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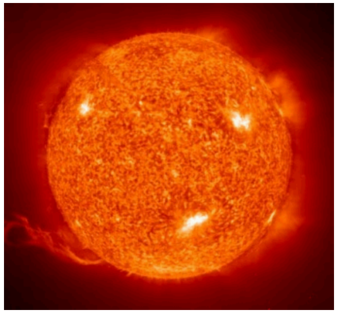

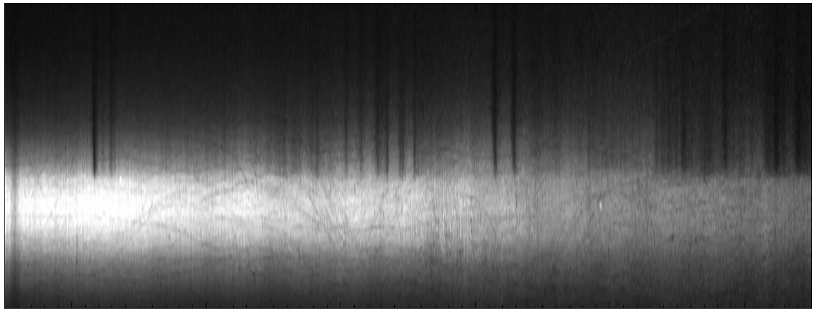

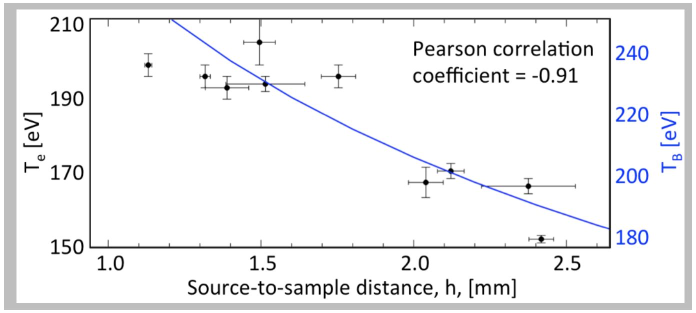

Parallax diagnostics of radiation source geometric dilution for iron opacity experiments

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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The stellar opacity collaboration involves universities, U.S. national labs, a private company, and the French CEA laboratory

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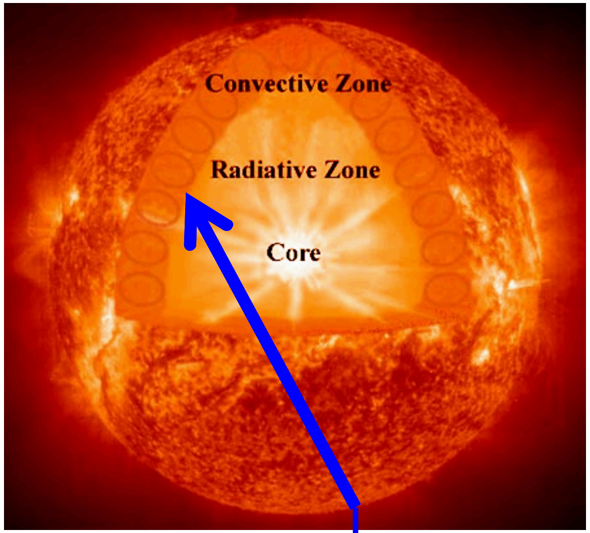
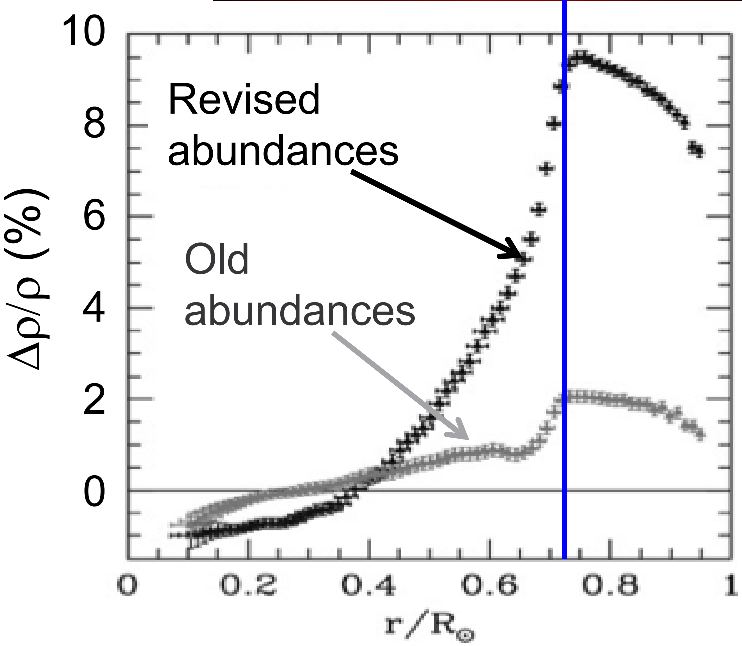
After solar abundance revision in 2005, standard solar models disagree with helioseismology

