Outbrief from the June 30-July 1 2015 Spectroscopy Workshop

National Diagnostics Workshop, Los Alamos

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Outline

- Overview of workshop
- Some Highlights from talks
- Review Format (what worked, what didn't)
- Discussion Day 1: Stagnation
- Discussion Day 2: Focused Experiments on single physics issue
- Future/Follow up
  - Spectroscopy needs at Z
  - Upcoming Spectroscopy platforms at NIF
  - Should major focus of National Diagnostic Plan for Spectroscopy be calibrations?
    - calibrations
    - focused experiments
- Summary

Discussions expressed thoughts and needs but not action items

Overview

- Workshop on X-ray Spectroscopy in support of HED science at Large Scale Facilities was held at LLNL
    - 2 days (June 30, July 1) PLUS ½ day classified discussion
    - 90 participants
        - U.S. National Labs (LLNL, LANL, Sandia, LLE, PPPL, SLAC, NRL)
        - European National labs (AWE, CEA, Weizmann Institute)
        - Academic (Imperial College, Oxford U., York U., U. Nevada-Reno)
        - Businesses (Prism Corp, ARTEP, General Atomics, NSTec)
    - ~15 participants joined via the Web.

- 28 talks
    - Diagnosing plasma conditions
        - high density stagnating plasmas
        - hot, solid density high Z plasmas
        - coronal plasmas (NLTE)
        - cold, dense plasmas (EXAFS)
    - Codes
    - Lineshapes
    - Opacity (experiment & models)
    - LMJ diagnostics
    - Calibrations

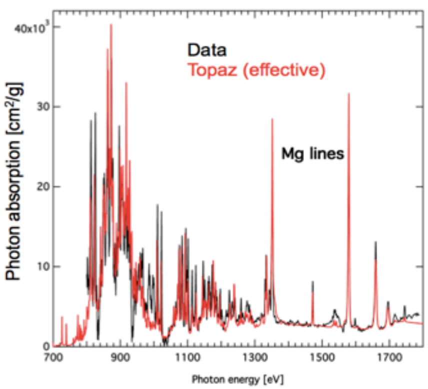
A wide variety of topics were discussed. A community was built

Some highlights: Opacity , High Resolution

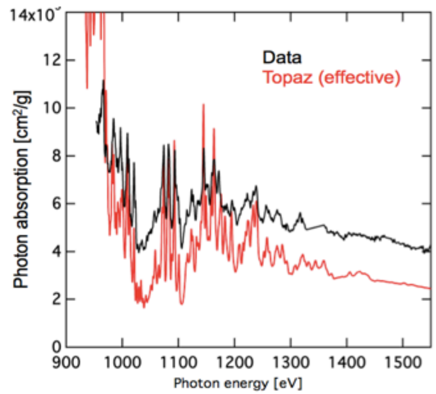
Opacity Results from “Z”

Data agree with models (TOPAZ) at 156 eV

Data disagrees with models at 182 eV



Old: Bailey *et al*, PRL 2007



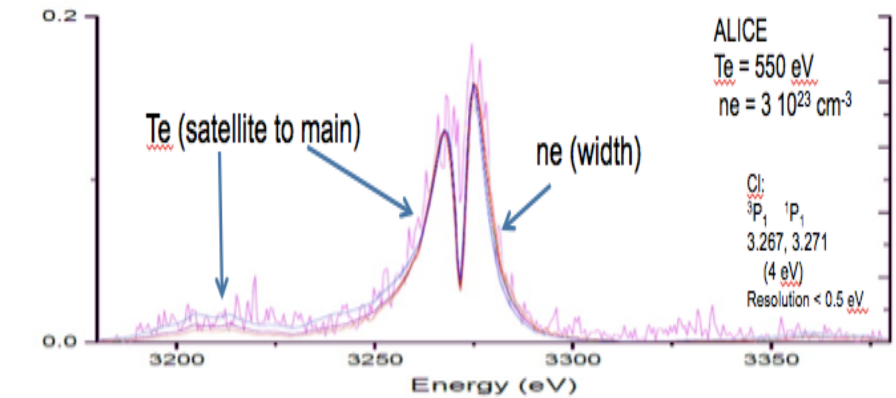
New: Bailey *et al*, Nature 2015

- Correct ionization state even at 182 eV
  (disagreement in linewidths ?)
- Disagreement in absolute value - why?
- Does model correctly capture the excited states?

J. Bailey (Sandia) talk C. Iglesias (LLNL) talk

Hi Resolution Spectrometer at Orion

Measure ne and Te from He-β complex



High resolution He-β spectra can measure ne and Te
(in certain regions of (ne,Te) space)

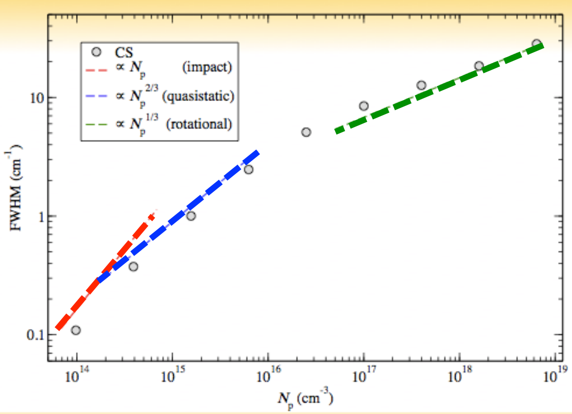
P. Beiersdorfer (LLNL, Data) talk
E. Hill (Imperial, ALICE code) talk

