SAND2008-1191C

Theoretical X-ray/EUV Spectroscopy and Imaging Studies of Wire Array and X-pinch Plasmas

A. S. Safronova, *N.D. Ouart, M.F. Yilmaz, P.G. Wilcox, G. C.Osborne*
V.L. Kantsyrev, U.I. Safronova, A. A. Esaulov, *K. Williamson, I. Shrestha*
Physics Department, University of Nevada, Reno, NV

J. B. Greenly, K. M. Chandler, *R. D. McBride, D. A. Chalenski*, D. A. Hammer,
B. R. Kusse, *Laboratory of Plasma Studies, Cornell University*

C. A. Coverdale, D.J. Ampleford, B. Jones

Sandia National Laboratories, Albuquerque, NM

NNSA Symposium

(Washington DC, February 26-28, 2008)

Sandia National Laboratories

Graduate students in Theoretical Plasma Spectroscopy group

Nicolas D. Ouart was born on April 13, 1981 in Chesterfield, Missouri. He received B.S. degrees in Electrical Engineering and Engineering Physics from the University of Nevada, Reno in 2004. He is currently a PhD graduate student at the physics department of the same university. He is working on modeling of radiation from z- and x-pinch plasmas.

M. Fatih Yilmaz was born on Nov. 8, 1977 in Kirikkale, Turkey. He received the B.S. degree in Physics from the University of Balkesir, Turkey. Since 2002, he is a PhD graduate student at the Physics department of the University of Nevada, Reno. He is working on modeling of radiation from z-pinch and x-pinch plasmas and MHD.

Penka G. Wilcox was born in Burgas, Bulgaria. She received her MS in Physics and Math from Plovdiv University, Bulgaria. Since Fall 2003 she is working on her Ph.D. at the Physics Department of UNR. Her research focuses on modeling of EUV radiation from low-Z plasmas.

Glenn Osborne was born in Walnut Creek, California, on April 28th, 1982. He received his B.S. degree in Physics in 2005 from the University of Nevada, Reno, where he is currently working on his Ph.D. at the Physics Department. He is doing theoretical and experimental work on x-ray spectroscopy of z- and x-pinches.

THE MAIN DIRECTION OF OUR WORK…

- **The main direction of our work is development of the non-LTE kinetic models and codes to describe x-ray and EUV radiation from Z-pinch plasmas and their application to the modeling of radiation produced at *1 MA Z-pinch generators, Zebra at Nevada Terawatt Facility of University of Nevada, Reno and Cobra at Cornell University.***

- **K- and L-shell plasmas from wire arrays with 6-26 wires as well as X-pinch plasmas produced on *1 MA University-scale Zebra or Cobra* have comparable characteristics (temperature and density) with those from *SNL-Z* wire arrays with 200-300 wires and because of smaller mass can provide more optically thin lines available for diagnostics.**

OUTLINE

- **Development of non-LTE kinetic models to describe radiation from Z-pinch and X-pinch plasmas**

- **Application of the models to study radiative properties and implosion characteristics of Planar Wire Arrays on the 1 MA Zebra at the NTF/UNR including the study of hot spots *(collaborative work with the NTF)***

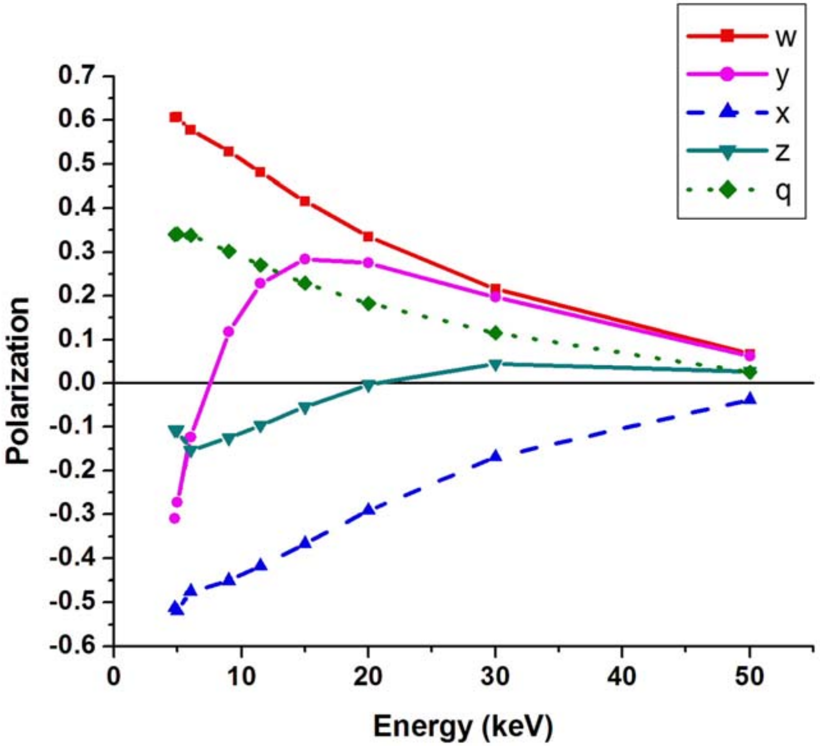
- **Spectroscopic and Implosion Characteristics of Mixed Nested Wire Arrays on the 1 MA Cobra at Cornell University *(collaborative work with Cornell High-Energy Center)***

- **Modeling of radiation from implosions of Copper Cylindrical and Conical Aluminum Wire Arrays on the 1 MA Zebra at the NTF/UNR *(collaborative work with SNL)***

Development of the non-LTE kinetic models

Atomic database: advance Relativistic Many Body Perturbation Theory calculations for the broad range of nuclear change z*

Study of effects of hot electrons. Polarization of x-ray K-shell line radiation: calculations and applications to the experiments**



New non-LTE model of Zn and its application to the modeling of implosions from brass PWA loads on Zebra and Cobra

*U.I. Safronova, A.S. Safronova, P. Beiersdorfer, J. Phys. B 40, 955-974 (2007)

**A.S. Safronova, V.L. Kantsyrev, P. Neill, U.I. Safronova, D.A. Fedin, N.D. Ouart, M.F. Yilmaz, G. Osborne, I. Shrestha, K. Williamson, T. Hoppe, C. Harris, P. Beiersdorfer, S.B. Hansen, Can. J. Phys. 86, 267-276 (2008)

Study of radiative properties of implosions of combined planar wire arrays composed from different wire material on Zebra at UNR/NTF (collaboration with NTF)*

Shot N	Number of wires	Compos.	Configur.	Wire ϕ (μm)	Mass of load (μg)	Al mass (%)
769	10	Al/Mo/Al	IIIIIIIIII	15/7.62/15	93	20
802	15	Al/Mo/Al	IIIIIIIIIIIIIII	15/7.62/15	140	13
803	14	Mo/Al/Mo	IIIIIIIIIIIIII	7.9/15/7.9	139	13
805	14	Mo/Al/Mo	IIIIIIIIIIIIII	7.9/19.8/7.9	154	21
804	10	Al/Brass/Al	IIIIIIIIII	17.8/10.9/17.8	152	21

V. L. Kantsyrev, A. S. Safronova, D. A. Fedin, V.V. Ivanov, A.A. Esaulov, V. Nalajala, I. Shrestha, S. Pokala, K. Williamson, N.D. Ouart, M.F. Yilmaz, P. Laca. T.E. Cowan, L.I. Rudakov, B. Jones, C.A. Coverdale, C. Deeney, P.D. LePell, A.L. Velikovich, A.S. Chuvatin. IEEE Trans. Plasma Sci. 34, pp. 194-212 (2006)