- Standard solar model (simulation)
  Inputs:
  - Abundance
  - EOS
  - Opacity
  - Etc.
- Helioseismology (measurements)

- Solar abundance revised in 2005
  - C, N, O, Ar, Ne → lowered by 35-45 %
- Now, standard solar model disagrees with helioseismic measurements

CZB location: 1σ → 13-30 σ

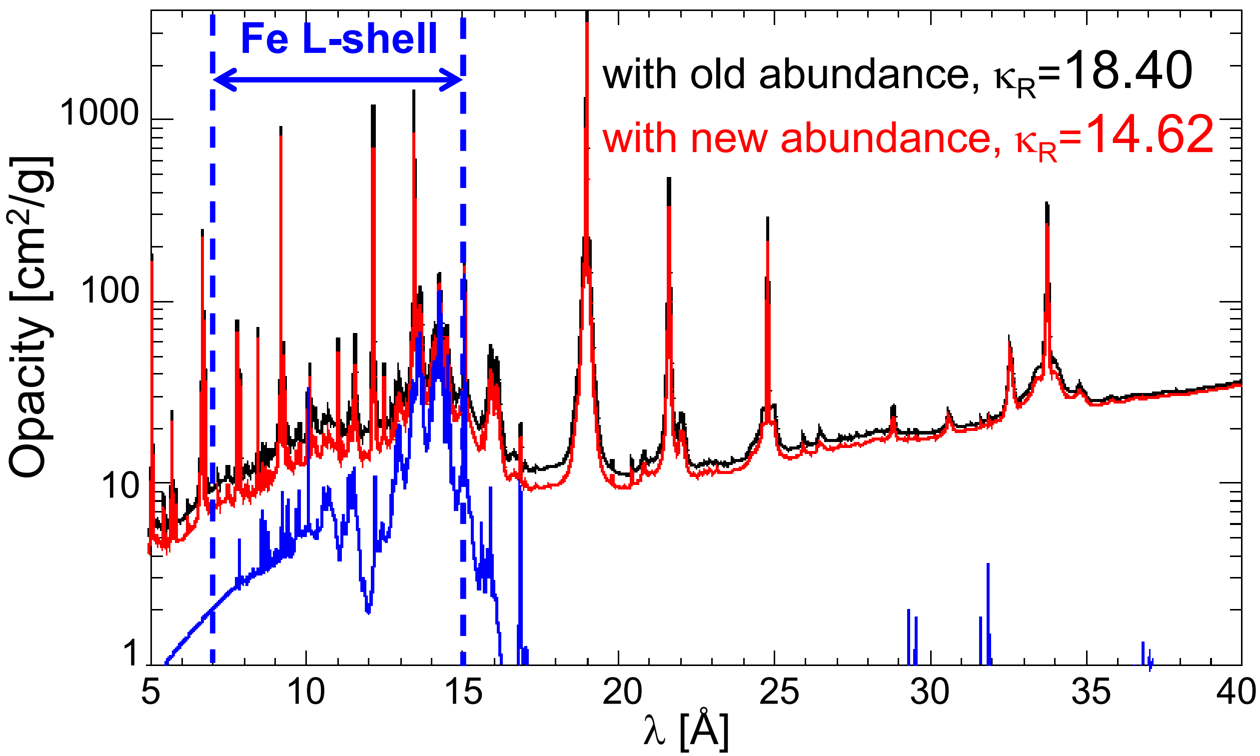




S. Basu *et al*, Physics Reports **457**, 217 (2008). M. Asplund *et al*, Annu. Rev. Astro. Astrophys. **43**, 481 (2005).