Some highlights: Lineshapes are used to • diagnose plasma conditions • calculate level populations

- Best lineshape calculations are computer simulations (CS)
- But codes need something _much_ faster (analytical model?)
- For Lyα in one component plasma (OCP), CS shows scaling in 3 regimes (T = temperature, N_p =perturber density)
  - impact (electrons) ~ $N_p / T^{1/2}$
  - quasi-static ("stationary ions") ~ $N_p^{2/3}$
  - "rotational" (dynamic -"moving ions") ~ $(T/M_p)^{1/2} N_p^{1/3}$ (M_p reduced mass)

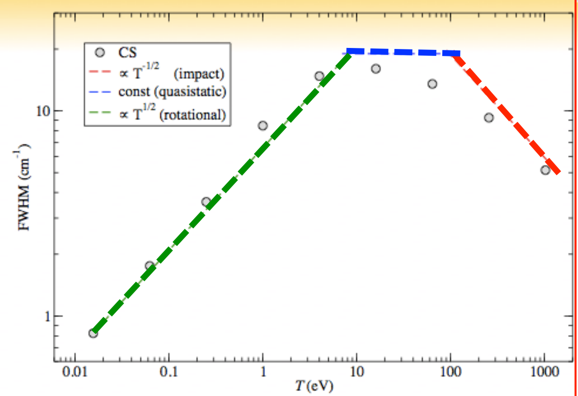
E. Stambulchik (Weizmann) talk

Lyman-α in an ideal OCP :: Varying N_p



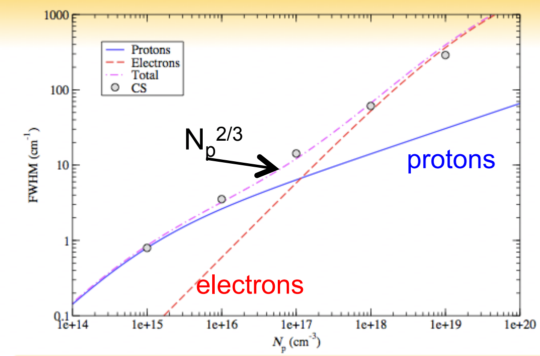
By varying N_p, broadening changes from the impact to rotational regime. Quasistatic-like dependence is just an intermediate case!

Lyman-α in an ideal OCP :: Varying T



Again, broadening changes from the impact to rotational regi[me] with the quasistatic-like dependence as an intermediate case.

Lyman-α in an ideal TCP :: Varying N_p



Over six orders of magnitude of N, FWHM scales close to ~ $N_p^{2/3}$. (Coincidentally, quasistatic-like dependence.)

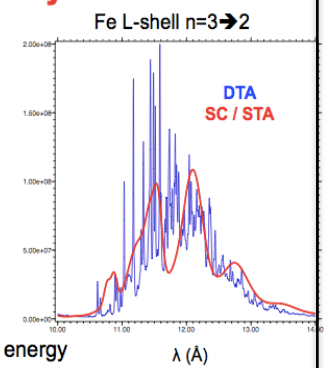
Ly-α and other Δn = 1 lines are well described by unified impact/rotational model

Some highlights: Overview of Codes

Definitions

Atomic Structure, Transitions and Acronyms

- Detailed Term / Line Accounting **DTA / DLA**
  - individual levels and transitions
  - detailed lineshapes for radiative bound-bound transitions
- Detailed Configuration Accounting **DCA**
  - levels lumped into relativistic (nlj) or non-relativistic (nl) configurations [(Ne) $3s^2 3p4s$]
  - transitions between configurations described by Spin-Orbit Split Array **SOSA** or Unresolved Transition Array **UTA**
- Superconfiguration **SC** combines configurations
  - related by quantum numbers $[(1)^2(2)^8(3)^3(4)^1]$ or similar in energy
  - transitions between superconfigurations described by Super Transition Array **STA**
- Screened Hydrogenic **SH**
  - Method of calculating energy levels (n), (nl), or (nlj) from screened charges
- Average Atom **AA**
  - Uses a single average charge state with non-integer occupancies