*A.S. Safronova, V.L. Kantsyrev, M.F. Yilmaz, G. Osborne, N.D. Ouart, K. Williamson, I. Shrestha, V. Shlyaptseva, S. Batie, B. Le Galloudec, A. Astanovitsky, V. Nalajala, W. McDaniel, High Energy Density Physics 3, 237-241 (2007)

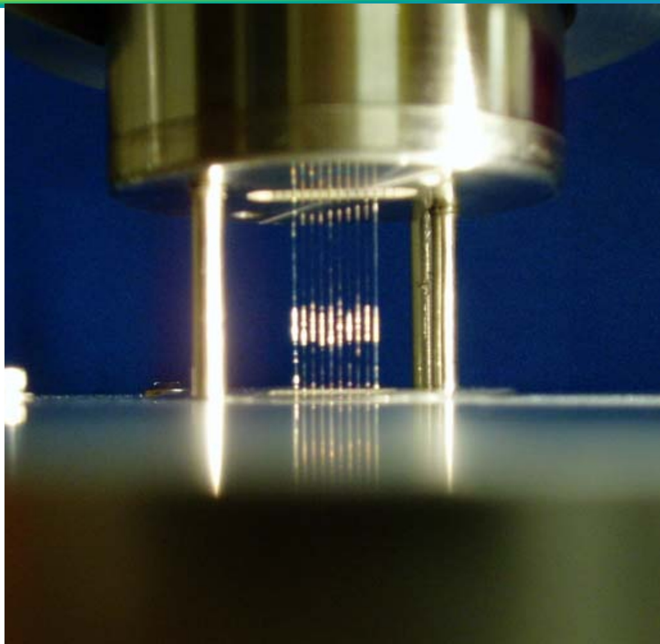
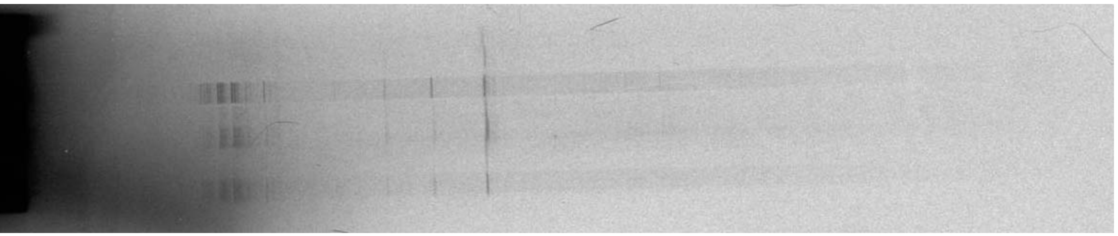


Illustration of spectroscopic modeling : K- and L-shell radiation from combined Al and Mo Planar Wire Arrays, Planar Mo/Al/Mo Wire Array: Zebra shot 803, IIIIIIIIIIIIII, 6x Mo 7.9 μm/ 2xAl 15 μm/ 6x Mo 7.9 μm