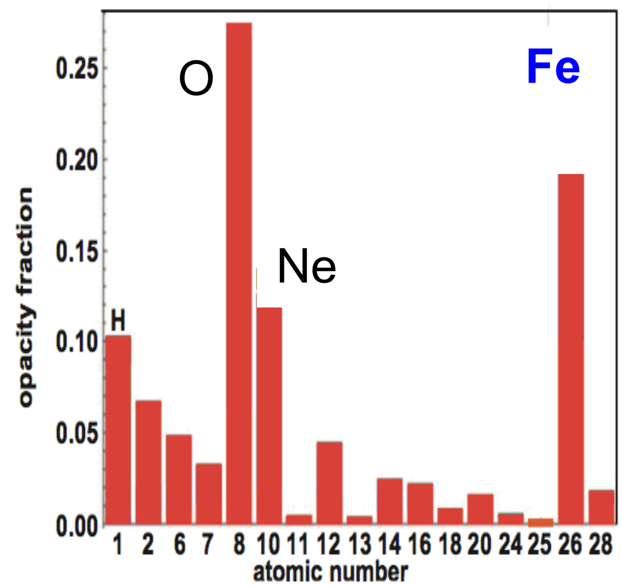
Disagreement could be resolved if the true opacity is higher than predicted

Solar mixture opacity at Convection Zone Base (CZB)



