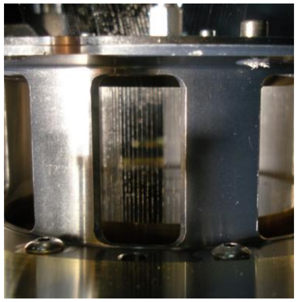
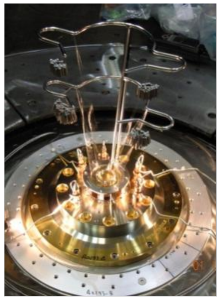
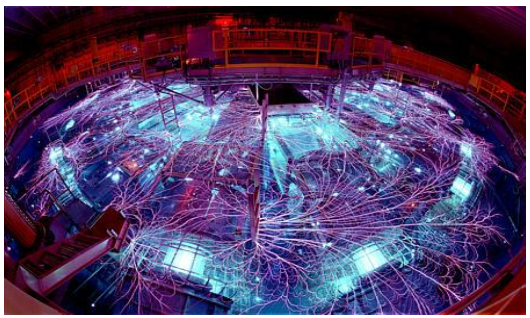
SAND2013-9466C







Updates to and recent applications of SCRAM

S.B. Hansen, *Sandia National Laboratories*

Sandia National Laboratories

Exceptional service in the national interest

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

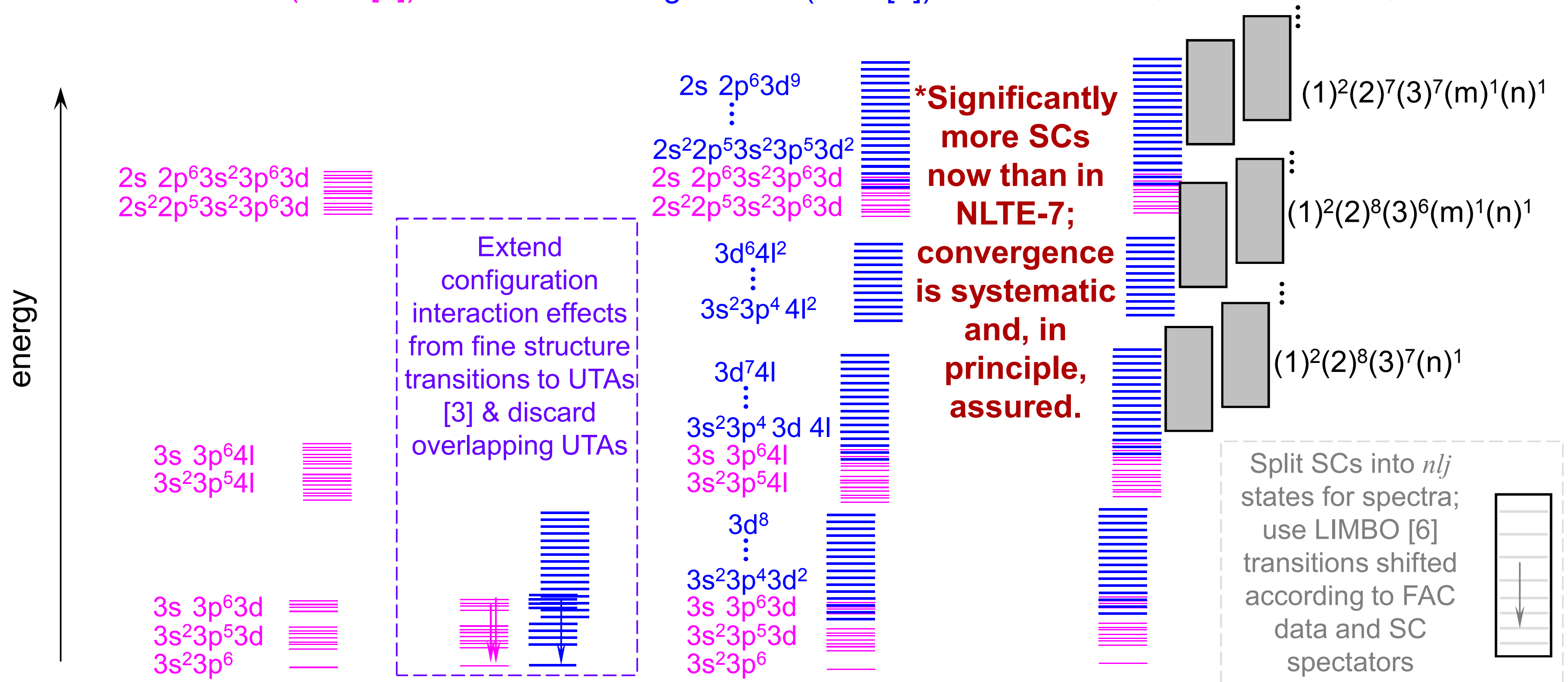
SCRAM [1,3] is a hybrid-structure code that combines fine structure, RCs, (FAC [2]) and SCs (screened hydrogenic [4])

Each ion has:

~200 fine structure "coronal" levels (FAC [2])

~14,000 (800) rel (non-rel) configurations (FAC [2])

~**1000*** superconfigurations [4-5] (screened hydrogenic/LIMBO)



Coronal fine structure for singly excited states → configuration interaction and metastables.