X-ray film recorded by a KAP crystal

anode

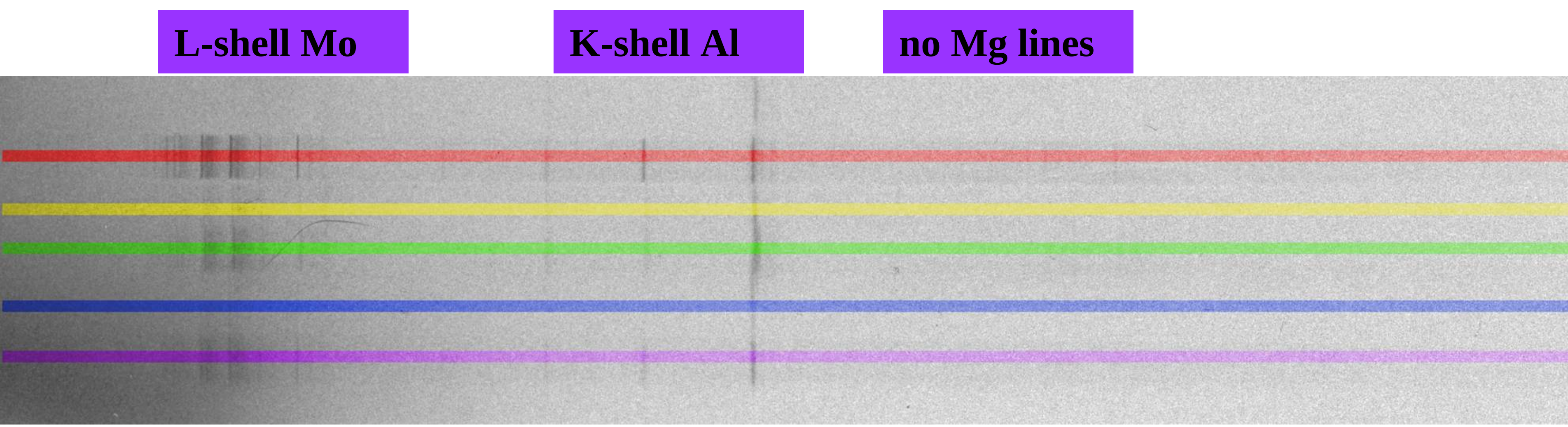


cathode

Pinhole X-ray images

λ<10.3 Å **λ<4.4 Å**

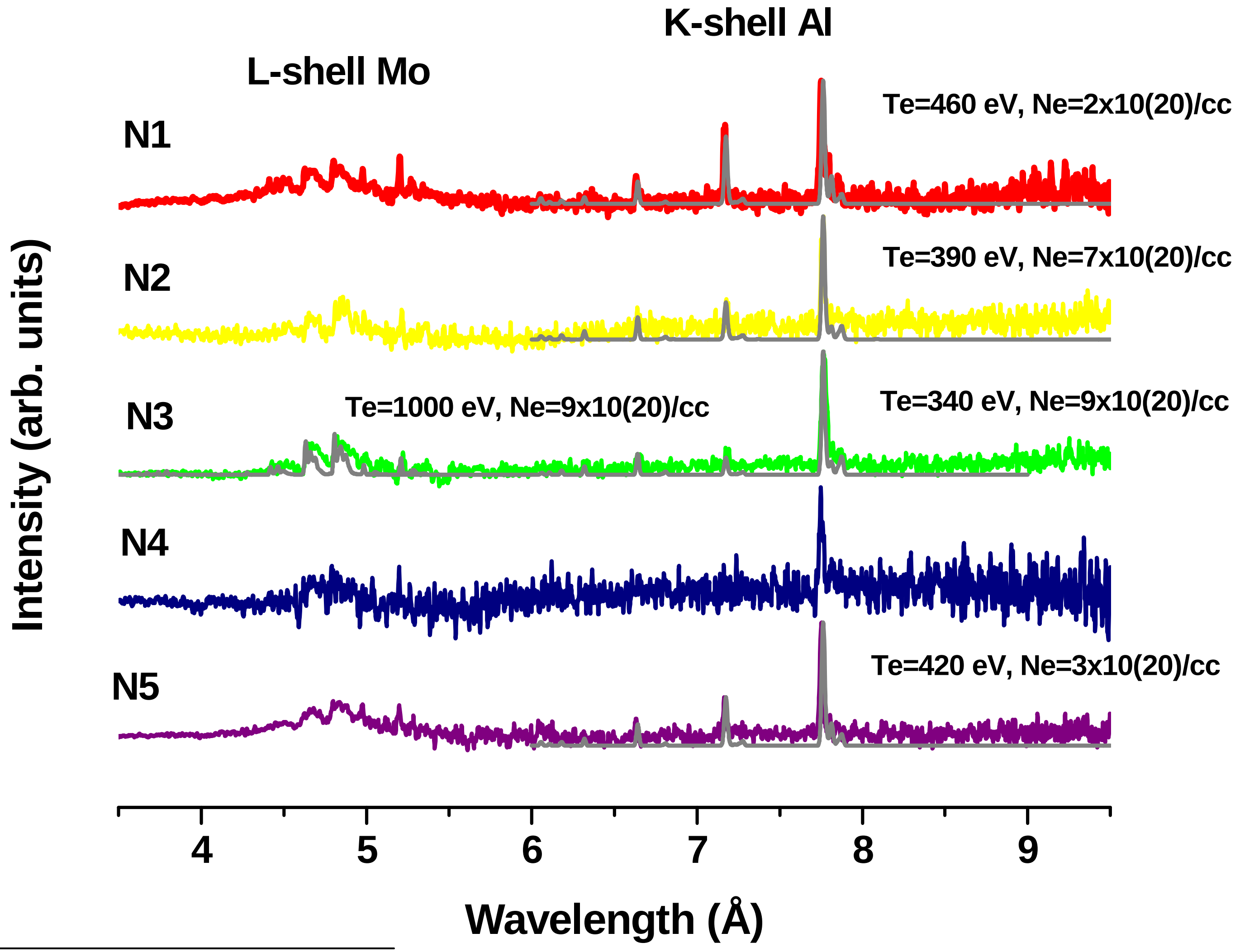
Position of the lineouts



Both L-shell Mo and K-shell Al radiate from localized hot spots

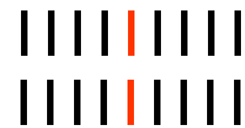
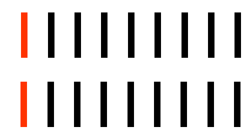
Planar Mo/Al/Mo Wire Array : modeling of axially resolved K-shell Al spectra shows gradients in plasma parameters of the central wires plasmas (Al) and allows the comparison with the parameters from primary material plasmas (Mo)*

Contrary to Al/Mo/Al, K-shell Al as well as L-shell Mo radiation show substantial variations with the distance from the anode.



*A.S. Safronova, V.L. Kantsyrev, M.F. Yilmaz, G. Osborne, N.D. Ouart, K. Williamson, I. Shrestha, V. Shlyaptseva, S. Batie, B. Le Galloudec, A. Astanovitsky, V. Nalajala, W. McDaniel, High Energy Density Physics 3, 237-241 (2007)

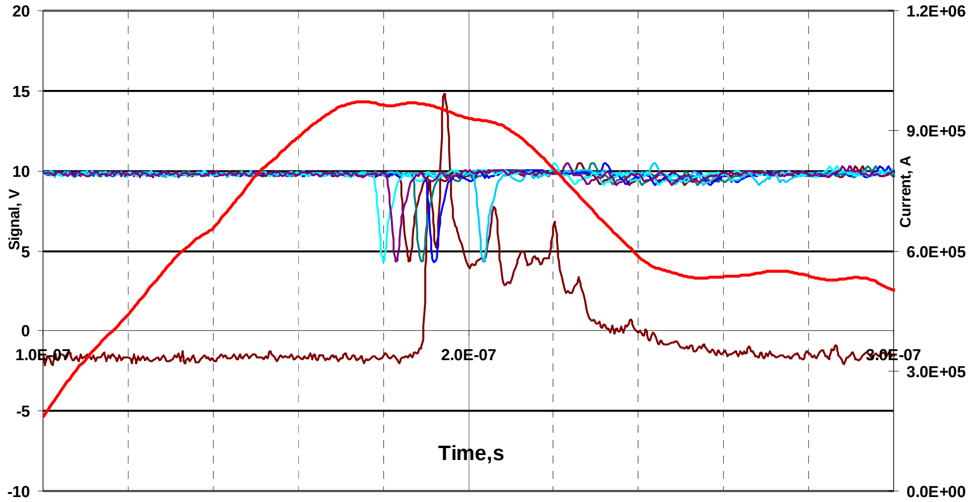
Planar Cu and Al wire arrays: one or two Al wires placed in different locations inside Cu planar wire array loads were used as tracer diagnostics of imploding Z-pinch plasmas

Shot N	Date	Load	N of wires	Mass (μg)	Al mass (%)	Bolo (kJ)	Load details
782	8/7/06	SPWA	10	143	18.5	14.4	
808	8/21/06	SPWA	14	183	4.6	14.3	
757	7/19/06	SPWA	10	143	18.5	11.2	
801	7/17/06	SPWA	15	143	100	10.4	
1291	10/24/07	DPWA	9x9	259	11.3	17.3	
1293	10/25/07	DPWA	9x9	259	11.3	17.6	

- Al wires shown in red have Φ=17.8 μm in Al5056/Cu loads and 15 μm in Al5052 load
- Cu wires (Ni 60, 96%Cu and 4% Ni) shown in black have Φ =10.16 μm

Shot 808 (SPWA). Time-gated pinhole images and axially resolved spectra. Hot spots are originated first at the cathode and then at the anode and correlate well with TISR spectra