CZB condition:
T_e=182 eV
n_e=9x10^{22} cm^{-3}

CEA OPAS calculation

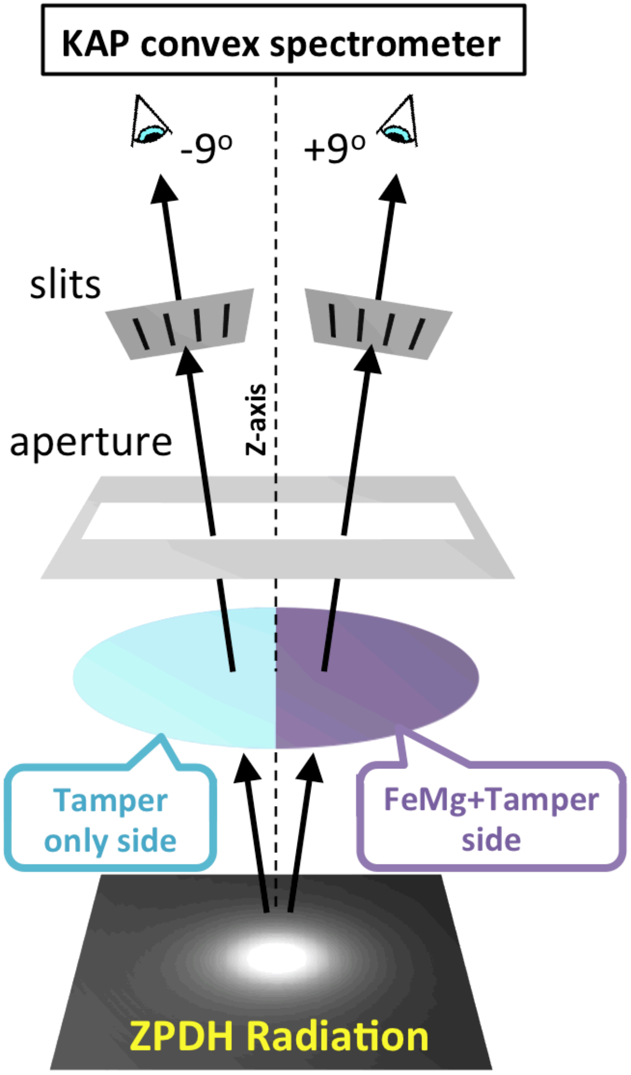


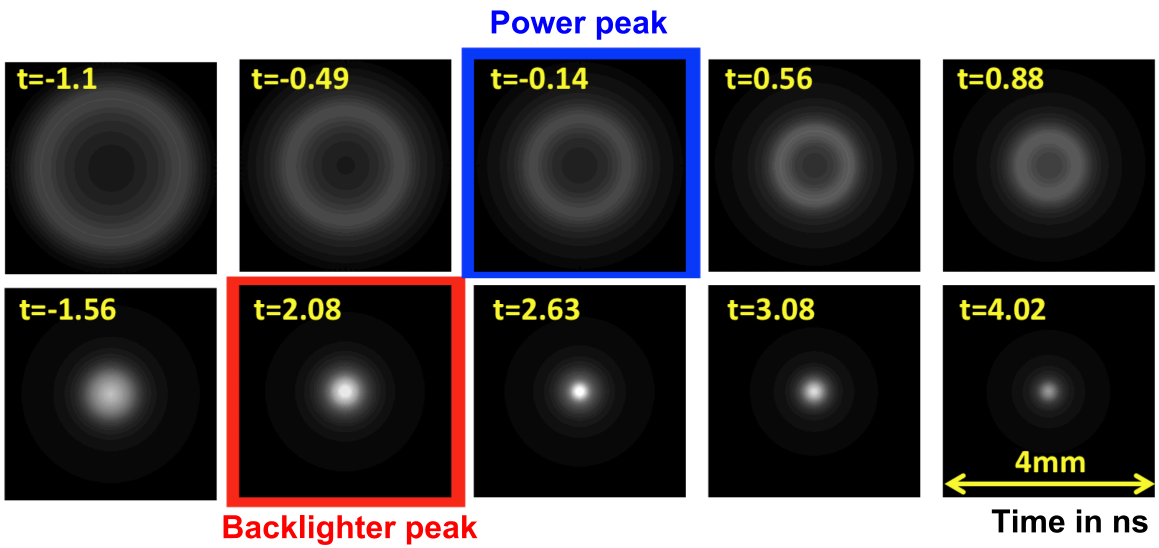
Rosseland mean opacity → heat transfer by radiation

$$\frac{1}{\kappa_R} = \int \frac{1}{\kappa_\nu} \frac{\partial B_\nu}{\partial T} d\nu \Big/ \int \frac{\partial B_\nu}{\partial T} d\nu$$

Let's measure Fe opacity at CZB conditions

FeMg is heated and backlight by Z-pinch dynamic hohlraum (ZPDH) radiation





- Target = half-moon sample
  - Semicircular FeMg sandwiched by circular tamper (e.g. plastic, CH)

- Sample is heated during the ZPDH implosion
- Sample is backlit at the ZPDH stagnation

- Attenuated ($I_{\nu,FeMg}$) and unattenuated ($I_{\nu,0}$) spectra are measured at ±9o spectrometers, respectively