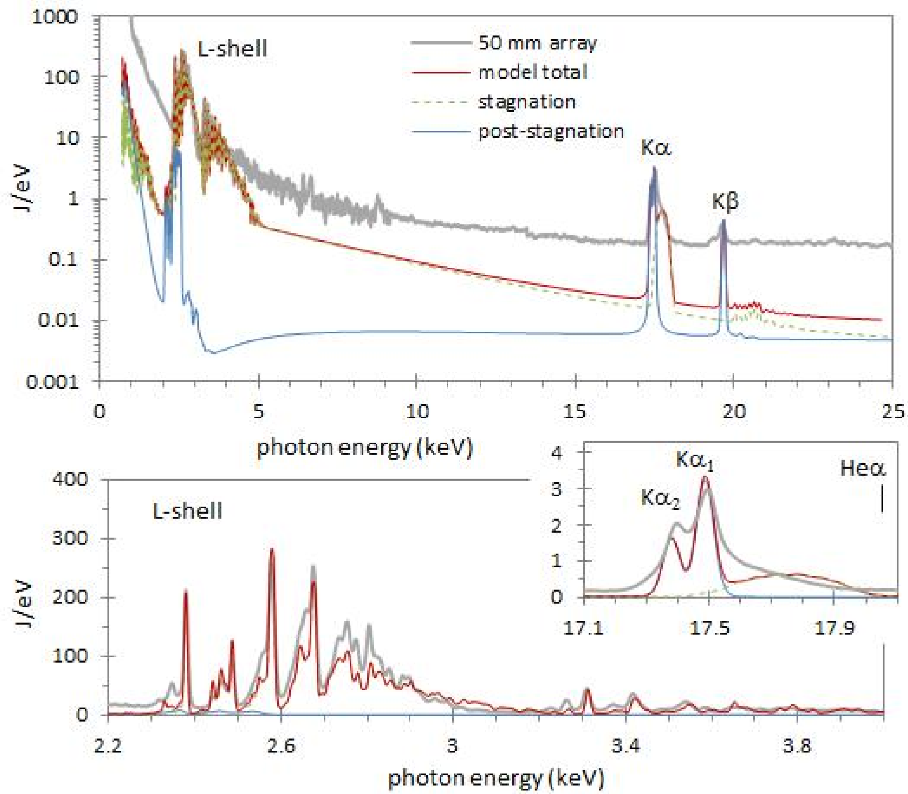
Supplemental configurations for doubly excited states provide continuity at moderate densities.

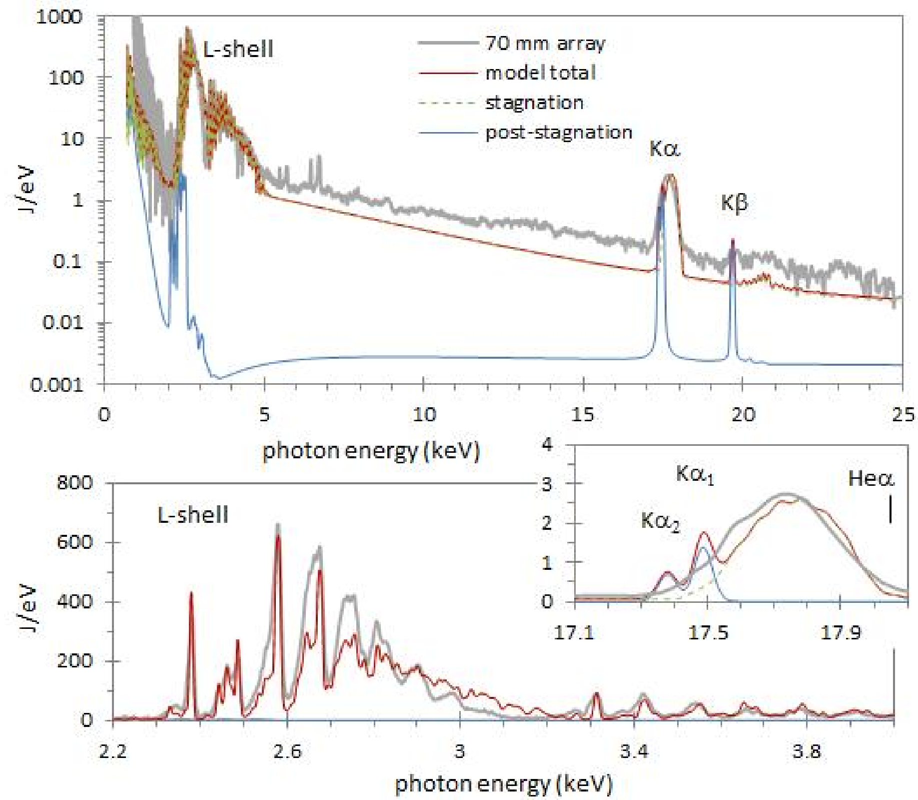
Supplemental superconfigurations ensure statistical completeness and converged d.r. channels