This is list of NLTE codes discussed

Code	Contact	Data Source	Atomic Structure	High-ρ CL	High-ρ degn	Radiation J_ν	Radiation EF	Radiation RT	Electrons hot	Electrons f_e	Other
ALICE	E. Hill (Imperial)	RCN + (ALICE)	DLA / DCA	✔		✔		1D	✔	✔	1D HD
ATOMIC RDCA	J. Colgan, M. Sherrill (LANL)	TAPS codes (LANL)	DLA / DCA	✔	✔	✔			✔	✔	
AURORA	J. Harris (AWE)	(AWE)	DLA / DCA	✔		✔					
CRAC	E. Stambulchik (Weizmann)	FAC	DLA / DCA	✔	✔				2T		
CRETIN DCA	H. Scott (LLNL)	SH / FAC / HULLAC / SCRAM	SC (+ DLA / DCA)	✔	✔	✔	✔	3D	✔	✔	1D MHD CX
DZAPP	NRL	RCN / FAC		?		✔	✔	1D			1D MHD
ENRICO	B. Wilson (LLNL)	(LLNL)	DCA	✔		✔			2T		
FLYCHK FLYSPEC	H.-K. Chung (IAEA)	FLY, SH, SC + DHS	FLY + SC DCA	✔		✔	✔		✔	✔	
PRISM	I. Golovkin (Prism Comp. Sci.)	ATBASE	DLA / DCA / SC	✔		✔	✔	3D	✔	✔	1D MHD
NOMAD	Y. Ralchenko (NIST)	FAC	DLA / DCA	✔		✔	✔		✔	✔	CX
SCFLY	O. Ciricosta (Oxford)	FLYCHK + DHS	SC	✔		✔	✔		✔	✔	
SCRAM	S. Hansen (SNL)	FAC + SH	Hybrid DLA / DCA / SC	✔			✔		✔		

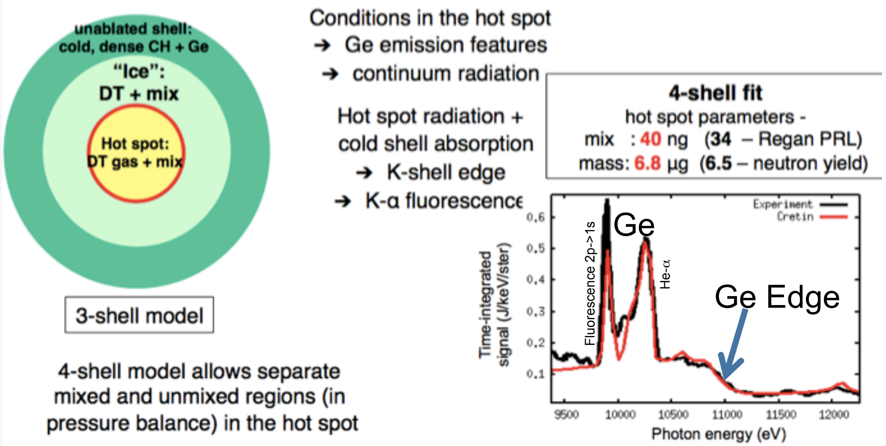
- Also LTE codes
- Not complete
- Also reviewed select experiments

H. Scott (LLNL) talk

This is a good reference

Some highlights: Indirect and Direct drive capsules

Measure HOT spot mass, MIX mass in Indirect Drive capsule

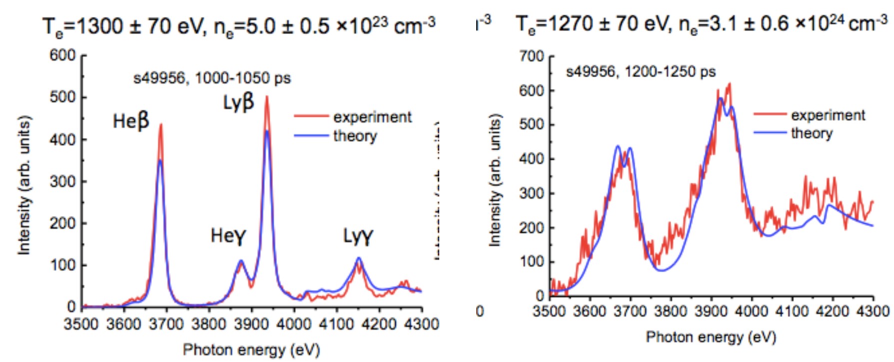


4-shell model allows separate mixed and unmixed regions (in pressure balance) in the hot spot

Collaboration:
O. Ciricosta, T. Preston, J. Wark (Oxford U.)
P. Durey, N. Woolsey (Univ of York)

Measure Te and ne in Direct drive, Ar-doped-D_2 plastic capsules

Fit line intensities and widths of argon β (1-3) and γ (1-4) lines



- Instrumental broadening included, FWHM=9eV
- Each spectrum is representative of Δt=50ps
- Steady state approximation good for $N_e > 1\times10^{22}$ cm^{-3}
- ρ [g/cm³] ≈ $3.24\times N_e$ [10^{24} cm^{-3}]
- Changes in plasma T_e and N_e conditions are reflected in characteristic changes in the argon tracer spectra

B. Hammel (LLNL) talk
S. Regan (LLE) talk (original analysis)

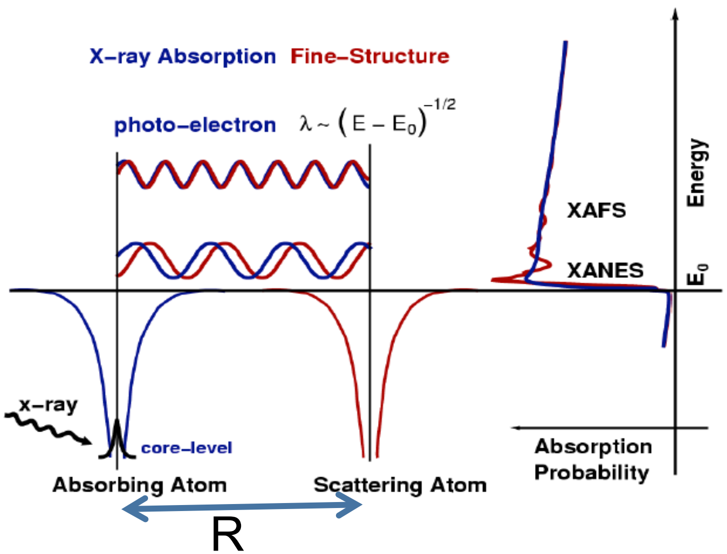
R. Mancini (U Nevada, Reno) talk

Some highlights: EXAFS (Extended Absorption Fine Structure) probes local electronic structure in solids