- FeMg Transmission in a single experiment

$$T_{\nu,FeMg}=\exp(-\kappa_{\nu,FeMg}\rho L) I_{\nu,FeMg}/I_{\nu,0}$$

Target configurations control FeMg conditions

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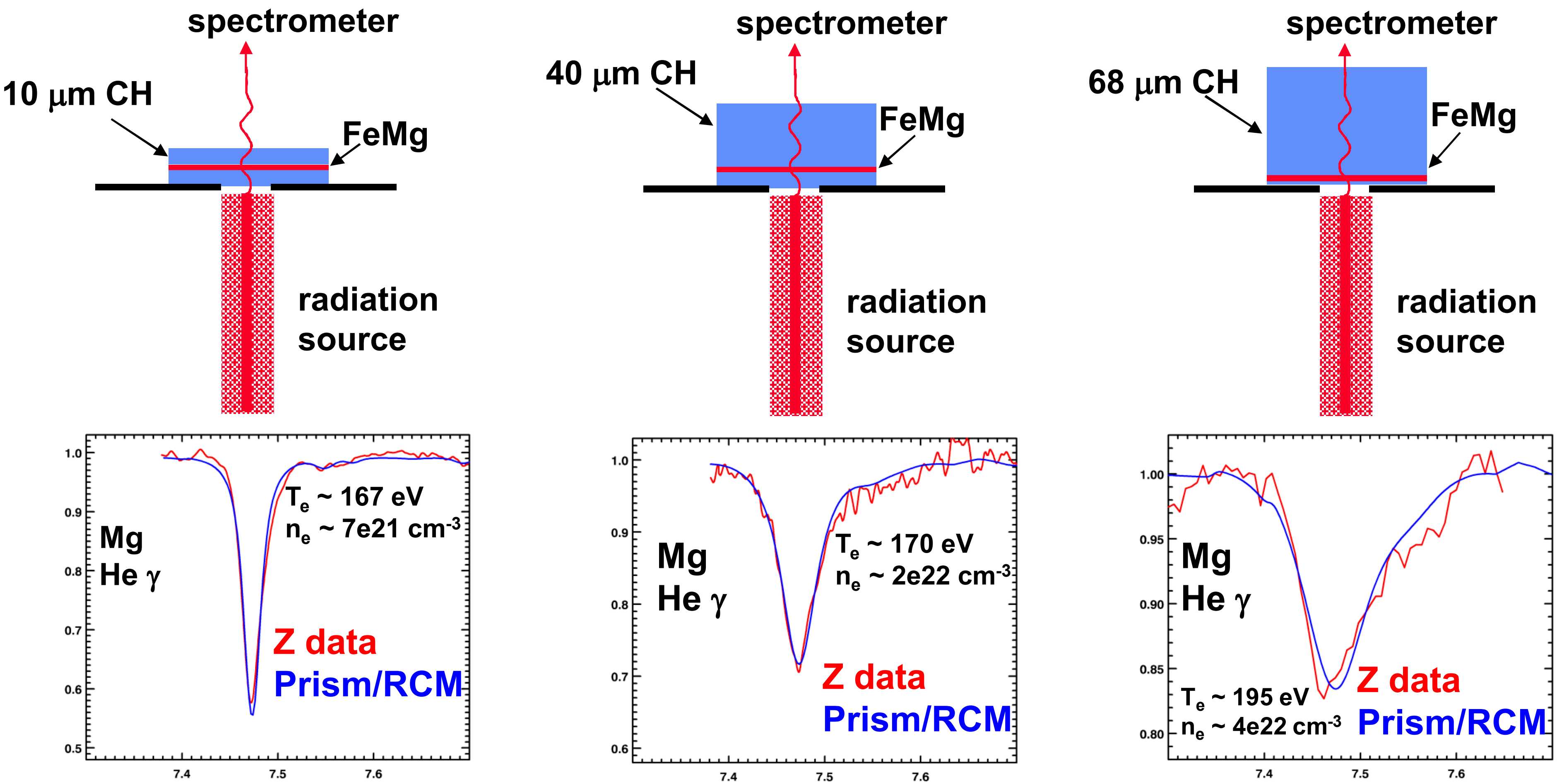

- FeMg conditions are inferred by Mg K-shell spectroscopy
- Density increases by increases the top tamper thickness (mass)

But, why does the temperature also increase?