[1] Hansen, Bauche, Bauche-Arnoult, and Gu, HEDP **3**, 109 (2007)
[2] Gu, Astrophys. J. **590** 1131 (2003)
[3] Hansen, Can. J. Phys. **89** (2011)
[4] Scott and Hansen, HEDP **6**, 39, (2010)
[5] Hansen, Bauche, and Bauche-Arnoult HEDP **7**, 27 (2010)
[6] Liberman, Albritton, Wilson, & Alley, Phys. Rev. A **50**, 171 (1994)

Application: Diagnosing Mo plasmas on Z

D. Ampleford's LDRD: produce high-energy photons from high-Z materials using beams rather than thermal processes [7] (cf. Kα production from fs lasers)



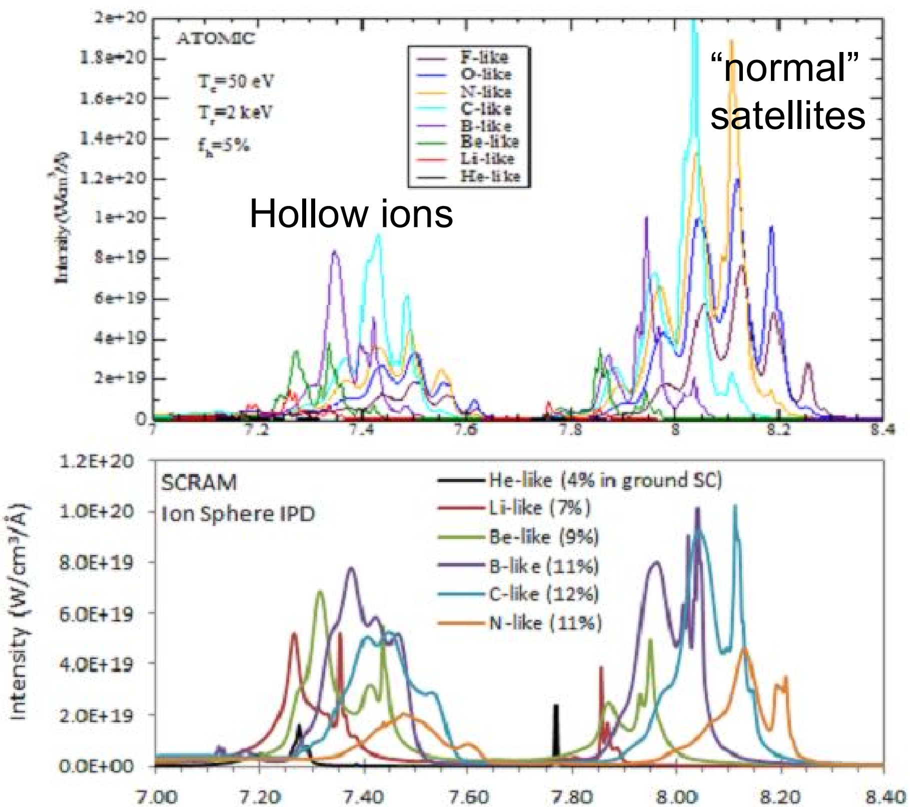


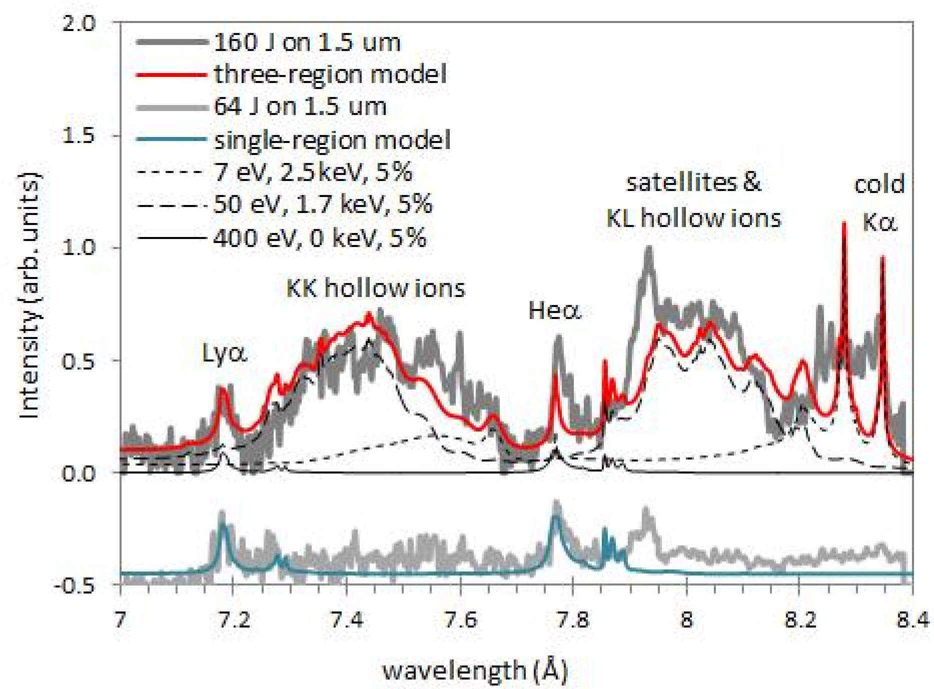
Model must have extensive multiply excited valence structure for Auger/d.r., and each such configuration must be paired with one that has K-shell hole [8]

