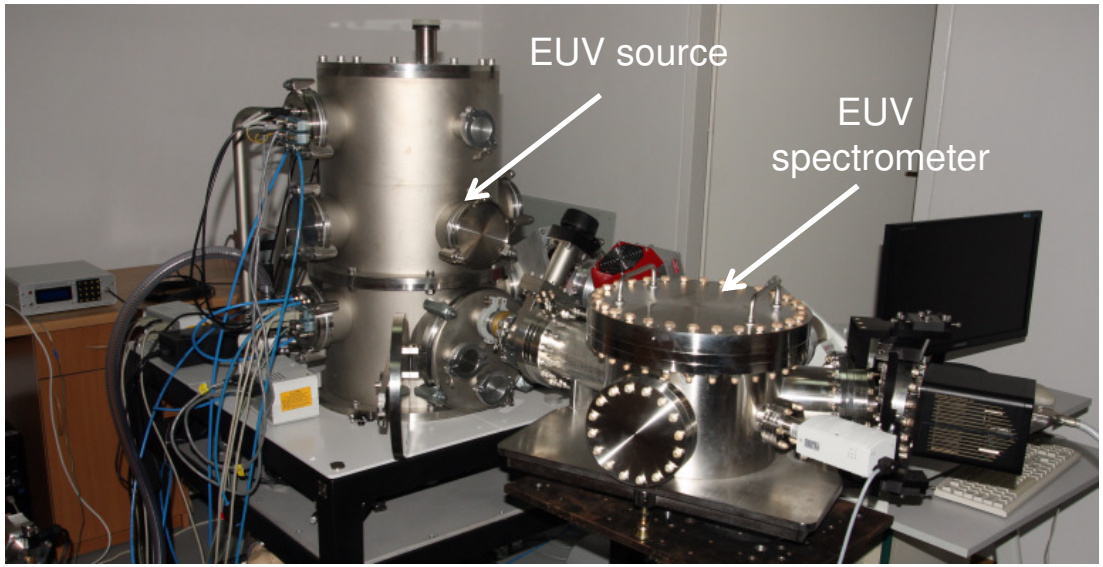
XPS measurements of PVDF surface:
a) Pristine sample, b) after treatment

Laser produced plasma EUV source: 0.8 J / 4 ns laser



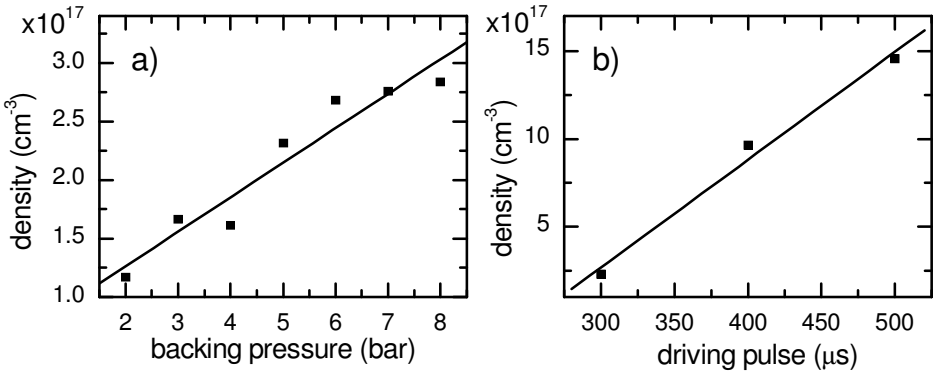


EUV spectrum



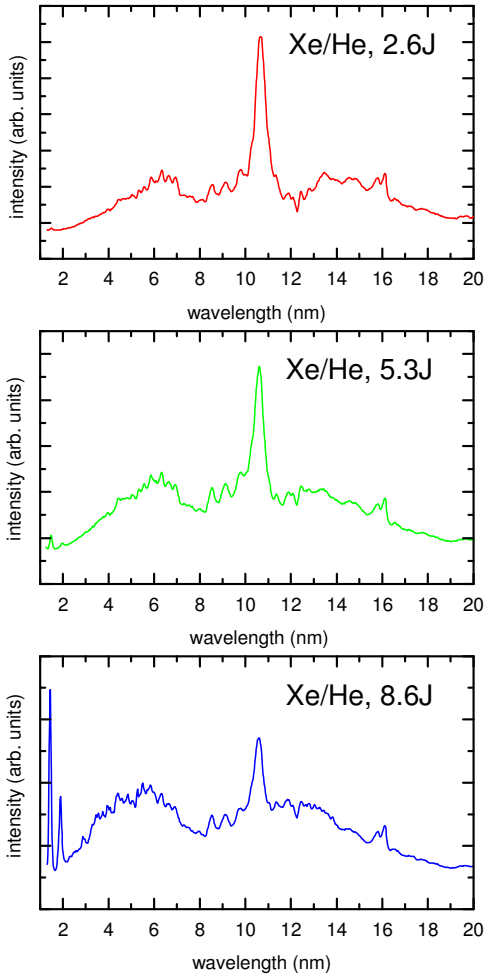
Maximum fluence:

Kr/Xe plasma ~ 75mJ/cm^2, Xe plasma ~ 130 mJ/cm^2

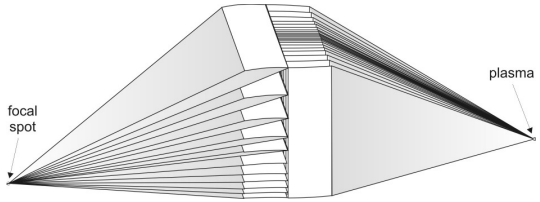


Particle density of the irradiated gas vs. backing pressure inside the injecting valve (a), and time duration of the driving pulse (b)

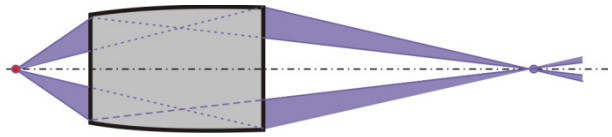
Laser-plasma produced EUV source: 10 J/ 10 ns laser system