X-ray photon (energy $E_{ph} > E_{K\_edge}$)

- excites core electron to continuum
- k vector of electron wave:

  $h^2_{bar}k^2_{electron} / 2m = E_{ph} - E_{K\_edge}$
- Phase is $k_{electron}R$

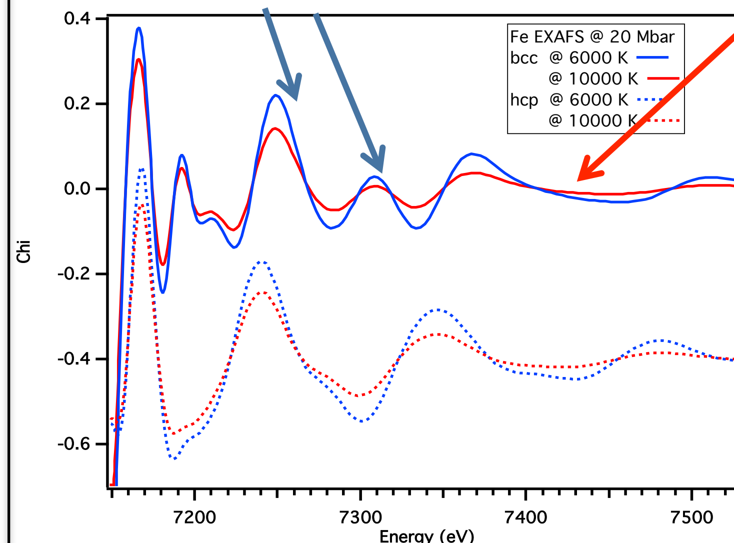


Interference of electron wave with reflections from neighboring atoms gives structure factor:

$$\chi(k) = \sum_j \frac{S_0^2 N_j f_j(k)}{kR_j^2} sin(2kR_j + 2\phi_j) e^{-2k^2\sigma_j^2} e^{-2R_j/\lambda(k)}$$

Local structure

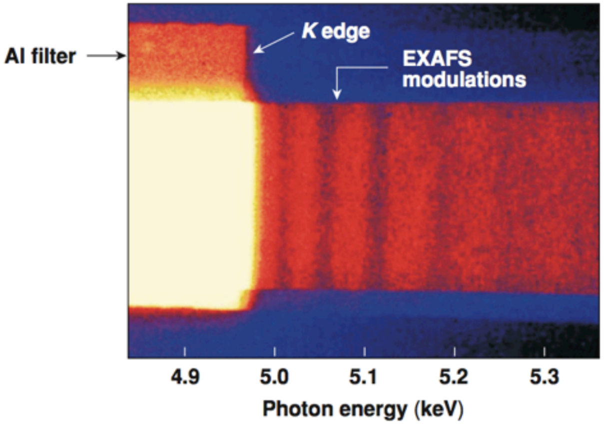
Disorder (Temperature) (faster decay of modulations)



B. Yaakobi (LLE) talk
F. Coppari (LLNL) talk

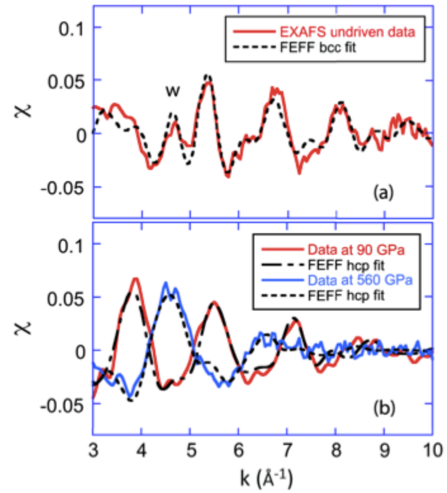
Yaakobi et al developed EXAFS platform at OMEGA to probe local structure in warm, dense matter

Raw EXAFS film image of unshocked Ti



Yaakobi (LLE) talk

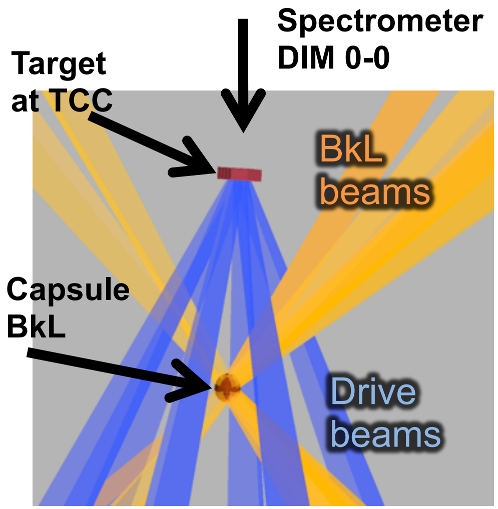
Analyzed EXAFS data for ramp-compressed Fe