[7] Hansen, Ampleford et al, submitted to Phys Plasmas [8]Chung, Lee, and HEDP **3**, 57, (2007)

Application: Hollow-ion emission from laser plasma [9]

We compared emission from ATOMIC/MUTA and SCRAM [10]

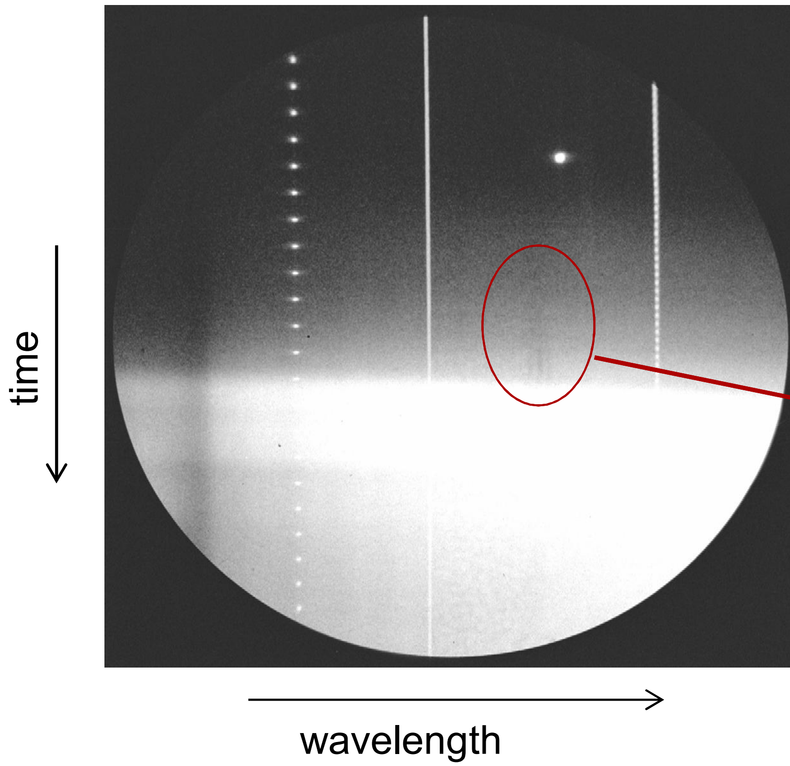


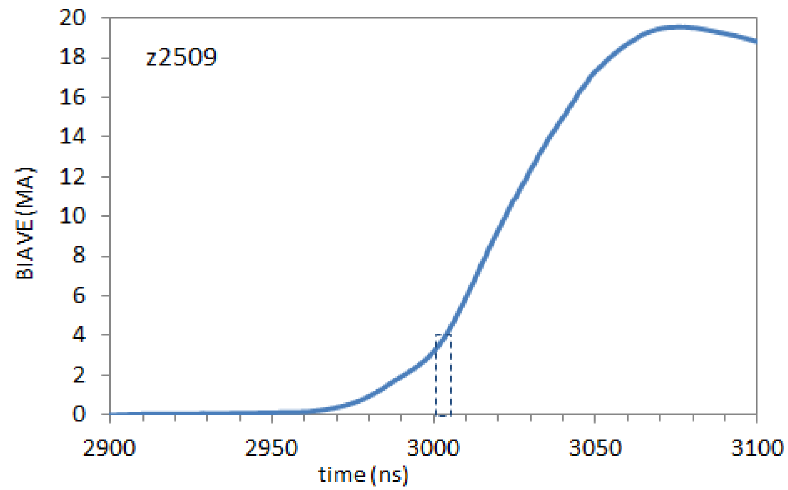


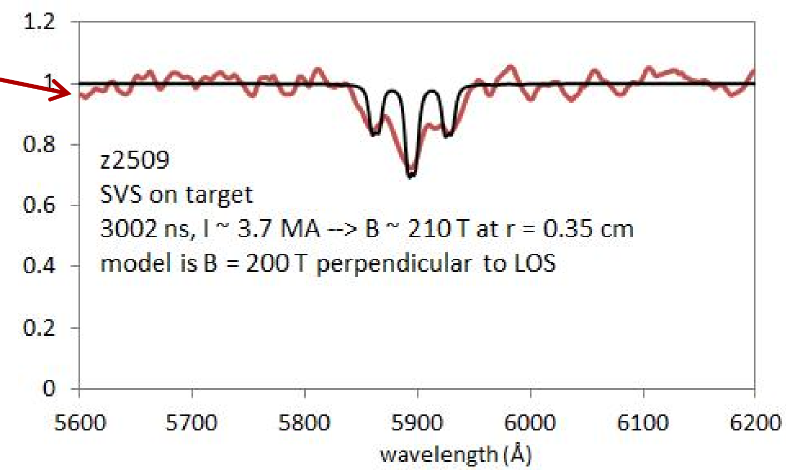
Models need extensive multiply excited valence structure for statistics (e.g. $1s^2\ (5l)^6$), and each such configuration must be paired with ones that have 1 & 2 K-shell holes