Current, PCD signals, and MCP frames



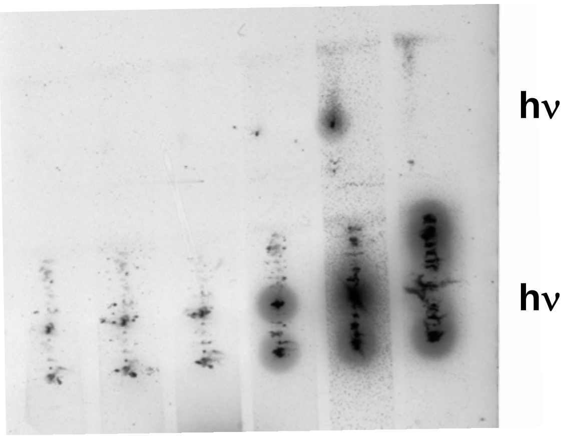
TGPH images

anode

cathode

anode

cathode



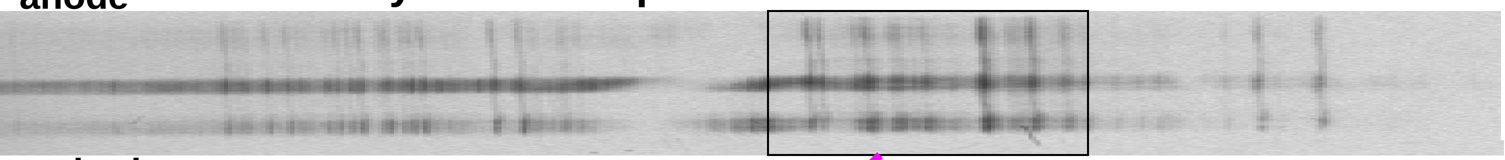
hν > 3keV

hν > 1keV

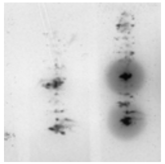
1 2 3 4 5 6

Axially resolved spectra

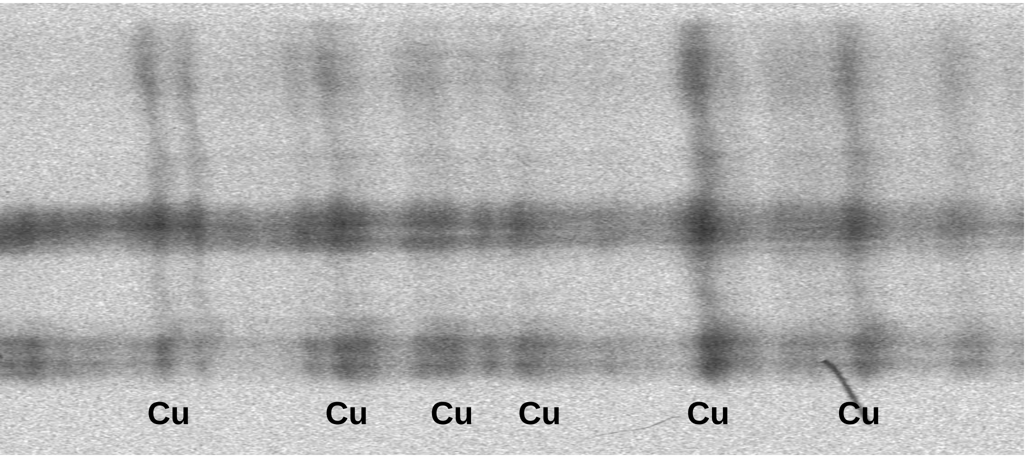
anode



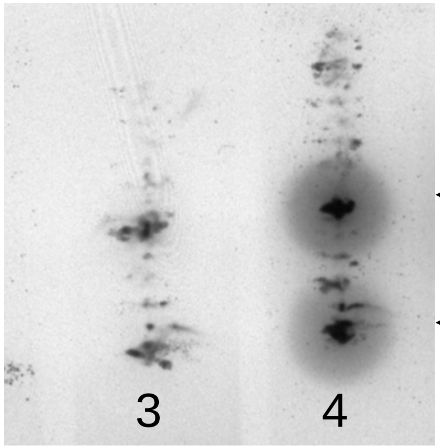
cathode



3 4



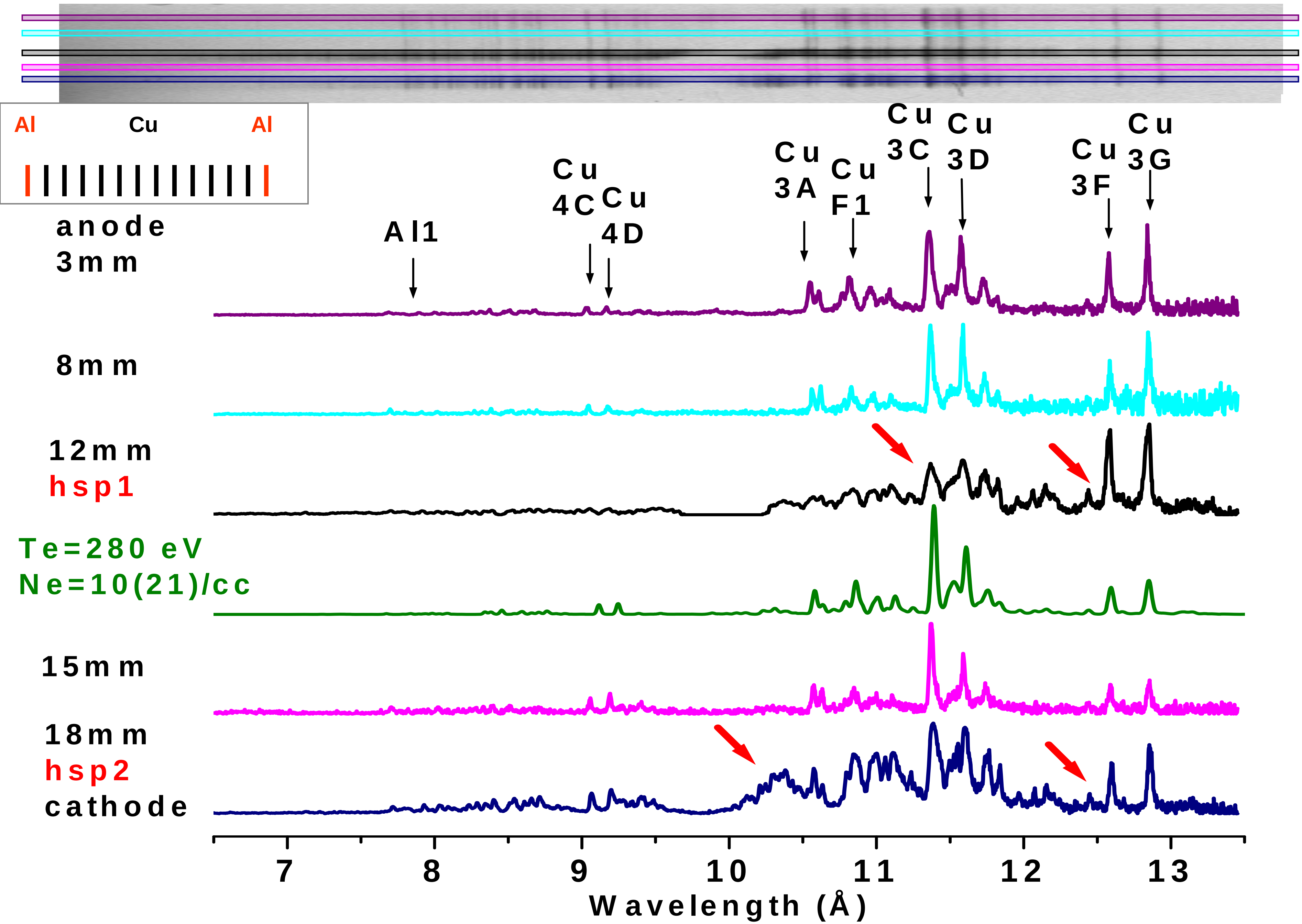
3A F1 F2 F3 3C 3D



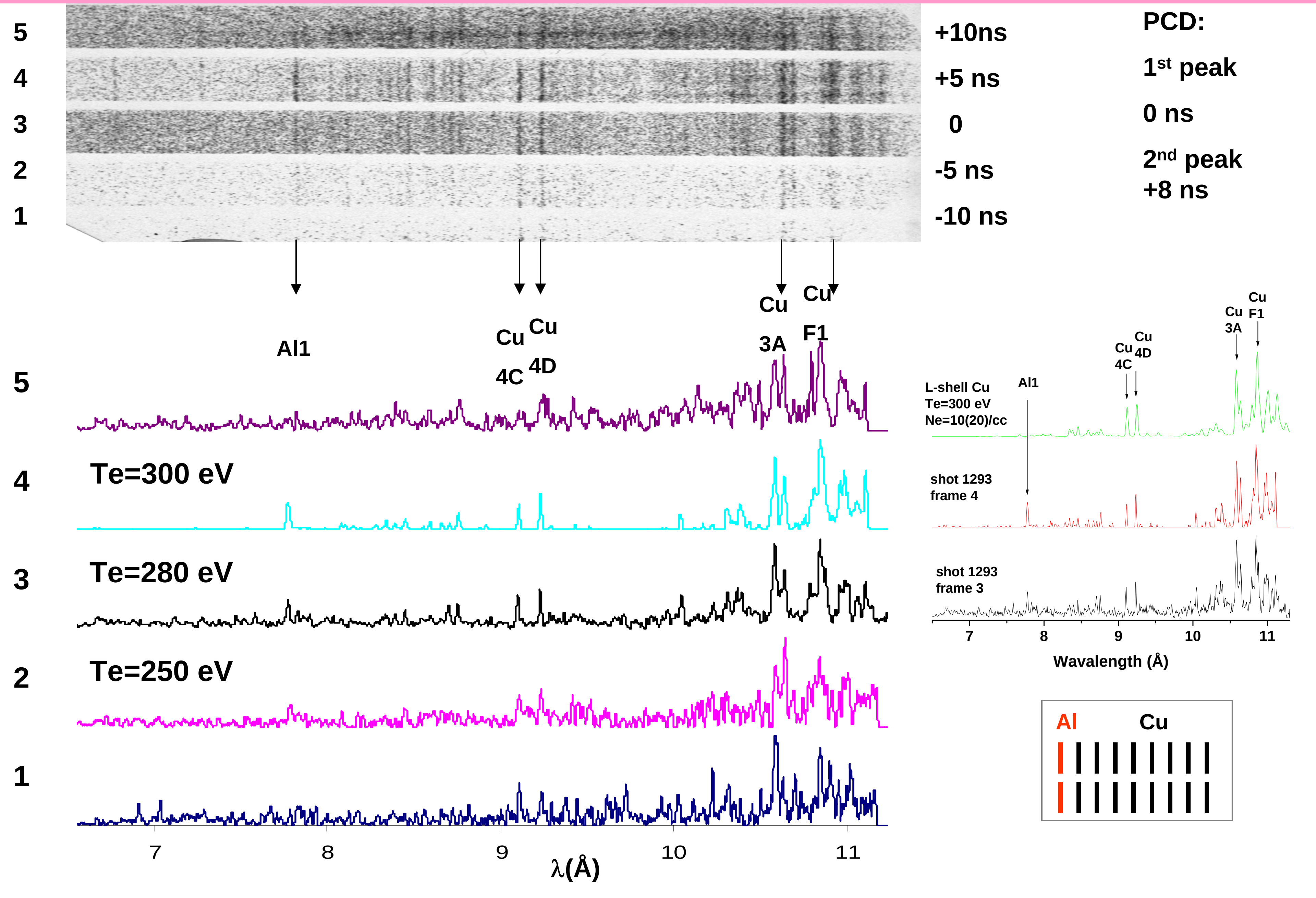
hsp1

hsp2

Shot 808 (SPWA). Axially resolved spectra. Spectra from hot spots show opacity features



TGSI spectra. Modeling of L-shell Cu radiation from shot 1293 (DPWA) shows that Te is gradually increasing during the development of the x-ray burst up to 300 eV



SUMMARY OF THE STUDY OF COMBINED PWAs

- **Implosion and spectroscopic characteristics of combined single (Mo or Cu as main material) and double (Cu as main material) planar wire arrays have been studied on 1 MA z-pinch generator at UNR using a new tracer diagnostics with few Al wires;**

- **The analysis of axially resolved spectra has shown that relative intensities of the most intense K-shell Al line are larger when the Al wires are placed at the edges (than when in the center) and increase towards the cathode both for SPWA and DPWA;**