SXR/EUV spectra from Xe plasma

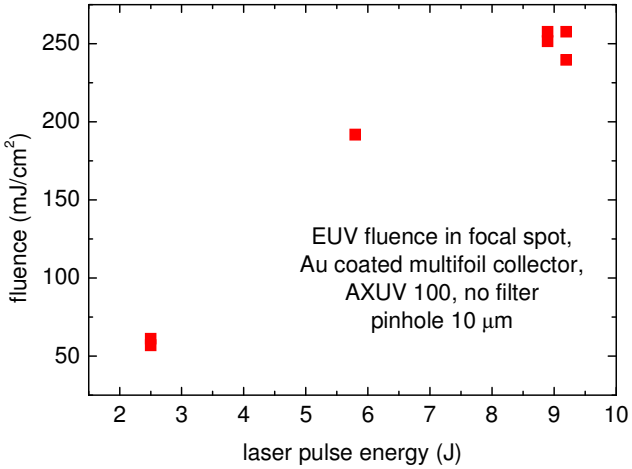


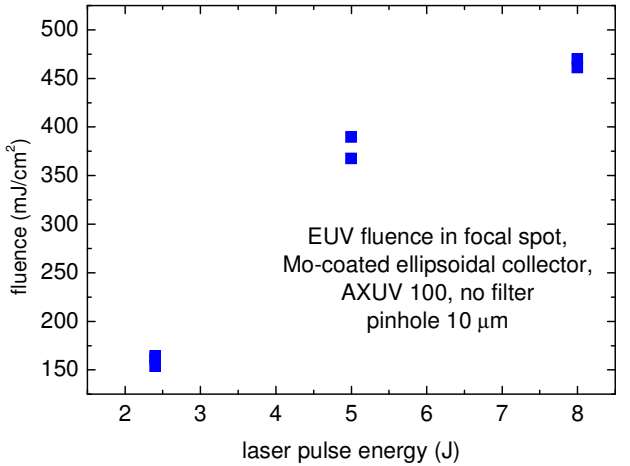
SXR/EUV focusing: Multifoil collector



EUV focusing: Mo-coated ellipsoidal collector

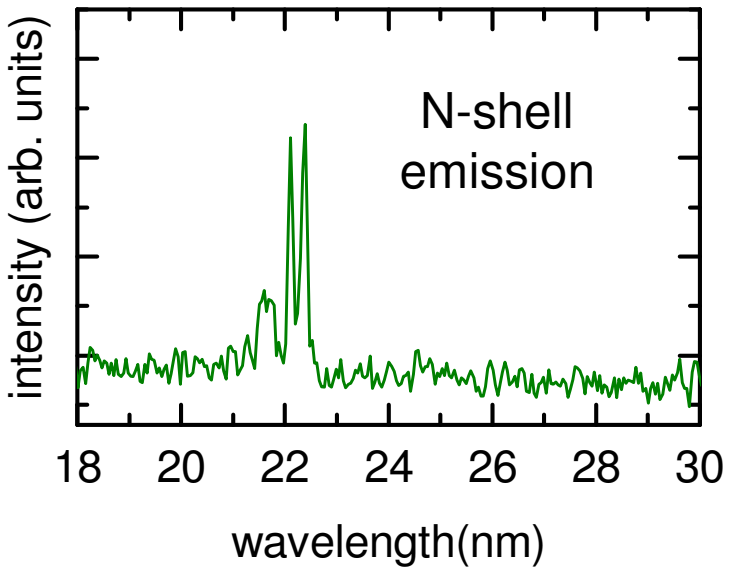
A. Bartnik et al., Phys. Scr. T161 (2014) 014061

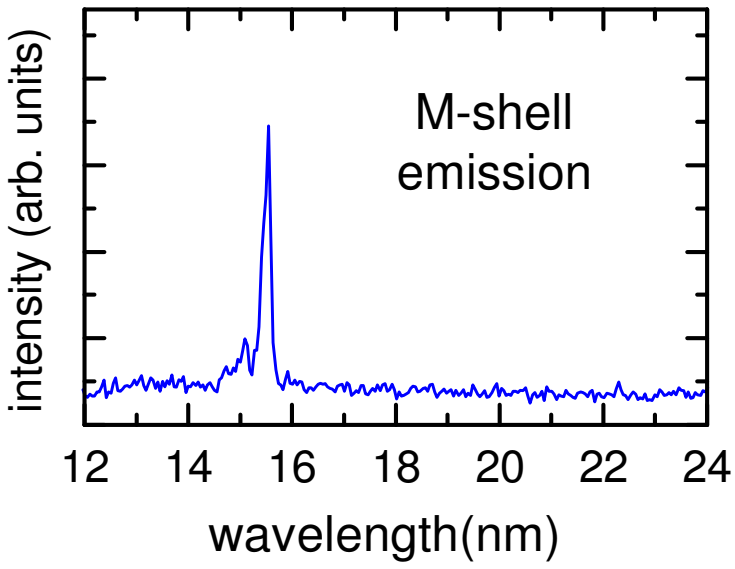




Fluence of the focused SXR/EUV radiation

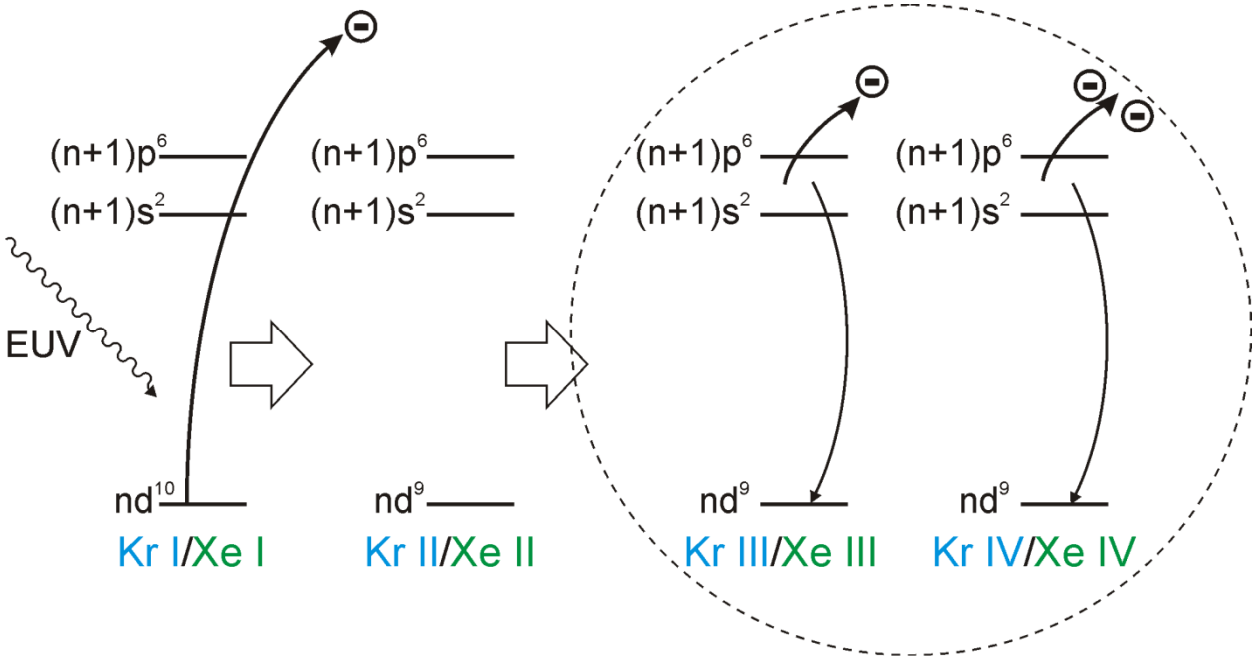
EUV induced photoionized plasma: Xe II, Kr II inner shell emission