[9] Colgan, Faenov Phys. Rev. Lett. 110, 125001 (2013)
[10] Submitted to Phys Plasma

In May 2013, Matt Gomez measured absorption lines from Z that appeared to form a Zeeman triplet

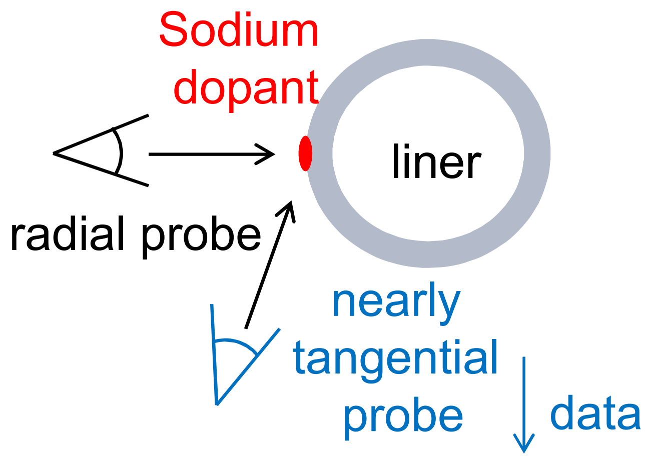


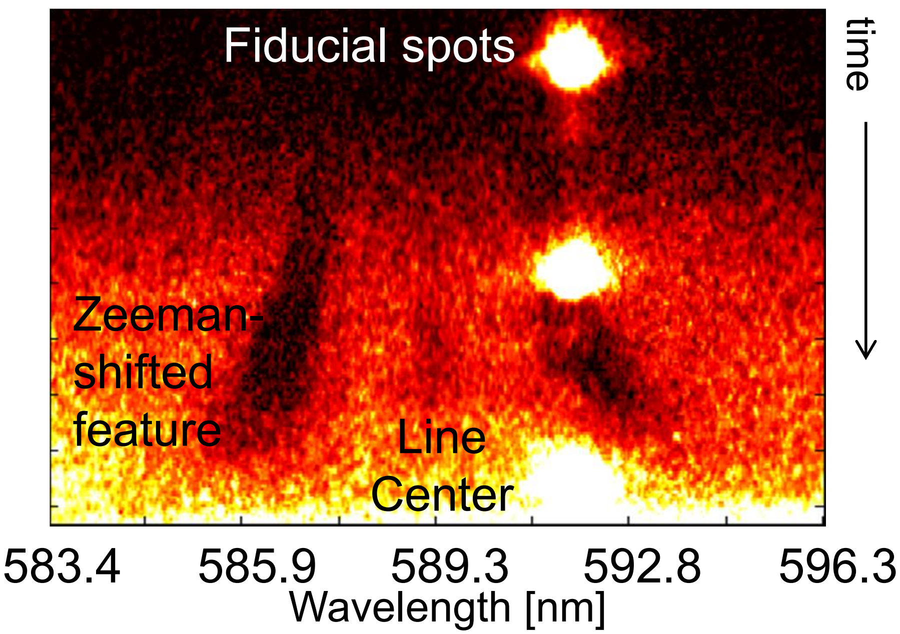


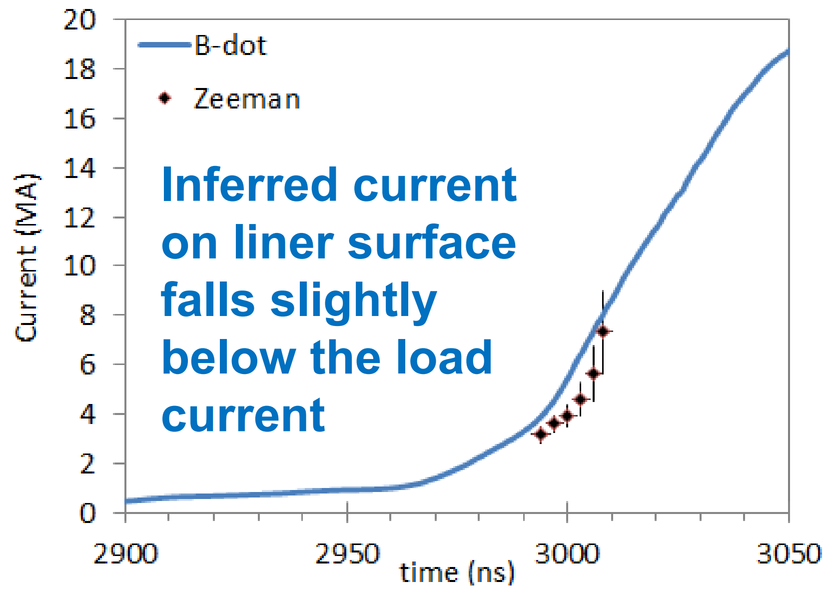


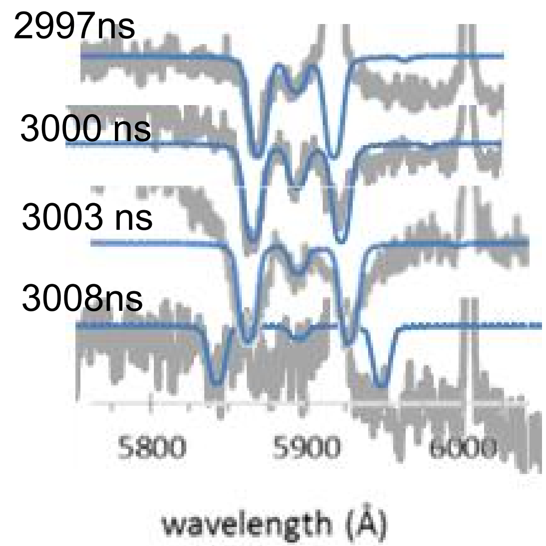
The absorption feature captured on the Streaked Visible Spectrometer (M. Gomez) was tentatively identified as the 3s – 3p transition in Na I. Although the origin of the sodium on the target was unknown, the splitting was consistent with estimated B ~200 T.

Placing droplets of salt water on various targets confirmed the line identification and provided **B** diagnostic





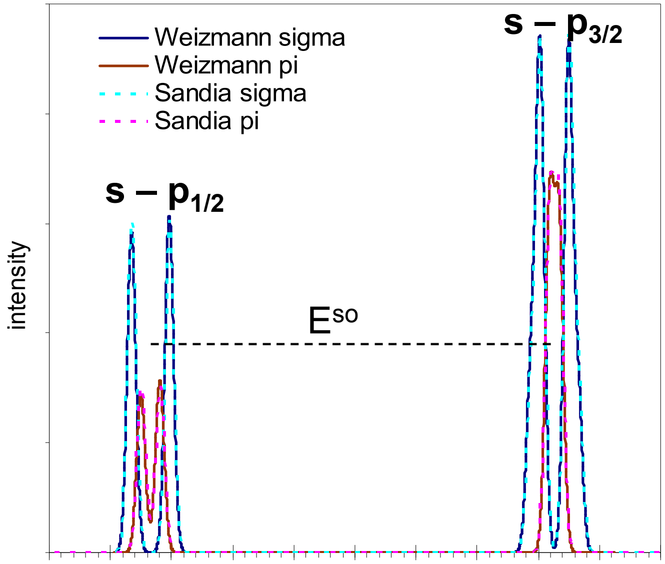




Fits from SCRAM (corrected to match NIST data) indicate B = 150 - 350 T 25° to SVS LOS ~10 ng/cm²

Zeeman splitting has been used to characterize B fields in laboratory and astrophysical plasmas

