Time Resolved $T_e$ from X-ray Streak Camera Measurements at the NIF

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Outline

- **X-ray Streak Cameras on NIF: SPIDER & DISC**
  - This talk will show $T_e$ using SPIDER; DISC will need to be adapted for $T_e$
- Method of inferring $T_e$ using a hot spot model & filters
- $T_e$ results using SPIDER from recent DT shots on NIF
- Opacity of fuel, ablator & plasma and uncertainty in filter thickness causes problems in calculating $T_e$
- Continuum Method of inferring $T_e$
- Future plan: Using DISC for inferring $T_e$ using the Continuum
The two X-ray Streak Cameras on the NIF, SPIDER¹ & DISC², are utilized differently

SPIDER is a fixed diagnostic that primarily measures bang time and burn widths from implosions, DISC is a DIM instrument used for 1D Radiography experiments and spectroscopy with NXS³

¹Streaked Polar Instrumentation for Diagnosing Energetic Radiation ²DIM Imaging Streak Camera ³NIF X-Ray Spectrometer
SPIDER is mostly a fixed diagnostic, whereas DISC can vary its recording parameters

- Both SPIDER and DISC use an identical streak tube design
- Calibrated sweep windows: 3, 5, 10, 20 ns
- SPIDER temporal slit: 150 µm $\rightarrow$ 13 ps temporal resolution
- SPIDER photocathode: 1 µm CsI
- DISC temporal slit: 100 µm – 500 µm
- DISC photocathodes: 0.15, 0.2, 1 µm CsI & 30 nm Au

SPIDER uses a fixed slit, photocathode and standoff distance while DISC can change these as well as affix a snout for 1D imaging, spectroscopy, etc.; However, it must occupy a DIM
SPIDER uses sets of four filters as Ross pairs & to infer $T_e$.

N150416: DT 3-shock adiabat shaping, DU Hohl, 1.77MJ, 390TW, 1.6mg/cc 4He fill, 1xSi, T-1(175um) CH capsule, Di=6.9/6.2, mini-quench
$T_e$ is inferred by comparing the measured signal to simulated signals using a model

**Generalized Hot Spot Emission Model**

Hot spot model using fits to DCA* 100 Gbar tables (Patel):

$$f_{\downarrow}H = \frac{2.8}{A_{\downarrow}v^2} Z_{\downarrow}H^2 \times 5.04E22 e^\uparrow - \frac{hv}{kTe} \frac{1}{(hv)^{0.39}} \frac{1}{(kTe)^{0.15}}$$

Bound-Free Absorption (Atzeni, Patel): 

$$Absorption \sim e^{\uparrow - (Emfp/hv)3}$$

$$Emfp \sim (\rho L)^{1/3}$$ is equivalent to the photon energy corresponding to a single mean free path through the shell

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*Detailed Configuration Accounting, Opacity model in HYDRA*

Absorption becomes insignificant above 20keV
$T_e$ and Absorption are simultaneously solved by minimizing the $\chi^2$ difference from measured signal

- Integrate the simulated signal over all energy for each filter
- Scan over a range of $T_e$ and $E_{mfp}$ until the squared difference between measured and simulated signal is minimized
- This analysis often results in no absorption

Least squares fit of $T_e$ and $E_{mfp}$ comparing measured signal to model is found for each time step
In this example, calculated $T_e$ is close to $T_{ion}$ measurement from N-TOF’s of 5.3 keV.

Calculated zero optical depth; Gaussian fit of signal produces smooth $T_e$ evolution.
This HDC DT shot produced two x-ray peaks, the 1\textsuperscript{st} from the core and the 2\textsuperscript{nd} from the shell.

It is expected that the 2\textsuperscript{nd} hump have a much lower temperature, since the carbon emission occurs in the colder shell region.
However, the analysis returns a low $T_e$ throughout the emission and a jump in the optical depth.

Jump in optical depth

DT Tion
~ 3.8keV
Fixing optical depth at 0, the calculated $T_e$ is within range of $T_{\text{ion}}$ and evolves as expected.

DT $T_{\text{ion}}$ ~ 3.8keV

Sharp drop in Electron temperature with shell emission

Systematic issue: (1) Opacity model may not capture HDC/NVH well, (2) filter transmission not as assumed
Opacity of fuel, ablator & plasma and uncertainty in filter thickness causes problems

Using thick filters that would sample the continuum region of the hot spot model would eliminate the reliance in opacity models and drastically reduce uncertainty in filter thickness.
Continuum model requires two thick filters to solve for $T_e$; add’l filters for Opacity or Ross pairs.

Titanium filters, 400 & 600 µm thickness are one choice that would focus on Continuum slope.
Simulating the SPIDER signal through thick Ti gives low signal

Simulation based on the 1st results shown: N150416

SPIDER Signal through thick filters would be close to detector noise: unreliable $T_e$ calculations
DISC would be better for inferring $T_e$ using the continuum slope method

- DISC on a DIM can get ~7X closer to TCC for up to 50X more solid angle than SPIDER

- In order to optimize dynamic range of the streak camera with the other thinner filters, 1% Open Area ratio Gold Mesh (20 micron thick) would be used to reduce signal on thinner filters

- Currently, DISC can’t operate in high neutron flux not only due to CCD, but also because the instrument contains components with EEPROM* and micro-controllers

*NElectrically Erasable Programmable Read-Only Memory

NIF may build a DISC usable in a high neutron flux similar to the HGXD’s
Simulated DISC signal through thick filters would give exceptional S/N

Simulation based on the 1st results shown: N150416

This signal level would theoretically result in good $T_e$ calculations; Possible to use even thicker Ti
Summary

- \( T_e \) can be inferred by performing a least squares fit of x-ray signal through certain filters to signal derived from a generalized hot spot model.

- The \( T_e \) results using data from SPIDER show reasonable time evolution and good agreement with \( T_{\text{ion}} \) but unrealistic absorption.

- There is uncertainty in the opacity model & filter thicknesses.

- The continuum slope method may be better for inferring \( T_e \).

- DISC would be ideal to record hard x-rays since it can be placed much closer to TCC and detect optimal signal levels using thick filters.

NIF may build a DISC usable in a high neutron flux similar to the HGXD’s.
Calculated $T_e$ using simulated signal gives similar values to thinner filter results

$T_e$ decreases through emission
Fixing optical depth at 0, the calculated $T_e$ is within range of $T_{ion}$ and evolves as expected.
Ge transmission source shows negative Ross pair results even though model shows positive.
Ge He$_\alpha$

Ge He$_\beta$

Tilted foil

Signal (J/keV/ster)

* S. Regan

E (keV)

N141213-001

N141214-002

ch. 3: 7.2–12.7 keV

1 mm

photon energy -->
Analyzed data on another DT symcap shot

DT shot using a 3-shock high foot pulse

Performance:
DT $T_{\text{ion}} \approx 5.1$ keV
DT Yield $\approx 6.2 \times 10^{15}$

N150528:
High Foot DT, 1.78MJ, 390TW, DU nominal hohl, 1.6mg/cc He fill, 1xSi, T-1 shell, 0.8K quench, P1 asymmetry imposed ice layer
Calculated peak $T_e$ is close to time-integrated $T_{\text{ion}}$ measurement of 5.1 keV

$T_e$ increases then decreases through x-ray emission
Calculated evolution of $T_e$ is very smooth if using a Gaussian fit of the signal.