Electron density estimation based on the absolute inner shell emission

$n_e > 10^{15} cm^{-3}$



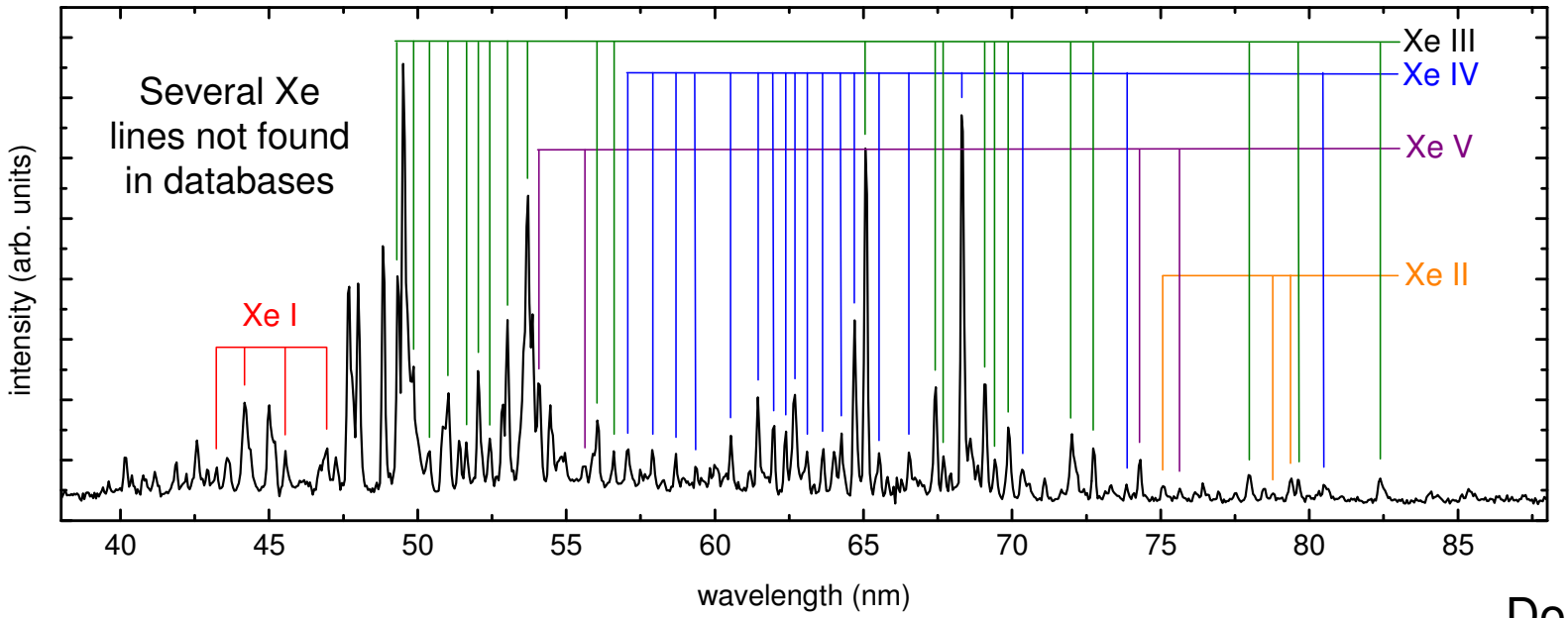
For krypton ions:

n= 3

For xenon ions:

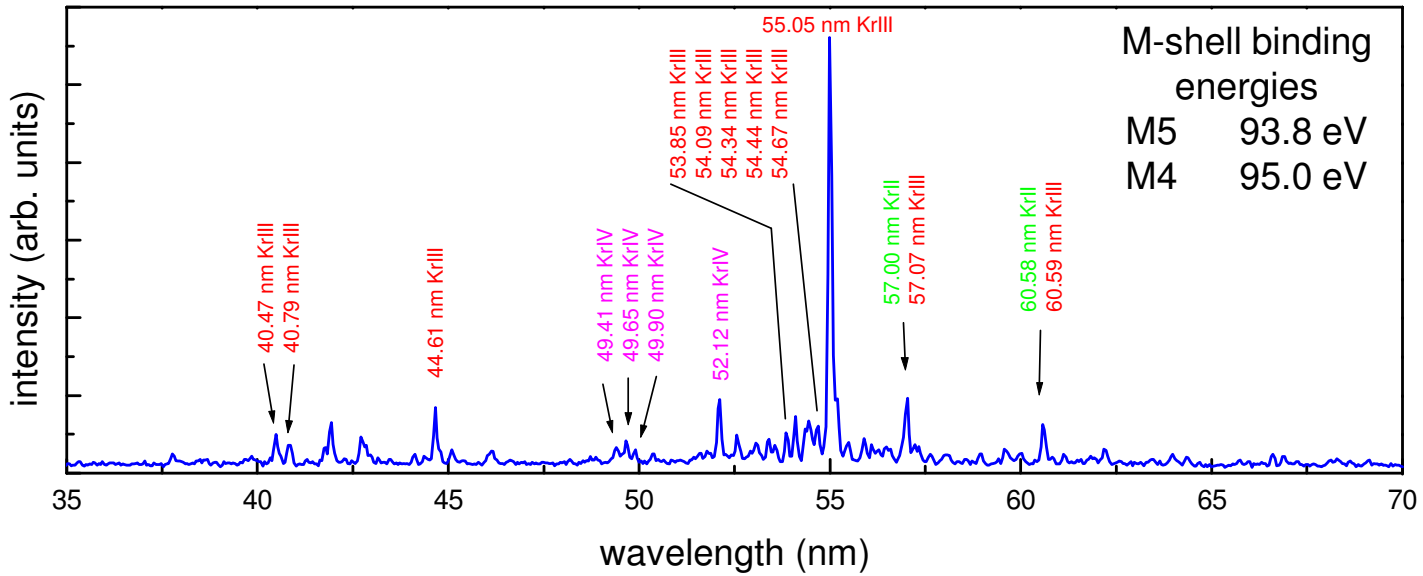
n = 4

EUV induced photoionized plasma: Xe, Kr EUV spectra



N-shell binding energies

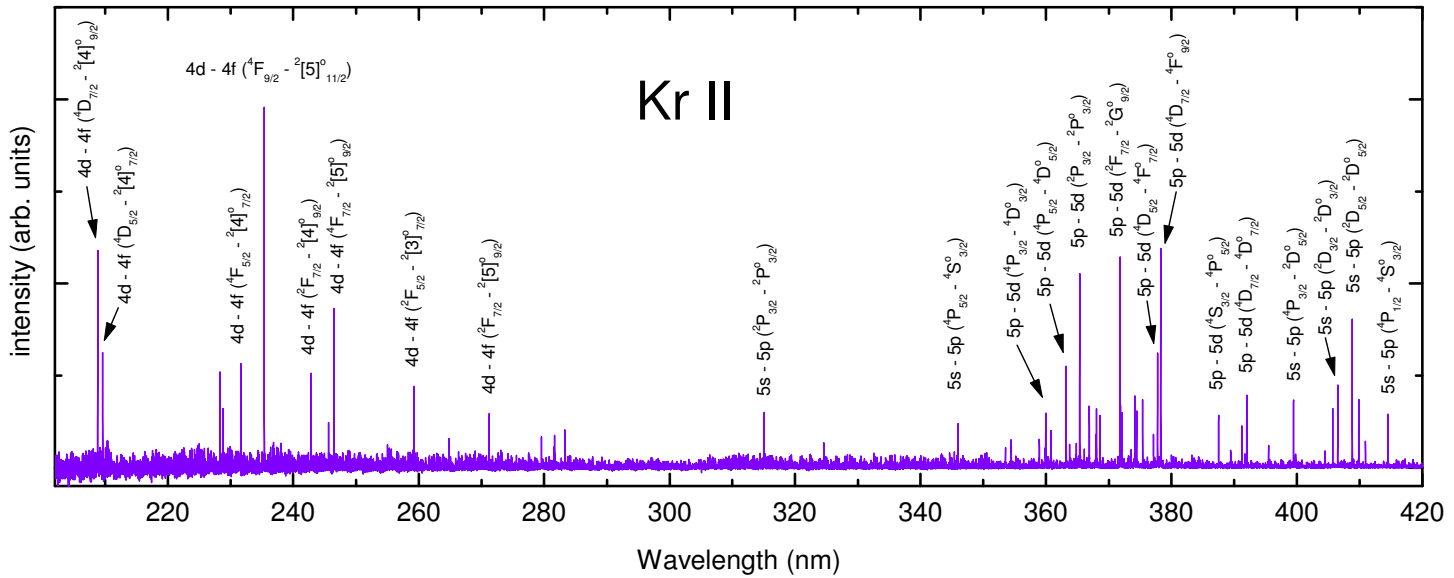
N5	67.5 eV
N4	69.5 eV

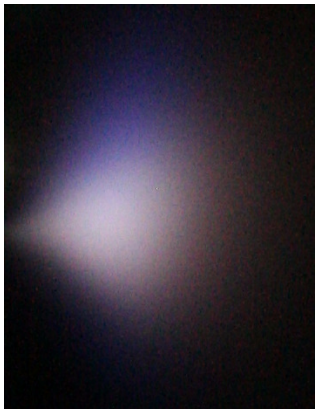


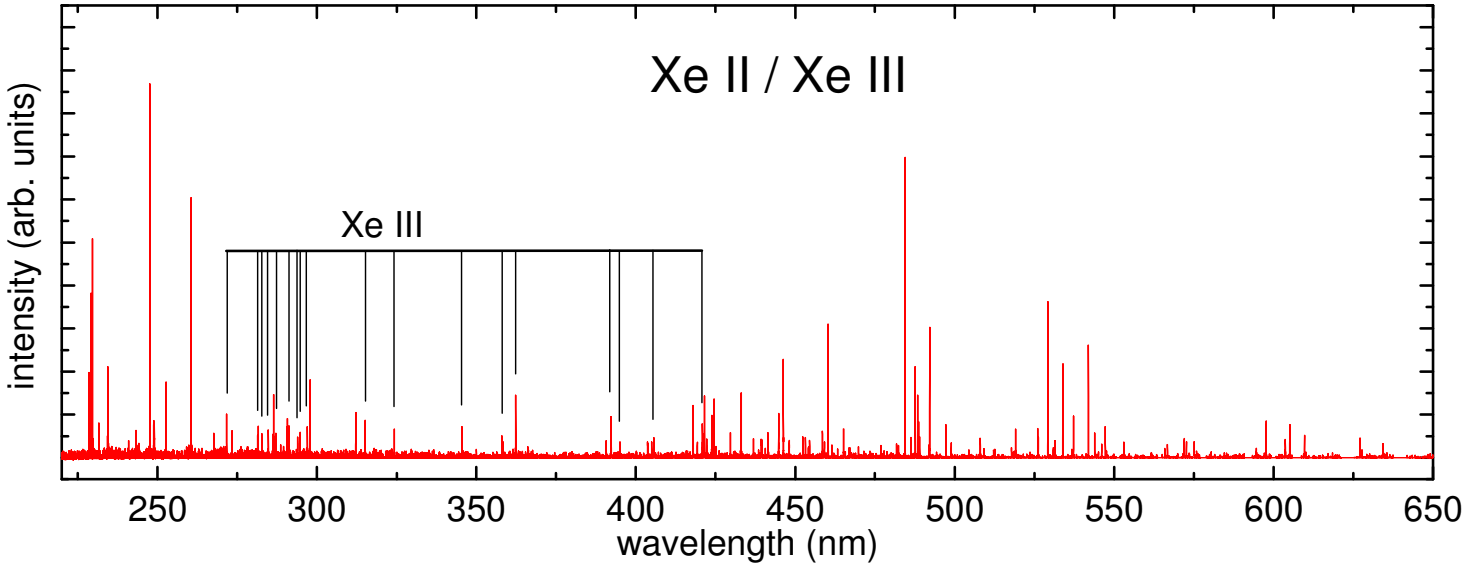
Dominating Xe III-IV and Kr III lines

Xe III – IV and Kr III - IV ions produced due to Auger effect

EUV induced photoionized plasma: Xe, Kr; UV/VIS spectra

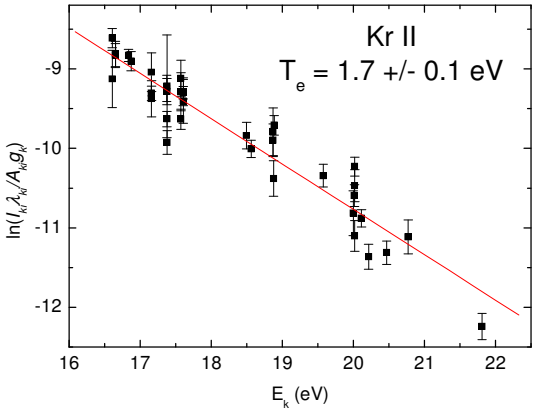


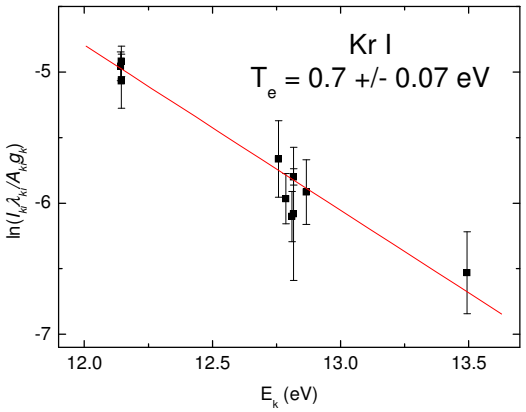




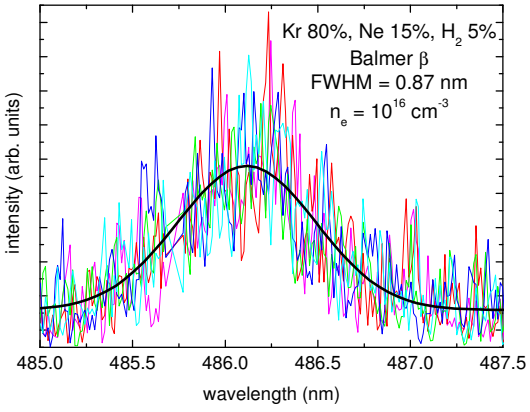
Dominating Xe II and Kr II lines, Xe III lines also detected

EUV induced photoionized plasmas: T_e and n_e estimation