When the effect of the external field is small relative to the internal spin-orbit splitting, differential splitting of s-p doublets can be used to determine |B|.

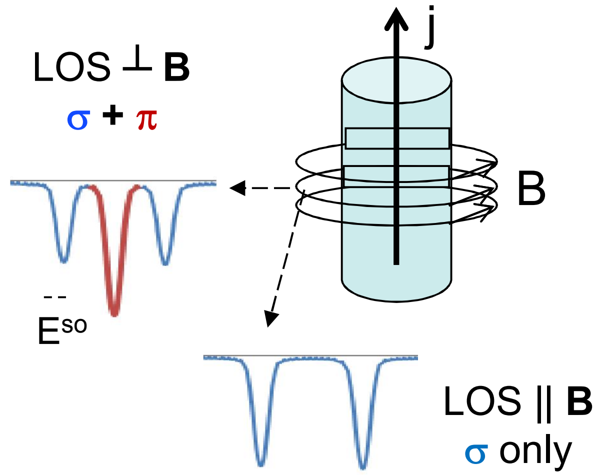


Comparisons courtesy E. Stambulchik

Few-T fields have been measured from 160 kA Z-pinch at Weizmann Inst.

Stambulchik, Tsigutken, and Maron
PRL **98**, 225001 (2007)

In strong external fields, s-p transitions form normal Zeeman triplets whose components reveal **B**



Few-100T fields have been measured in explosive flux-compression experiments and around magnetic white dwarfs

Garn, Cairn, Thomson, Fowler, RSI **37,** 762 (1966)
Reid, Liebert, and Smith, *Ap.J.* **550**, L61 (2001)

Weizmann method:
take advantage of differential splitting

Since Lyα2 (or any $np_{1/2}$ – $ns_{1/2}$ line) is broadened more than Lyα1 (or any $np_{3/2}$ – $ns_{1/2}$ line) but has identical Stark, temperature, motional, and opacity broadening, the difference between the two widths isolates the effect of B field.