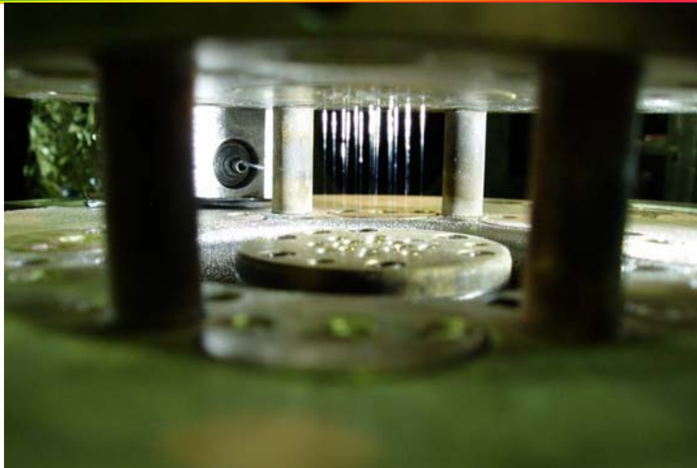
- **The analysis of time-gated spectra has shown that the relative intensities of Al1 line, zero or small just before the beginning of the x-ray burst, increase with time and peak at the maximum of the PCD signal. For DPWAs, they are larger when the Al wires were initially at the edges of the array at every frame;**

- **WADM provides possible explanation why the relative intensity of Al1 line is larger in the case when Al wires are initially at the edge of the array**

Nested wire array experiments on 1 MA Cobra at Cornell University used uniform and mixed wire loads to study implosion characteristics of outer and inner arrays*

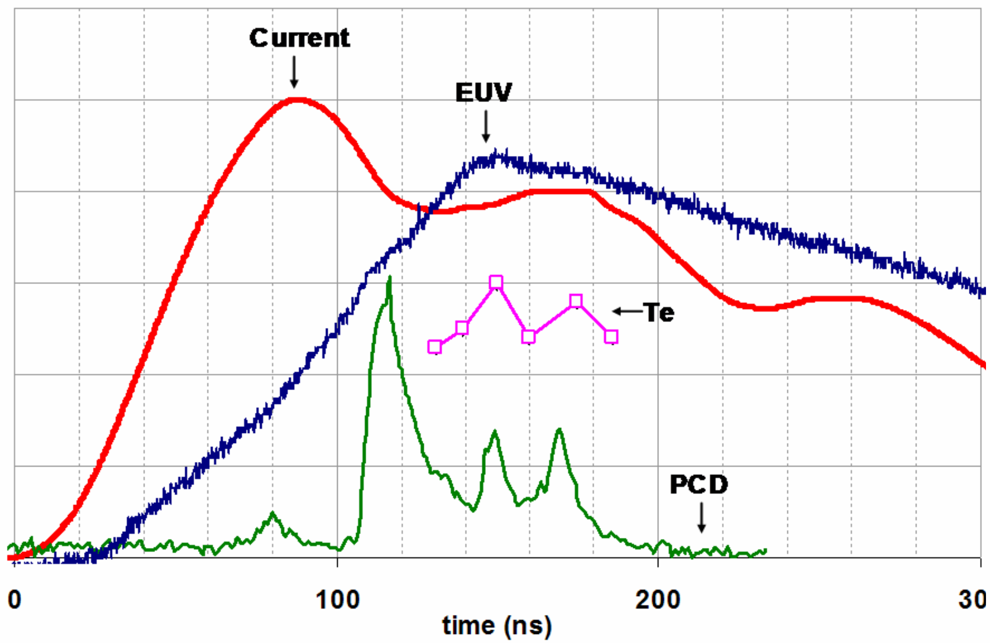
Shot N	Outer array Number of wires	Outer array Wire material	Inner Array Number of wires	Inner Array Wire material	Mass (μg)
448,449,458, 459	8	SS304	4	Al5056	55
451,454,457,462 *446,447*	8	Al5056	4	SS304	52
450,452,455,*445,453*	8	Al5056	4	Al5056	50
456	8	Al5056	8	Al5056	67
460,*444*	8	SS304	8	SS304	77
461	8	SS304	4	SS304	58

Composition and diameter of wires:
Al5056 (95% Al, 5% Mg),10 μm
SS304 (69% Fe, 19% Cr, 9% Ni),6.25 μm