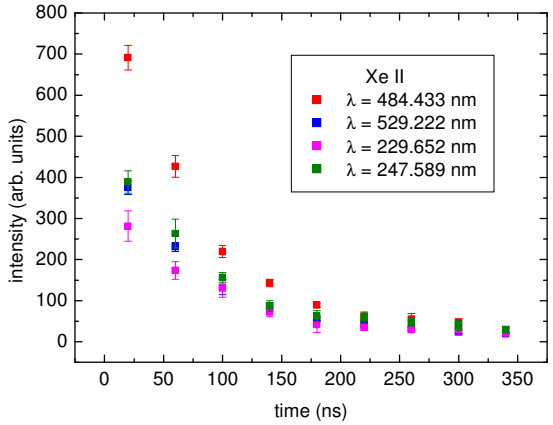




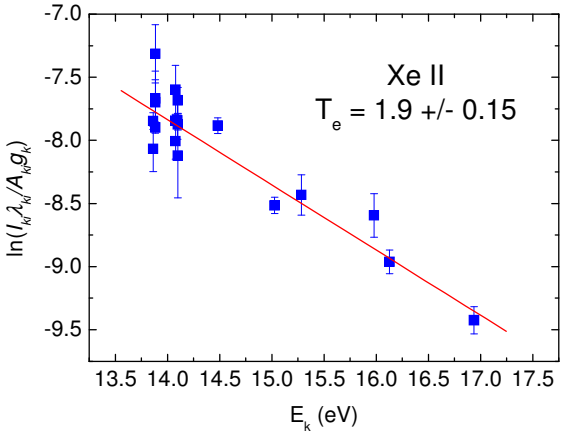
Boltzmann plots for **Kr I-II** emission lines, based on spectral measurements in UV/Vis ranges



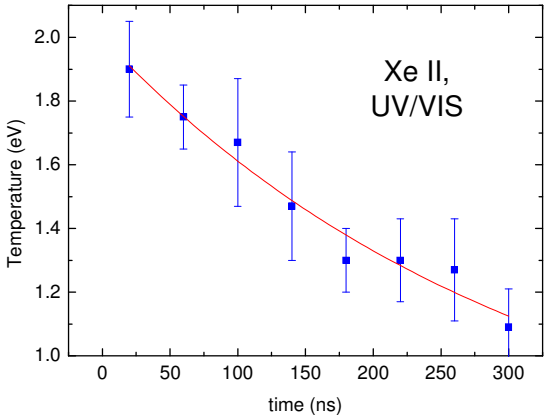
Electron density, based on Stark broadening of Balmer β line



Time dependence of selected **Xe II** emission lines

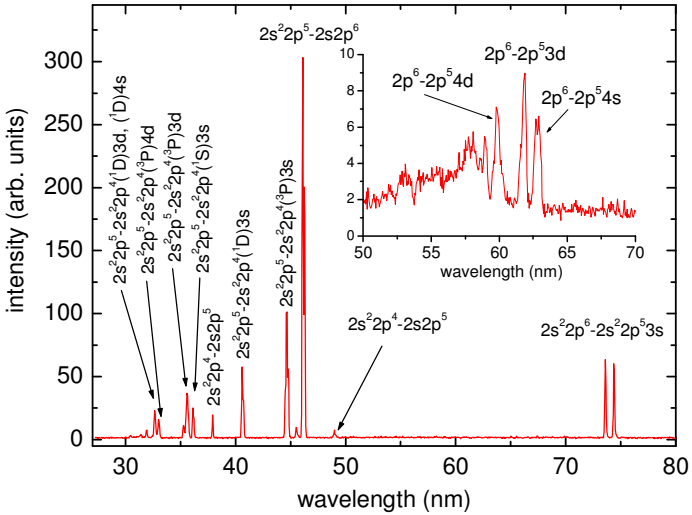


Boltzmann plot for **Xe II** emission lines, measured in UV/Vis range

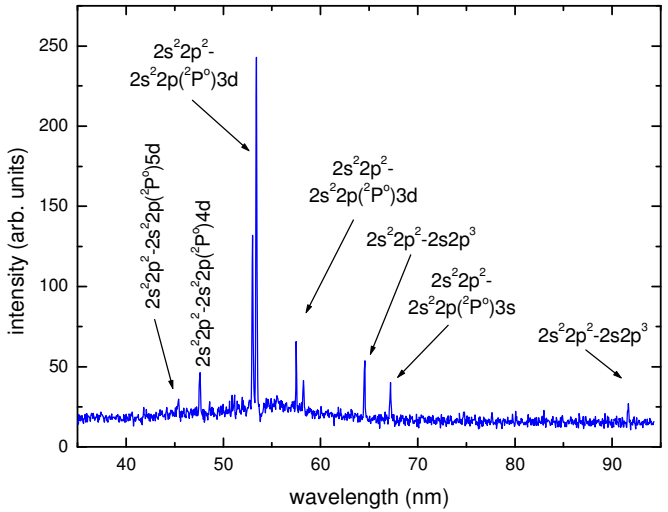


Time dependence of electron temperature based on **Xe II** UV/VIS emission spectra

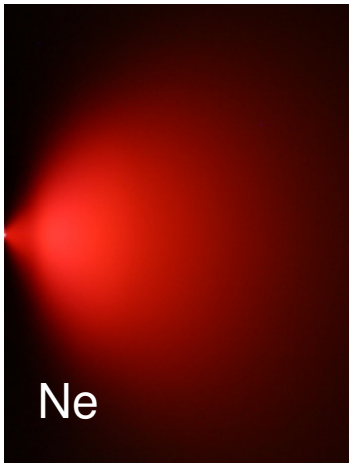
EUV induced photoionized plasmas: Ne and molecular gases