- Clear signature for the bcc-hcp (close-packed) transition

Ping,PRL 111, 065501 (2013)

Similar EXAFS platform will be developed at NIF

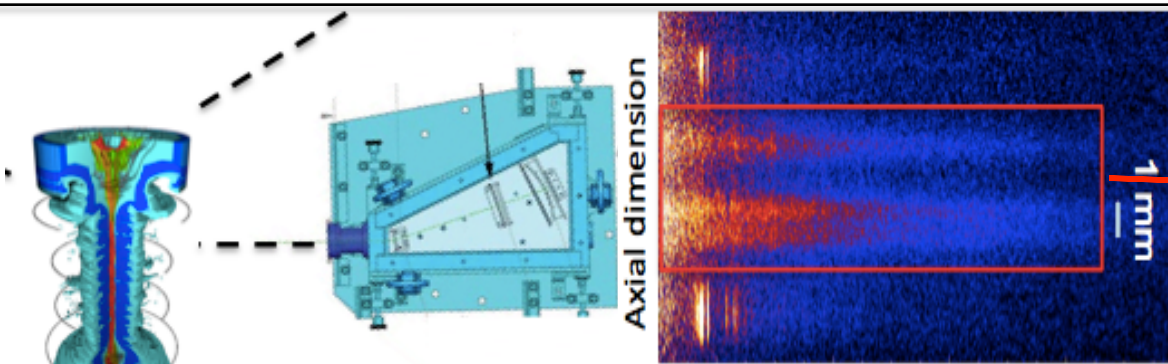


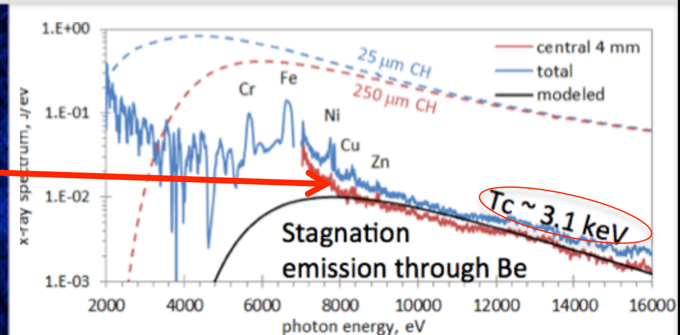
Coppari (LLNL) talk

Platform will be extended to NIF to study ramp-compressed mid to high Z materials

Some highlights: Measuring Te in MagLIF implosions and NIF hohlraums

MagLIF: Te is measured from continuum using time-integrated spectrometer



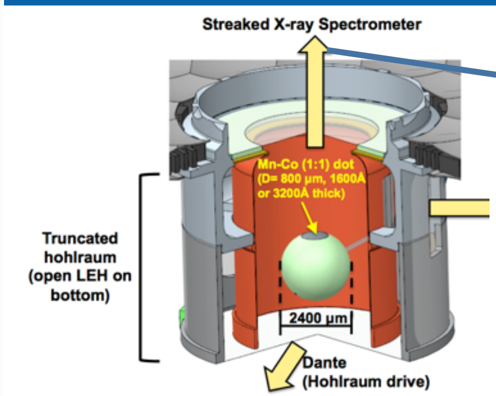


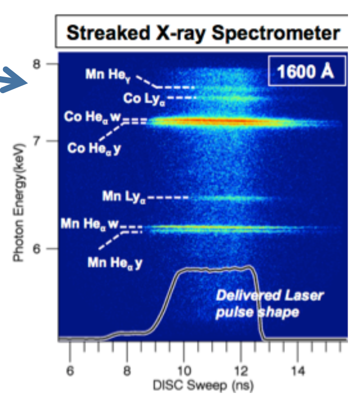
(continuum from Deuterium)

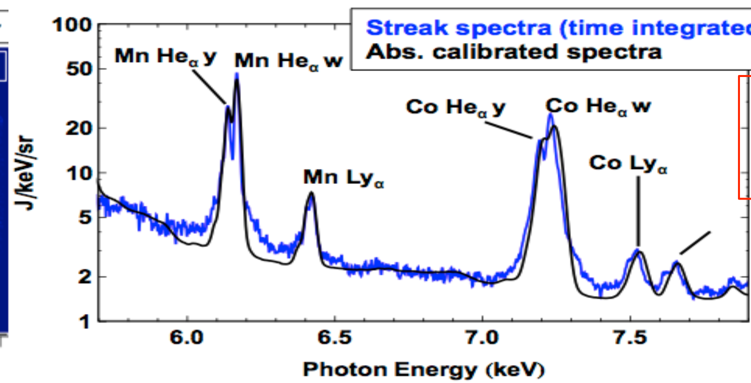
CRITRs: axially and radially resolved, time-integrated spectrometers (7-50 keV)

P. Knapp (SNL) talk

NIF Hohlraum: Te vs time is measured from line emission of dopants in a Mn/Co DOT