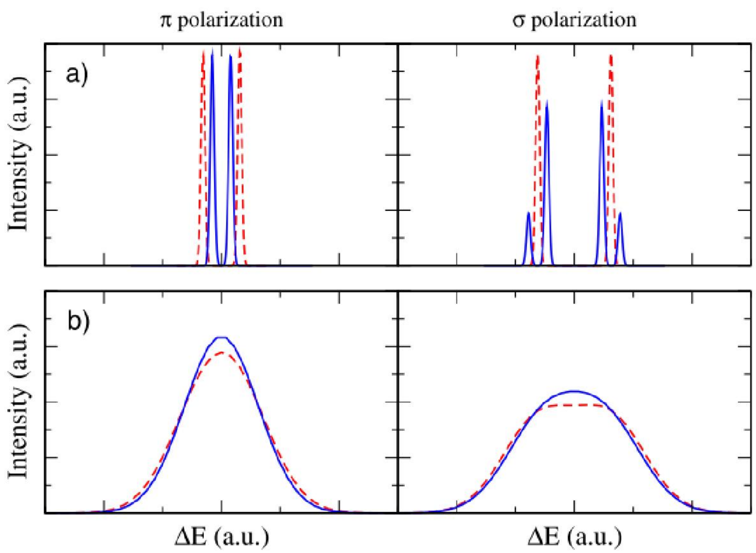


FIG. 1 (color online). Zeeman splitting of the $^2S_{1/2}$-$^2P_{3/2}$ (solid curves) and the $^2S_{1/2}$-$^2P_{1/2}$ (dashed curves) components of a ^2S-^2P transition, convolved with a small (a) and a dominant (b) Doppler effect (that is assumed to be the same for the two components). Profiles of the σ and π polarizations are given separately. For the comparison, the intensity of the $^2S_{1/2}$-$^2P_{1/2}$ component is scaled up by 2 times, to match the intensity of the $^2S_{1/2}$-$^2P_{3/2}$ component.

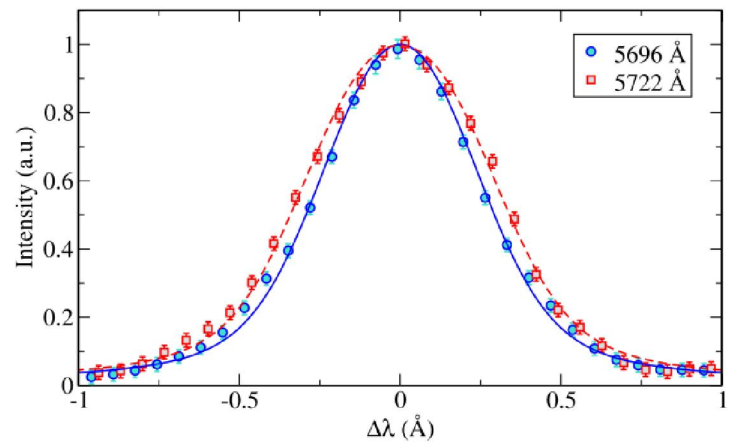
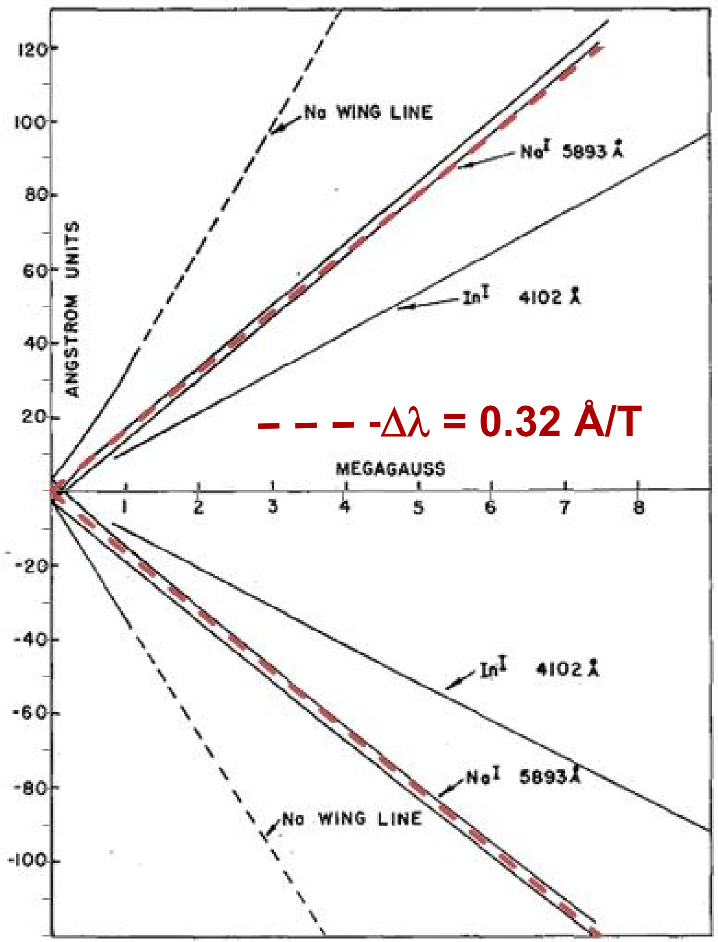
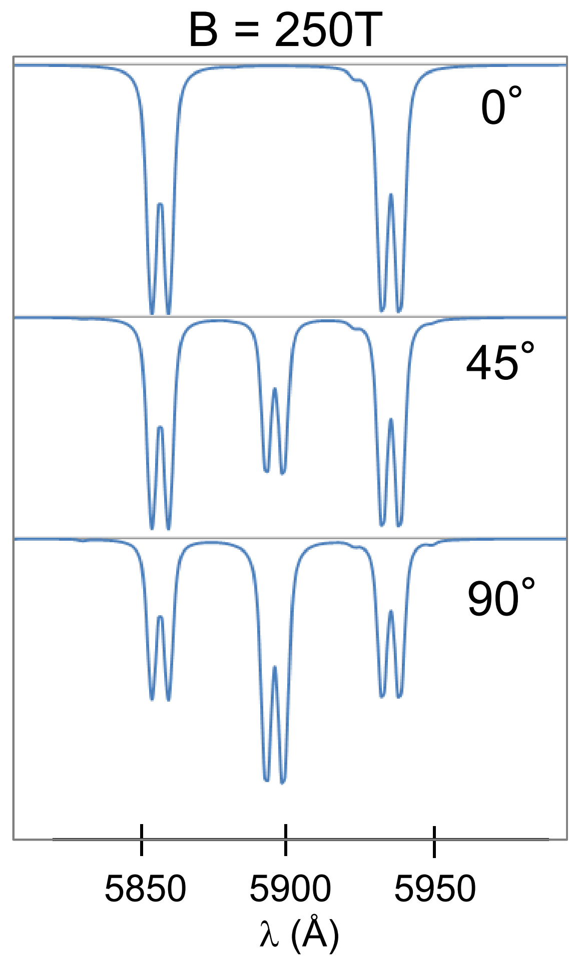