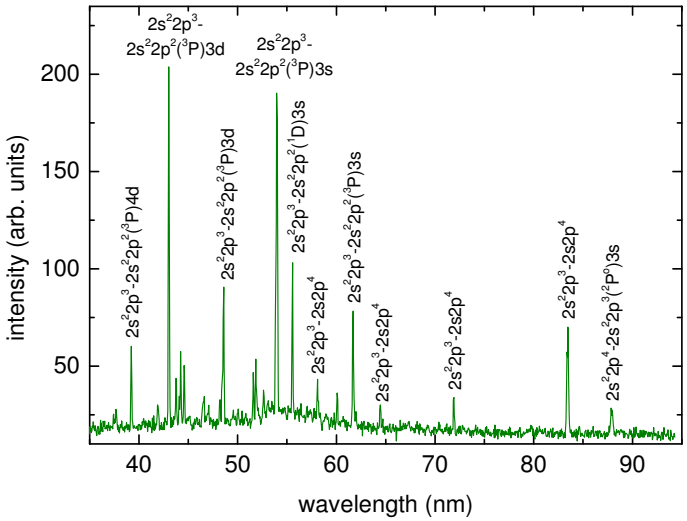
Ne: aquisition for 100 EUV pulses



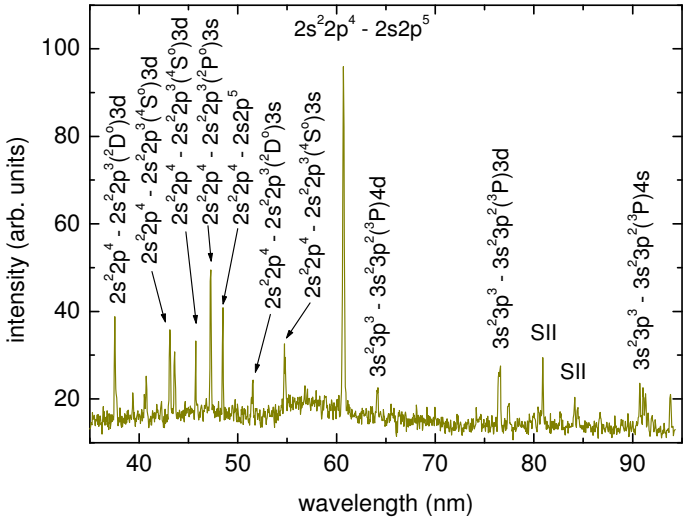
N_2: aquisition: 4000 EUV pulses



Optical images of photoionized plasmas



O_2: aquisition: 4000 EUV pulses

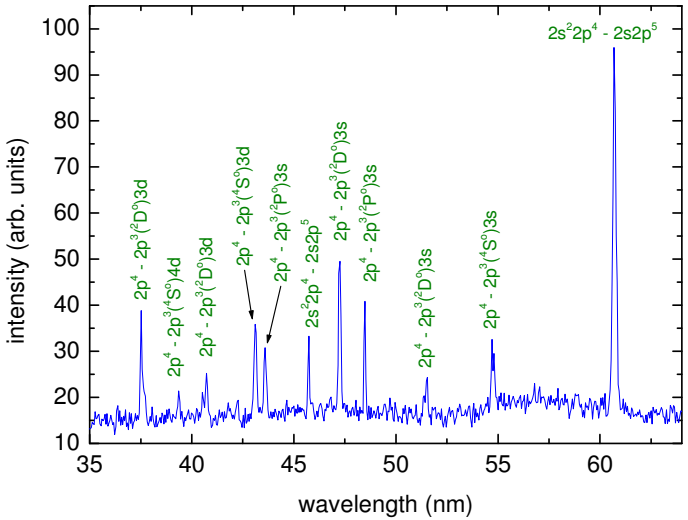


SF_6: aquisition: 4000 EUV pulses

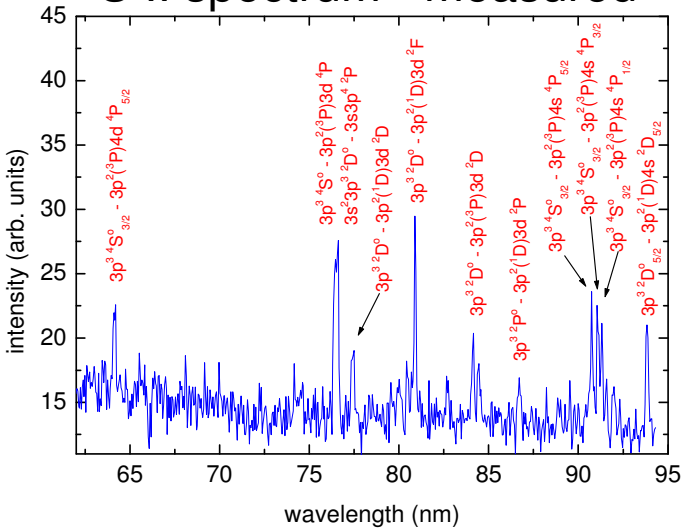
A. Bartnik et al, Physics of Plasmas 21, 073303 (2014)