M. Barrios (LLNL) talk

The Format: what worked and what didn't

- People enthusiastic about a focused meeting

- People didn't like the idea of parallel sessions

- Configuration of meeting worked
  - LLNL LOFT computer worked well for US citizens and Foreign Nationals
  - WEBEX worked (10-15 people joined; LLE, Weizmann presented via Webex)

- Many people said they learned a lot, new collaborations formed, old ones strengthened (ex: LLNL-Weizmann to look at capsule physics)

- Not enough discussion – need more discussion throughout day rather than just at end
  - contradicts desire for single (not parallel) sessions

- Discussion session format should be improved
  - Plan them better –>
    - agree beforehand to definite questions and goals
    - talks associated with discussions should educate

Community is ready for more focused discussions on fewer topics

Discussion Day 1: Stagnation Spectroscopy

- Stagnating plasmas occur in Indirect Drive, MagLIF, Direct Drive
  - At workshop, did not discuss stagnation in DD or MagLIF
  - In future, more discussion on MagLIF , DD

- Spectroscopy of Hot Spot in Indirect Drive
  - Cannot dope DT
    - dopants freeze out onto ablator at higher temperature than needed to freeze DT
    - Plan: measure electron temperature (Te) from the DT free-free continuum
  - Alternative capsule design: Use foam layer instead of DT ice
    - Use liquid DT in foam+ dopant (Kr)?

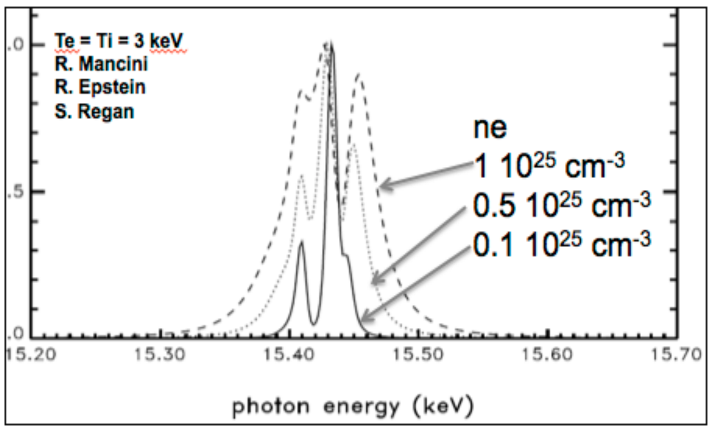
      OR
    - Dope foam with Cu + liquid DT
    - Foams require development

- Surrogate capsules (symcaps) CAN be doped with Kr as no DT ice layer
  - We can benchmark our DT measurements
  - We can measure electron density (ne) and Te

A point design to use spectroscopy to measure ne, Te in symcap is being developed

A resolution of 5 eV at the Kr He-β line of 15.5 keV is sufficient to measure ne and Te

Kr He-β structure broadens with ne



Resolution of 5 eV or E/ΔE =3000

- This does not include other charge states

Signal level for Symcap

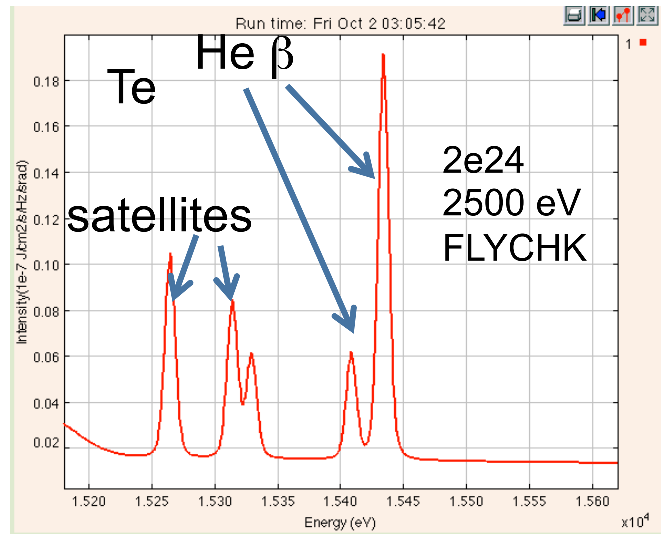
Te = 2.5 to 3 keV

Ne = 1 to 5 e24

Burnwidth : 150-200 ps

TO estimate signal:

Te = 3 keV
Ne = 2. e24
Kr: 1 Kr atom in 10^4 D-He3
Time resolution = 30 ps
Size: 50 μm diameter



(need better model than FLYCHK)