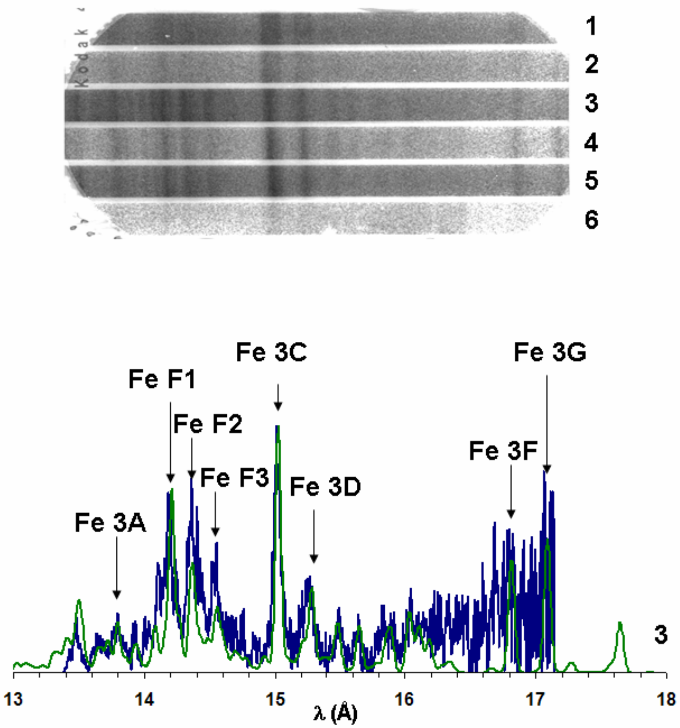


*A.S. Safronova, V.L. Kantsyrev, A.A. Esaulov, N.D. Ouart, M.F. Yilmaz, K. Williamson, I. Shrestha, G. Osborne, J. B. Greenly, K. M. Chandler, R. D. McBride, D. A. Chalenski, D. A. Hammer, B. R. Kusse. Phys. Plasmas (in press, March 2008)

Modeling of time-gated L-shell spectra from implosions of nested wire arrays (collaborative work with Cornell University)*



a)



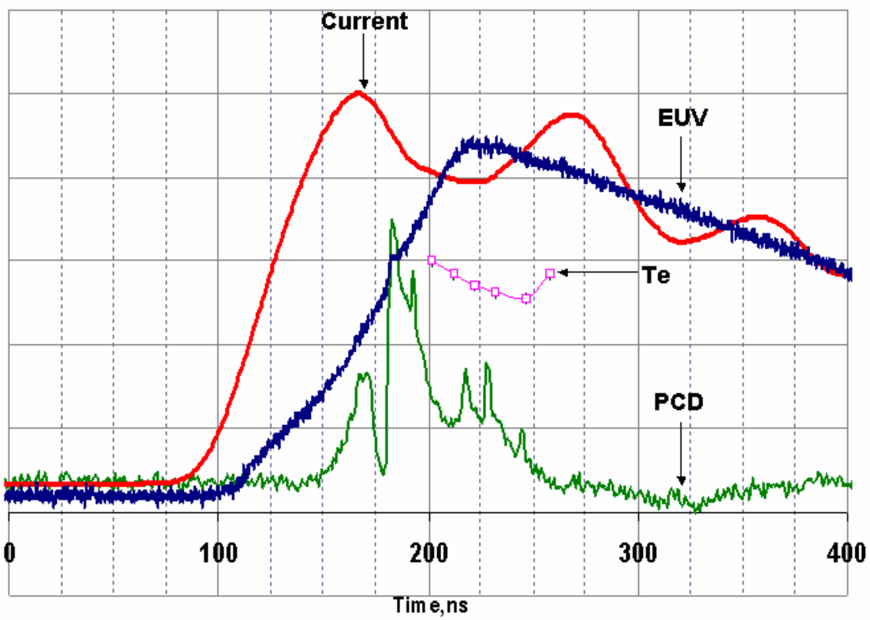
b)

Uniform SS nested wire array with 4 wires in the inner array (Cobra shot 461). a). Current waveforms, PCD (filtered through 8 μm Be), and EUV signals, and the values of Te (changing between 175 eV and 215 eV) from modeling of TGSI spectra. b). The image of the experimental x-ray TGSI spectra recorded by six MCP frames and the corresponding lineout from frame 6 fit with modeling at Te =215 eV and Ne=10^{20} cm^{-3}.

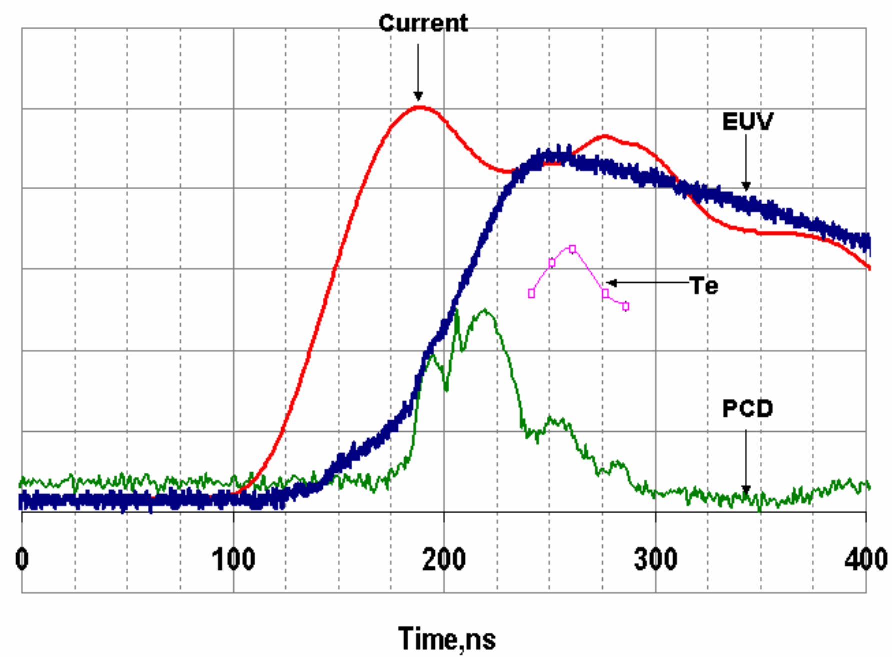
Te follows the PCD signals and peaks at times of the second (and all subsequent if present) x-ray burst .

***A.S. Safronova, V.L. Kantsyrev, A.A. Esaulov, N.D. Ouart, M.F. Yilmaz, K. Williamson, I. Shrestha, G. Osborne, J. B. Greenly, K. M. Chandler, R. D. McBride, D. A. Chalenski, D. A. Hammer, B. R. Kusse. Phys. Plasmas (in press, March 2008)**

Modeling of time-gated L-shell spectra from implosions of nested wire arrays (collaborative work with Cornell University)* (continued)



a)



b)

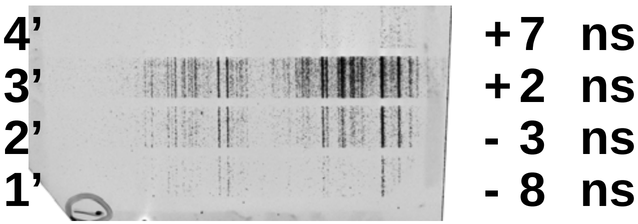
Mixed Al and SS nested wire arrays with 4 wires in the inner array. Current waveforms, PCD (filtered through 8 μm Be), and EUV signals, and values of Te from modeling of TGSI spectra. a) Al/SS nested array (shot 459) , the values of Te are changing between 340 eV and 400 eV; b) SS/Al nested array (shot 462), the values of Te are changing between 165 eV and 210 eV.

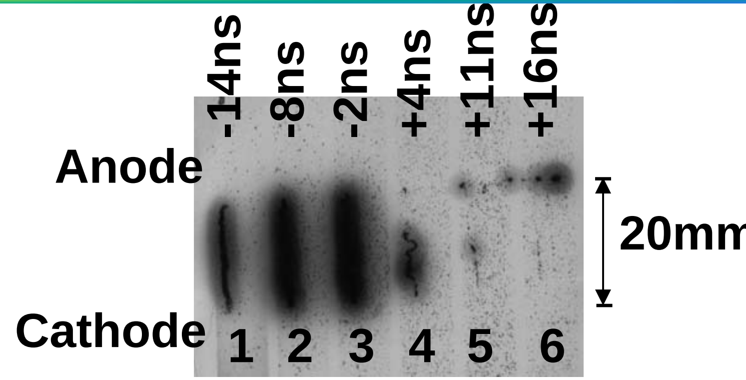
Modeling of TGSI spectra indicated that the electron temperature Te has shown two major types of time-dependencies. In particular, the first type is when Te follows the PCD signals and peaks at times of the second (and all subsequent if present) x-ray burst. The second type is when Te has one of the highest value at the first frame (which is the closest to the main x-ray burst) then slightly changes and increases at the last frame which coincides with the second maximum of the current.