SF_6 photoionized plasma

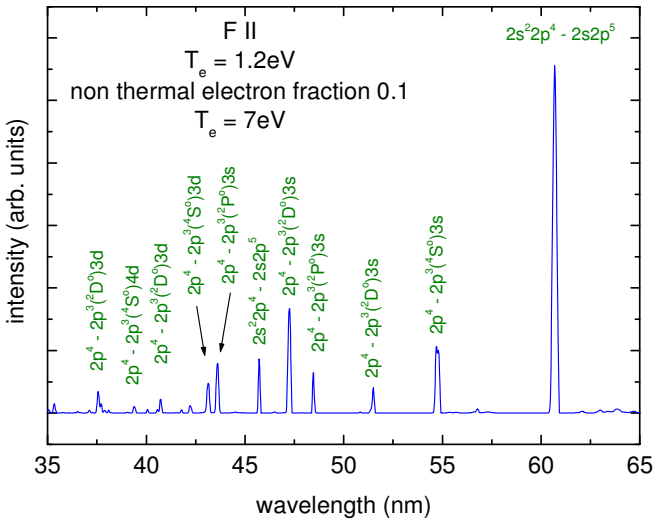
F II spectrum - measured



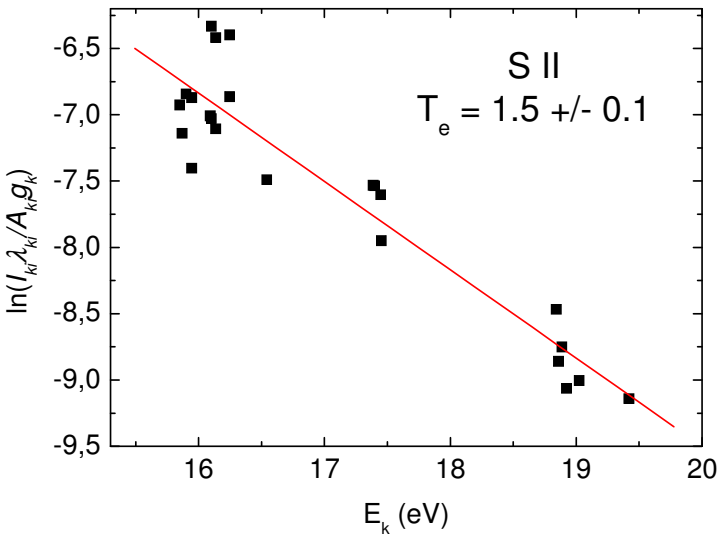
S II spectrum - measured



F II spectrum - PrismSPECT

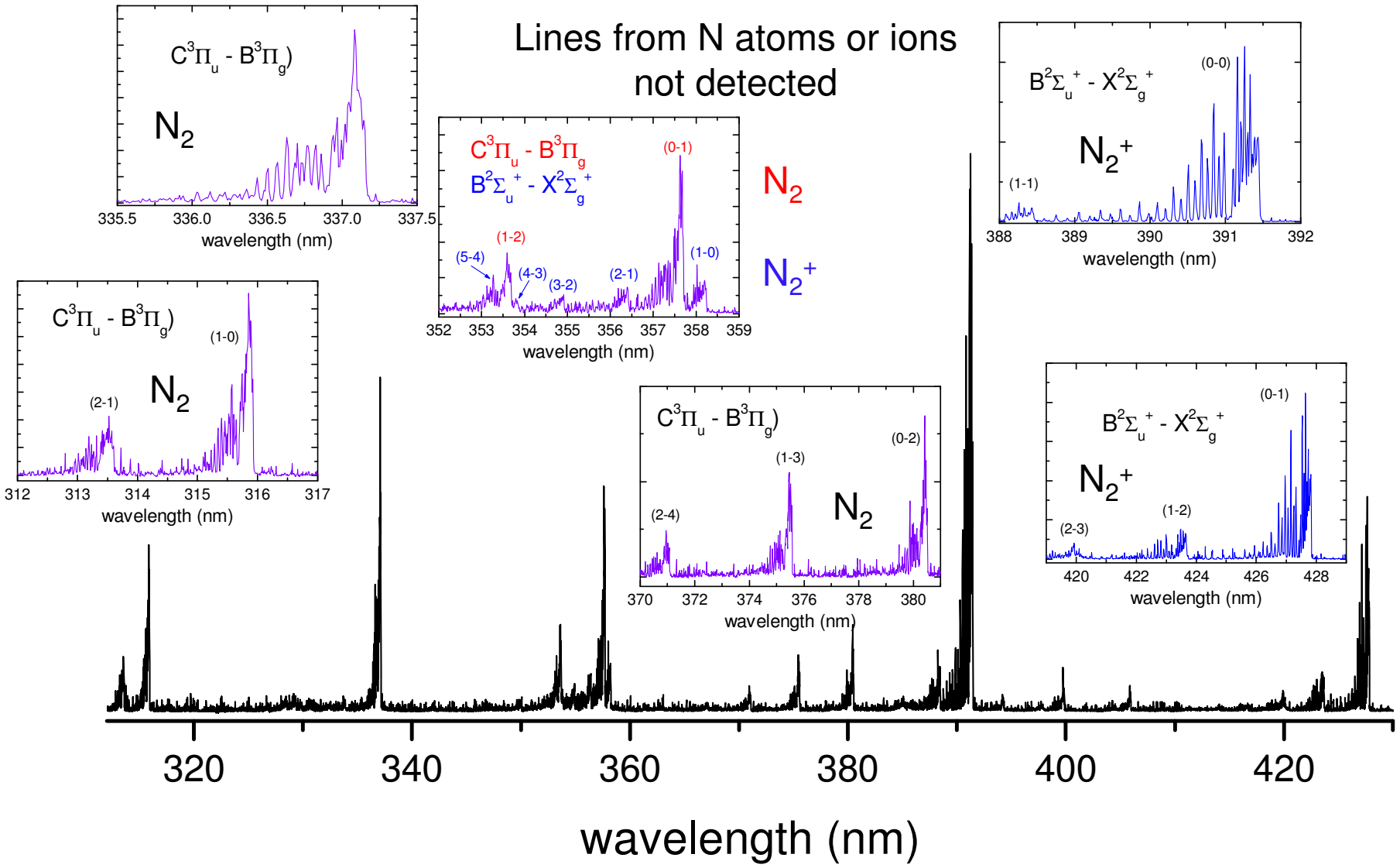


S II Boltzmann plot

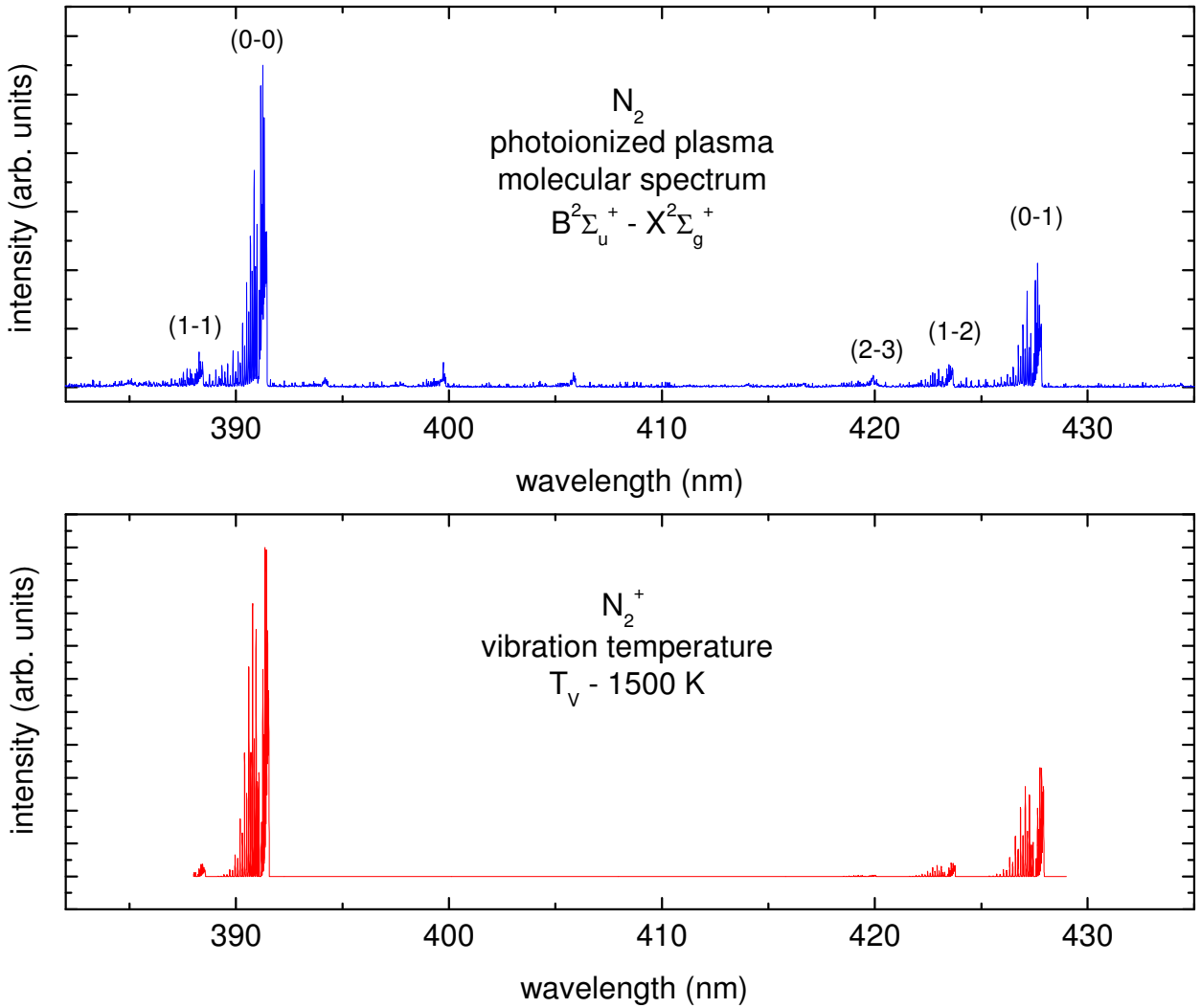


N_2 – optical spectra

Photoionized plasma created in nitrogen. 1 min./10 Hz exposure



N_2 – optical spectra



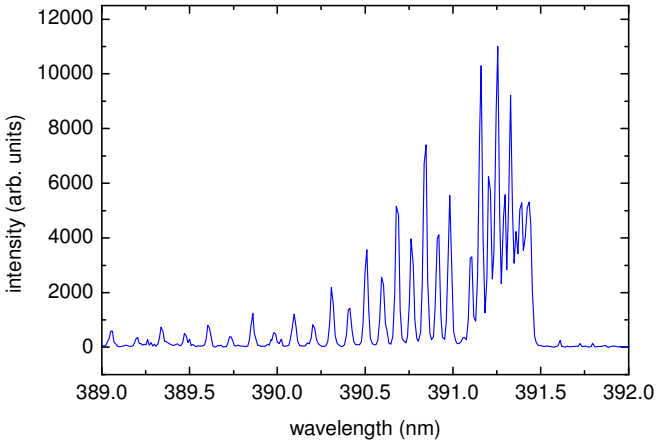
Experimental spectrum, 1min./10 Hz exposure

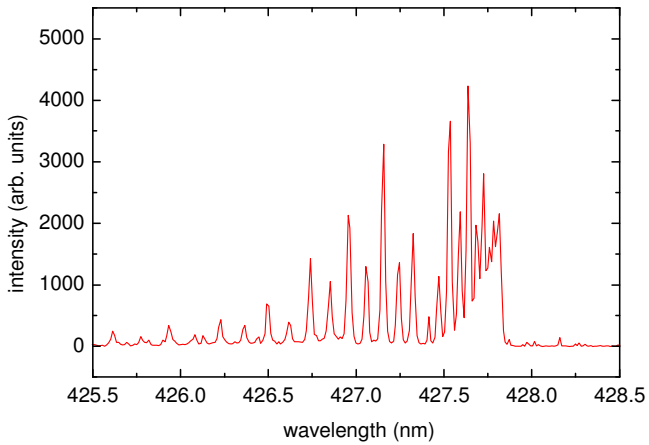
Simulated spectrum using a LIFBASE code

J. Luque and D.R. Crosley, "LIFBASE: Database and spectral simulation (version 1.5)", SRI International Report MP 99-009 (1999)

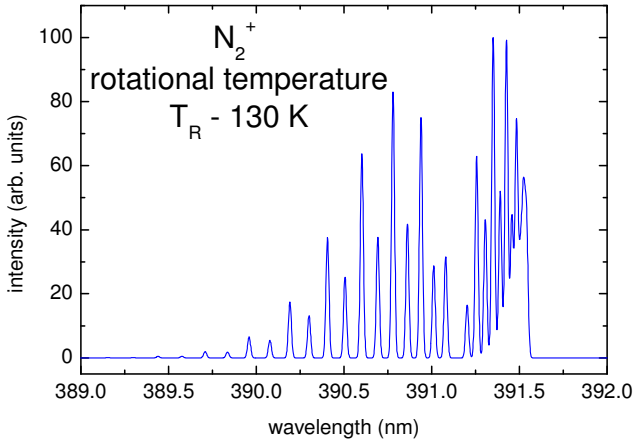
N_2 – optical spectra

Experimental spectrum,
1min./10 Hz exposure