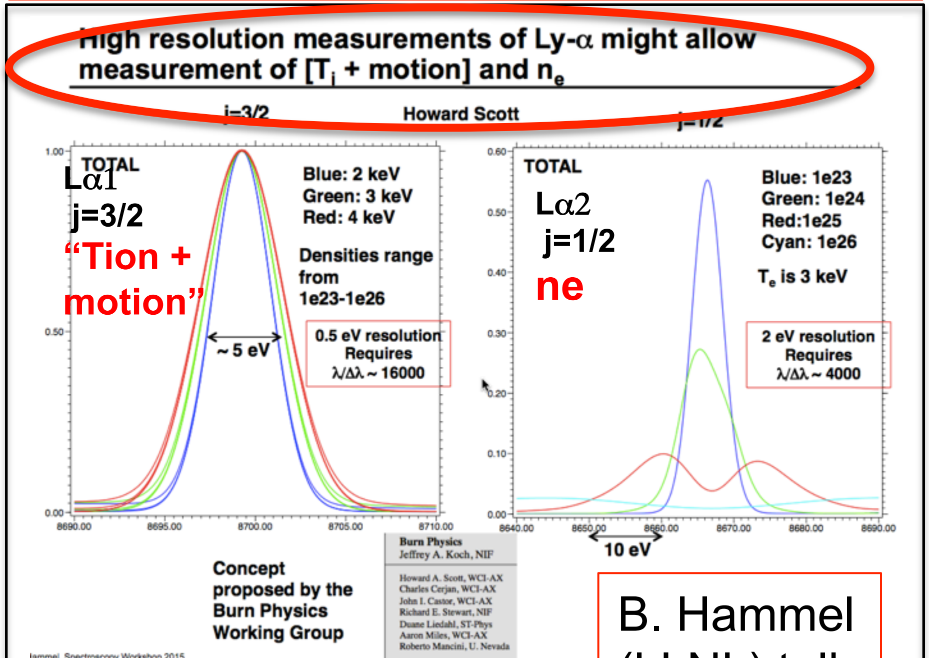
- Further modeling of Kr spectra is needed
- PPPL is designing a Kr He-β spectrometer to mount to a streak camera (**K. Hill talk**)
  - Cylindrical crystal (von Hamos) • Later: conical • conical with elliptical** profile?]
  - Easily modifed to look at lines from other nearby ions (for foam-doped DTs)

**A. MacPhee

The plan is to use a symcap to benchmark the Te from continua with Te from line spectra

Stagnation spectroscopy : Measuring Tion is complicated by hydrodynamic motion (velocity)

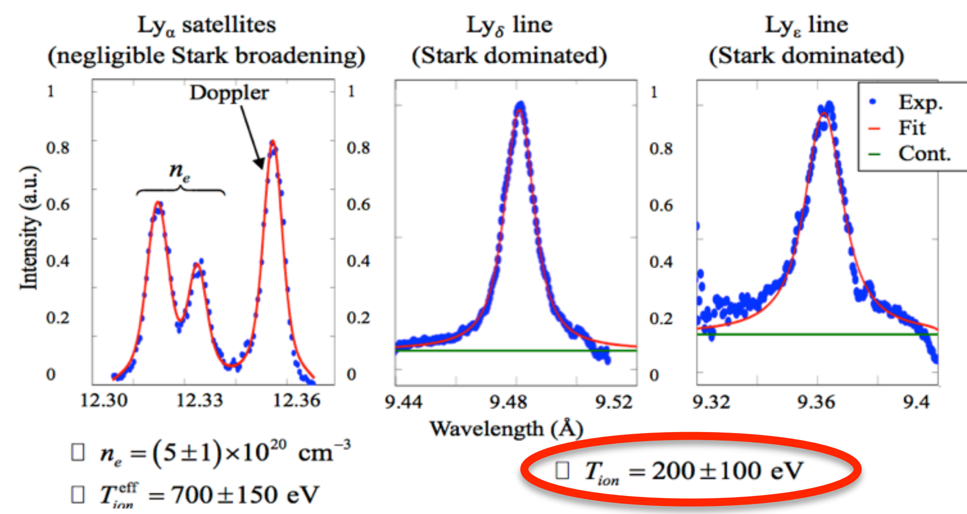
IF can dope foam with Cu in DT capsule



B. Hammel (LLNL) talk

Line width is Doppler Broadened by ion temperature AND ion velocity

Tion using 2 spectrometers: Lyα(sat) & δ, ε



Lyδ Lyε : Stark dominated by ionic fields so sensitive to Tion

Neon in WIS Z pinch

2. Stark method D. Alumot et al., invited talk, *ICOPS* (2013). D. Alumot, Ph.D Thesis, WIS (2014).

Lyα satellites:
J. Seely, PRL 1979

Y. Maron (Weizmann) talk

Could a "standard candle" platform be developed to measure Tion from neutrons and spectroscopy? Can we figure out how to separate temperature from velocity?

Discussion Day 2: Focused expts on single physics issues needed to benchmark physics in new HED regimes

- Lineshapes to measure density (10^{22}-10^{25} cm^{-3})
  - electron broadening model
    - good (to > 20%??) for beta lines in He and H- like ions
    - predicts half the measured width in Li-like and Be-like isolated lines
  - ion broadening (important in alpha lines) how important ? How well understood?
    - Suggest new expts: Orion compare H,He like to Li, Be like; X-ray TS???
  - NIF (OMEGA?) Benchmark line broadening model for density by measuring
    - Line width • Expansion of target

- Continuum lowering, IPD– need to do scaling experiments, simple Be, x-ray TS?
  - high T, high density (Orion) to low T, high density (LCLS)
  - different in doped vs undoped; impt for NIF capsule expts?