***A.S. Safronova*, V.L. Kantsyrev, A.A. Esaulov, N.D. Ouart, M.F. Yilmaz, K. Williamson, I. Shrestha, G. Osborne, J. B. Greenly, K. M. Chandler, R. D. McBride, D. A. Chalenski, D. A. Hammer, B. R. Kusse. Phys. Plasmas (in press, March 2008)**

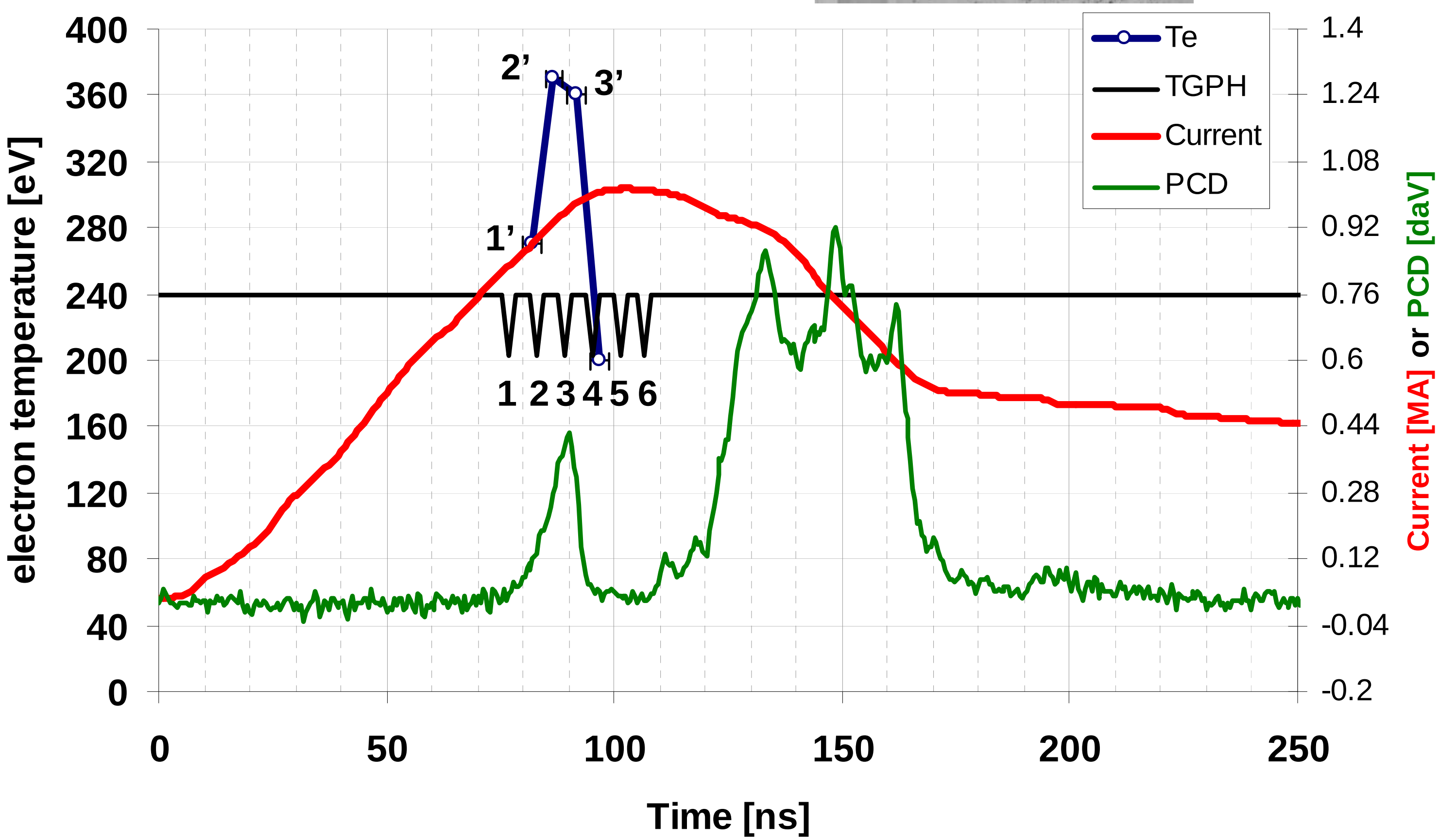
Measurements of plasma conditions in precursor plasmas at the 1-MA Zebra facility (collaborative work with Sandia National Laboratories)