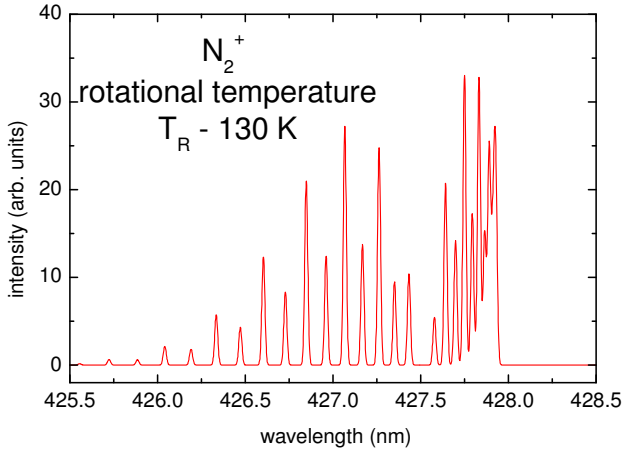




Simulated spectrum
using a LIFBASE code



$B^2\Sigma_u^+ - X^2\Sigma_g^+$
0 - 0



$B^2\Sigma_u^+ - X^2\Sigma_g^+$
0 - 1

J. Luque and D.R. Crosley, "LIFBASE: Database and spectral simulation (version 1.5)", SRI International Report MP 99-009 (1999)

Summary

- photoionization experiments using the LPP EUV sources were demonstrated
- inner shell processes were described and their influence on plasma formation was indicated
- examples of spectra originating from photoionized plasmas induced in atomic and molecular gases were shown
- from EUV and UV/Vis spectra strong contribution of molecular processes in photoionized plasmas was indicated
- electron and ion temperatures from emission spectra were estimated

ACKNOWLEDGEMENTS

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