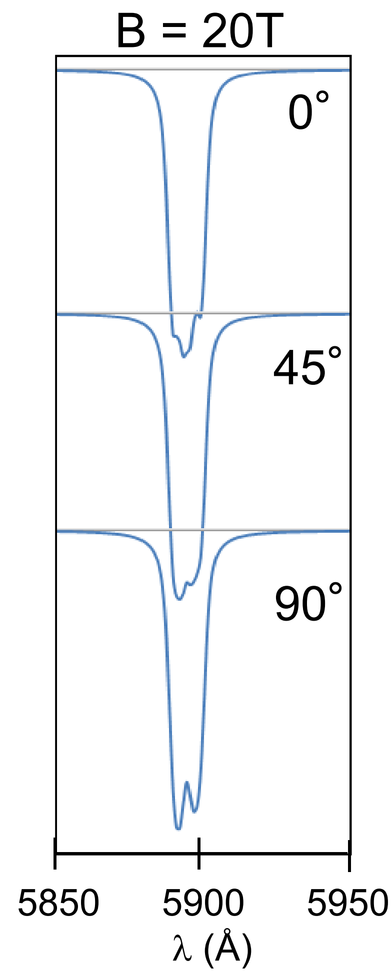
FIG. 5 (color online). The AlIII $4p$-$4s$ (5696 & 5722 Å) doublet. The line shapes of the two components are peak-normalized and shifted to a common spectral center. The smooth lines represent best-fit calculations for $B = 0.9$ T, $N_e = 2 \times 10^{16}$ cm^{-3}, and $T_e = 10$ eV.

Stambulchik, Tsigutken, and Maron, *Phys. Rev. Lett*. **98**, 225001 (2007).

In the strong-field (Paschen-Back) limit, σ splitting is directly proportional to |B| and π intensity indicates $\hat{B}$







Bethe and Salpeter, *Quantum Mechanics of One and Two Electron Atoms*, 1957

The relative strength of σ and π components indicates field direction

Summary

- Current loss is a critical issue for modeling and optimizing target performance on Z, but measuring the current at the load is challenging
- SVS measurements of Zeeman splitting in optical absorption features from Na I can provide continuous measurements of both the magnitude and direction of B fields, and thus current
- To obtain measurements over longer durations, we will need to understand how the droplets vaporize and ionize and explore options for positioning dopants and the SVS
- We are also exploring additional dopants* to increase the effective range of the measurement
  - Ba II 6s-6p lines at 4554 and 4934 Å
  - In I 5p-6s lines at 4102 and 4511 Å

*NIST ASD