See poster by the graduate student N.D. Ouart et al for details

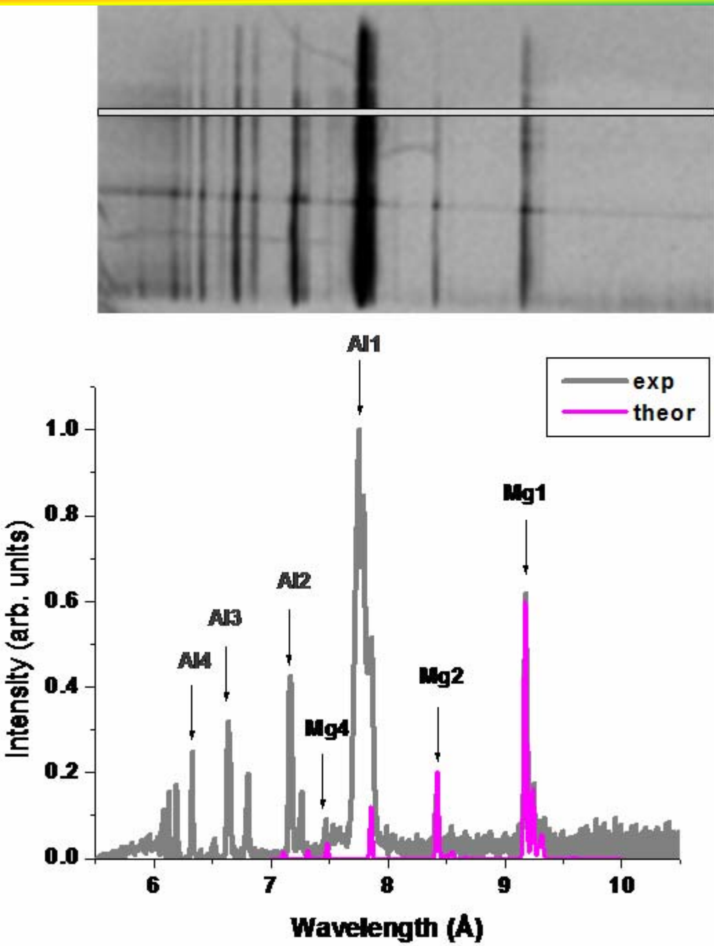


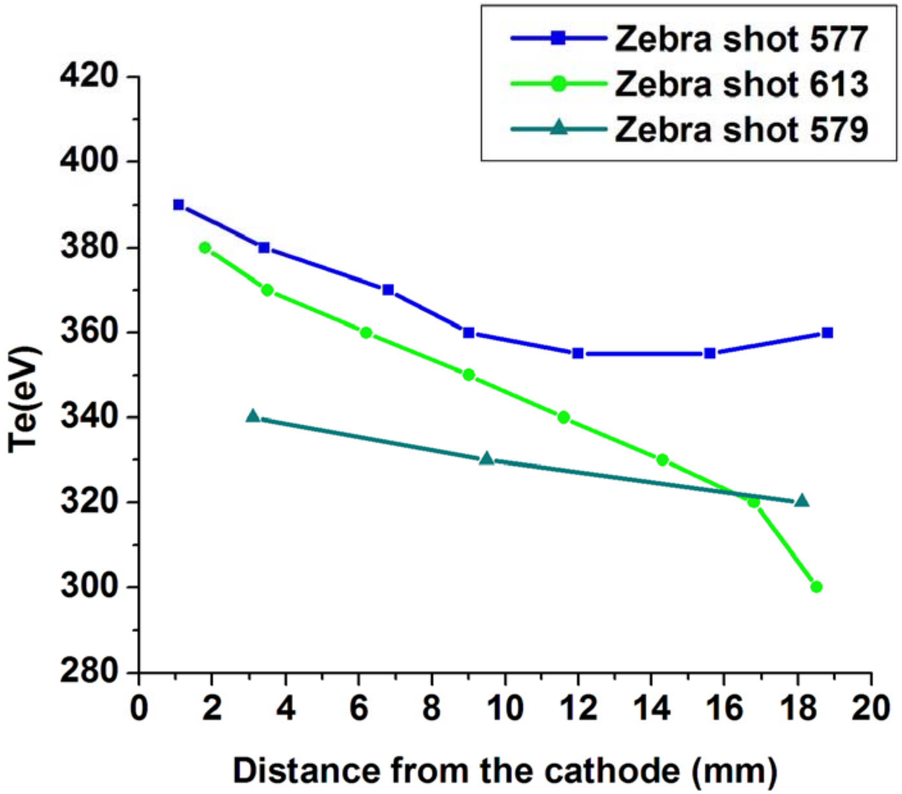


Time-gated pinhole images, spectra, T_e, and timings (Zebra shot 1045)



Modeling of radiation from conical wire arrays (collaborative work with Sandia National Laboratories)*

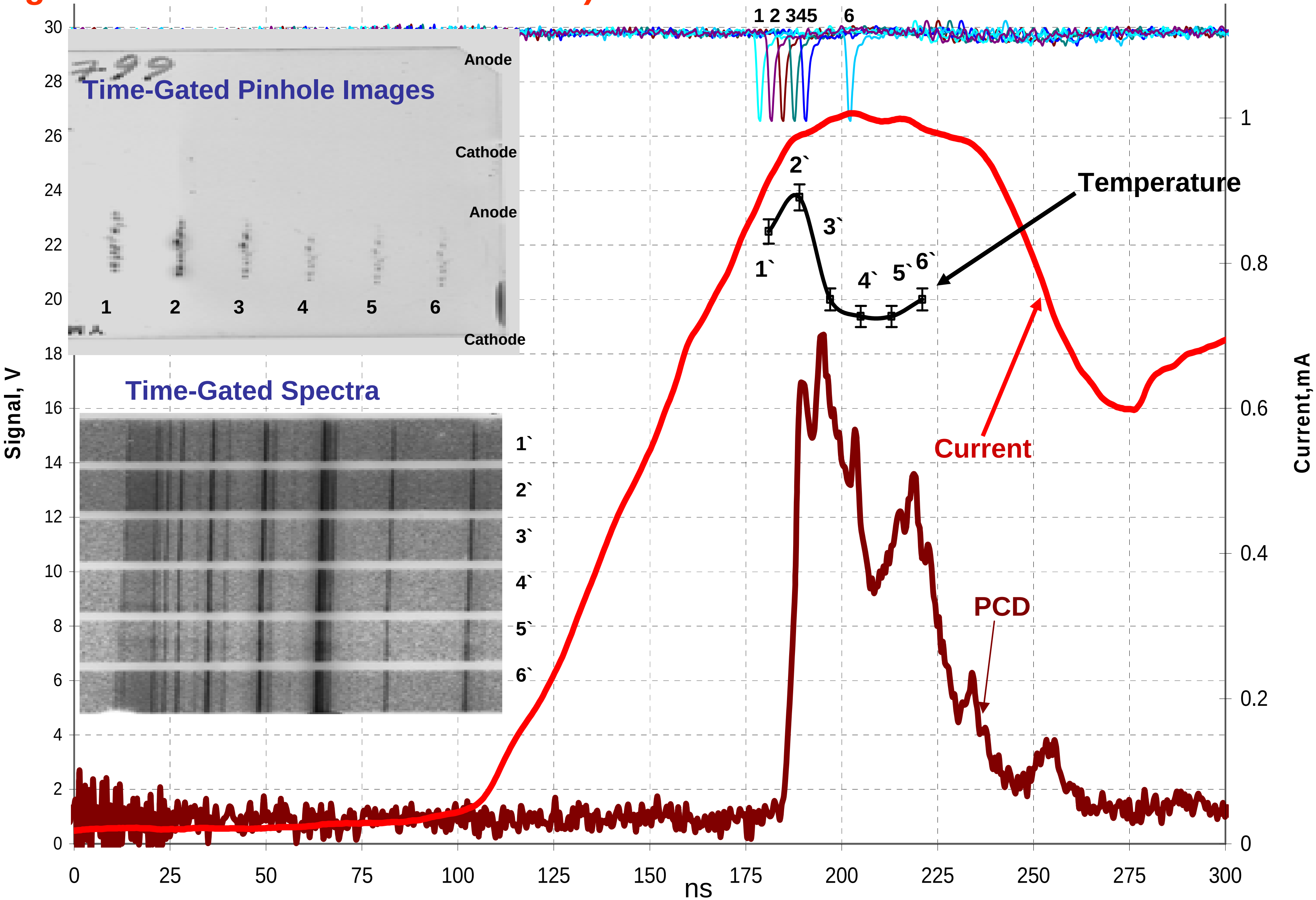




The electron temperature near the cathode was the highest and then was decreasing towards the anode whereas only slight variations in the electron density was found. This effect was found to be not so pronounced for cylindrical wire arrays for which Te changes much less from the cathode to the anode (see data for shot 579).

***D.J. Ampleford, S.V. Lebedev, S.N. Bland, S.C. Bott, J.P. Chittenden, C.A Jennings, V.L. Kantsyrev, A.S. Safronova, V.V. Ivanov, D.A. Fedin, P.J. Laca, M.F. Yilmaz, V. Nalajala, I. Shrestha, K. Williamson, G. Osborne, A. Haboub, A. Ciardi, Phys. Plasmas 14, 102704 (2007).**

Study of K-shell radiation from Al PWAs (for more details see poster by the graduate student M.F. Yilmaz et al)



Zebra 799 TDS#6 [Planar Array- Al, N= 10, Φ_{wire} =15 μm, IWG=1mm]

SUMMARY

In 2007- 2008:

- **5 papers have been published and 3 are currently in press;**

- **28 abstracts have been submitted to the major conferences, 12 by graduate students**

- **Three different collaborations incorporated in this research provide a unique opportunity of exchange and joint utilization of data, ideas, and experiences for faculty and graduate students**

- **More details of this research and collaborative work will be in talks by :**

  V. Kantsyrev et al
  B. Jones et al

  and graduate student posters by:

  N. Ouart et al
  F. Yilmaz et al
  I. Shrestha et al
  K. Williamson et al

ACKNOWLEDGMENTS

- **This work was supported by NNSA under DOE Cooperative Agreements DE-FC52-06NA27588, and in part by DE-FC52-06NA27586 and DE-FC52-06NA27616.**

- **The Cornell co-authors were supported by Cornell's NNSA Center contract DE-FC03-02NA00057.**

- **Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States department of Energy under Contract DE-AC04-94AL85000.**