- NLTE plasmas:
- Emissivity • Optical Depth effects • Te from line ratios

Other issues: • Effect of excited state populations on: • LTE opacity • Lines shapes
• Configuration Interaction • Two photon processes

Basic experiments (rather than integrated ones) are needed to benchmark atomic physics

Future: Spectroscopy diagnostics needed - Z

- Time resolved spectra is needed for Te
  - now use spherical focusing xstals to get enough signal
  - crystals are destroyed on every shot
  - Gated, single of sight capability (such as hCMOS + pulse dilation) in FY19-20

- Need focused effort to measure Tion–
  - NTOFs (scintillators and PMTs) need to be closer to diagnose lowest MagLIF shots
  - Spectroscopic:

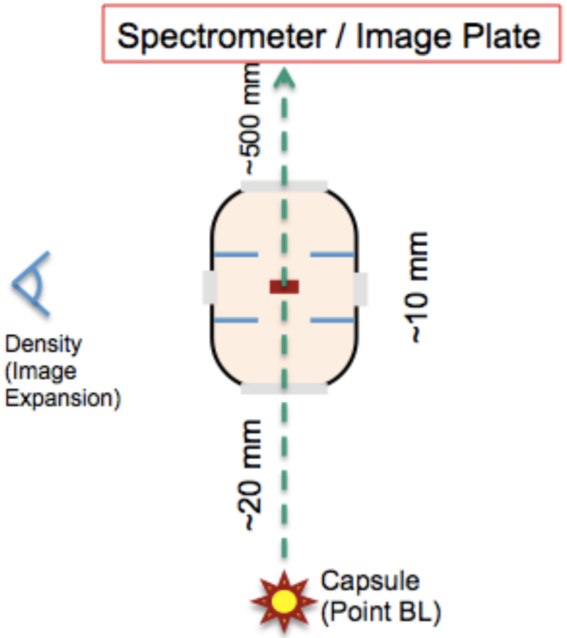
    How to deconvolve flows from temperature ?

    Which lines are best

Universal need for: • Gated, SLOS imagers • Tion decoupled from hydro
(but parameters, timescale, energy range, may differ)

Future: Time gated, high dynamic range detectors are needed for spectroscopy at NIF

Opacity Platform at NIF:
- Point Backlighter (capsule)
- Spectrometer + Image Plate



T. Perry (LANL) talk

EXAFS and Opacity Platforms:

- short duration capsule Point Backlighter
- Spectrometer + Image Plate
    - High dynamic range
    - Excellent resolution
    - TIME integrated so collect background
        - X-ray drive
        - Self-emission from target
    - Shot cycle time

BOTH platforms benefit from high dynamic range, good resolution, gated detector

Gated detector that can be placed at any orientation can revolutionize spectroscopy

Future: spectroscopy Platforms being developed at NIF

- High density, high T (Stagnation)
  - DIM-based He-beta spectrometer (Te and ne) onto DISC (streak camera)
    - von Hamos • conical • ?conical with elliptical cross section

- Materials studies in High density, Low T (warm dense matter)
  - EXAFS spectrometer (also snout in a DIM) • ? High resolution XANES ?

- Opacity: • Spectrometer designed by P . Ross (NSTec), R. Heeter (LLNL)
  - Based on SNL design • Spectrometer on framing camera for density

- DOT (Te in hohlraums)
  - ?new spectrometer for ne? • do we need $\Delta Z=3$?
  - ? Time-resolved imaging spectrometer looking in from side?

- new Au M band spectrometer: VIRGIL (built J. Weaver (NRL)) → add time resolution

- Te-Tion new platform using Ar dopant to measure Te, ne, Tion

What do we have in common?

We are a diverse group (source size, timescales, absolute intensities, debris issues…)

BUT we can agree on three things

1. Need for high dynamic range, high resolution gated detector (Gated C-MOS)

2. Need for focused experiments

3. Importance of Calibration

Should a National Diagnostics Plan for Spectroscopy be Calibration?

Should a National Diagnostic Plan for Spectroscopy be calibrations?

- Very expensive to calibrate (what standards do we need?)
  - relative sensitivity over energy range of interest more important than absolute
  - go to high resolution, satellite to main/satellite ratios
    - avoids relative calibration issue
    - how good are the codes?

- Pool resources and understanding
  - Ex: NSTec (M. Haugh) and SNL (G. Loisel) (M. Haugh (NSTech) talk)
    - understand crystal rocking curves:
      - radius of curvature
      - x-ray energy
      - material
      - thickness
  - CEA is also worrying about calibrations for LMJ (C. Reverdin (CEA) talk)

- NIST has calibration facilities and standards (J. Seely, (ARTEP) talk)
  - Can we calibrate there?
  - Develop secondary standards?

- Calibration facilities have been lost
  - every spectrometer that went “down hole” was calibrated locally
  - should we selectively rebuild?
  - Train young spectroscopists with “hands-on” experience ?

Summary

- Workshop had 90 participants + 15 joined remotely ; 28 talks
  - Built a community
  - Viewgraphs will be available to public (25 out of 28):
    - internal NIF WIKI (now)
    - NIF User Website (soon)

- New collaborations were formed (LLNL-Weizmann) and old ones strengthened

- APS-DPP is next month
  - ?working lunch on ideas for focused experiments ?
    - line widths
    - excited state populations

- HTPD is next June:
  - " mini symposium ” on calibrations?

- Sometime next year – Stagnation (Indirect drive, direct drive, MagLIF)
  - How to measure “Tion” using spectroscopy

Lawrence Livermore National Laboratory