Sample-source distance can be measured with parallax

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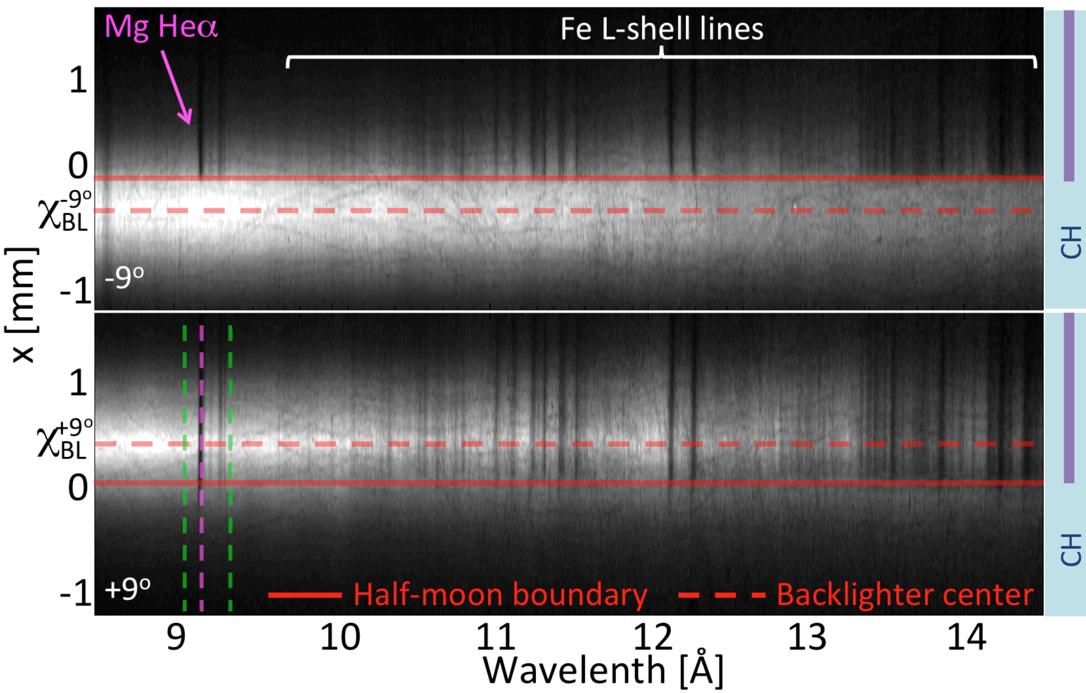
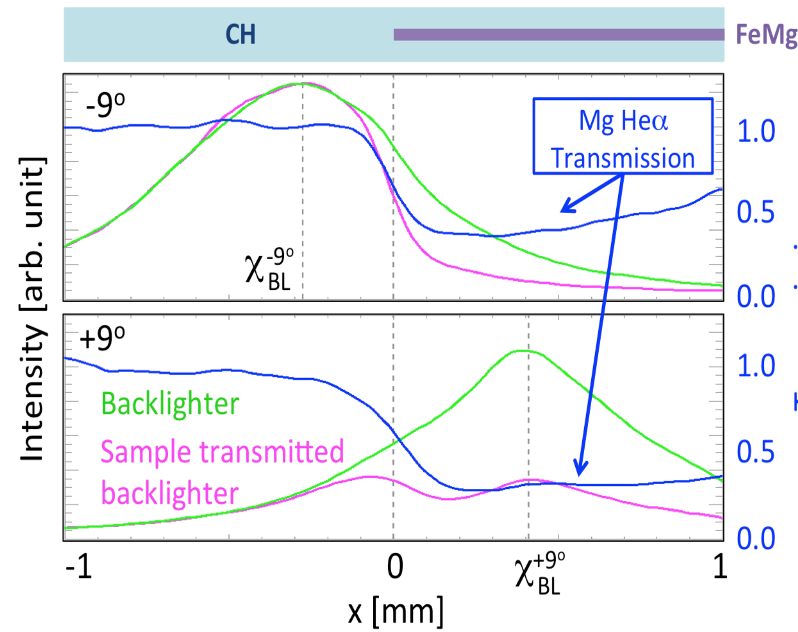
Image data measured at ±9°



Spatial lineouts at ±9°



<u>Sample-source distance:</u>

$$h = \frac{x_{BL}^{+9^\circ} - x_{BL}^{-9^\circ}}{2\tan(9^\circ)}$$

- +9° shows longer FeMg lines because of apparent backlighter location
- Spatial lineouts at line center (e.g., Mg Heα) and at nearby continuum define the apparent backlighter peaks, $\chi_{BL}^{+9^\circ}$ and $\chi_{BL}^{-9^\circ}$
- Transmission spatial lineouts can be determined by magenta/green
- Transmission spatial lineouts define the half-moon boundary, x=0

Fe temperature, T_e, is correlated with measured sample-source distance, h

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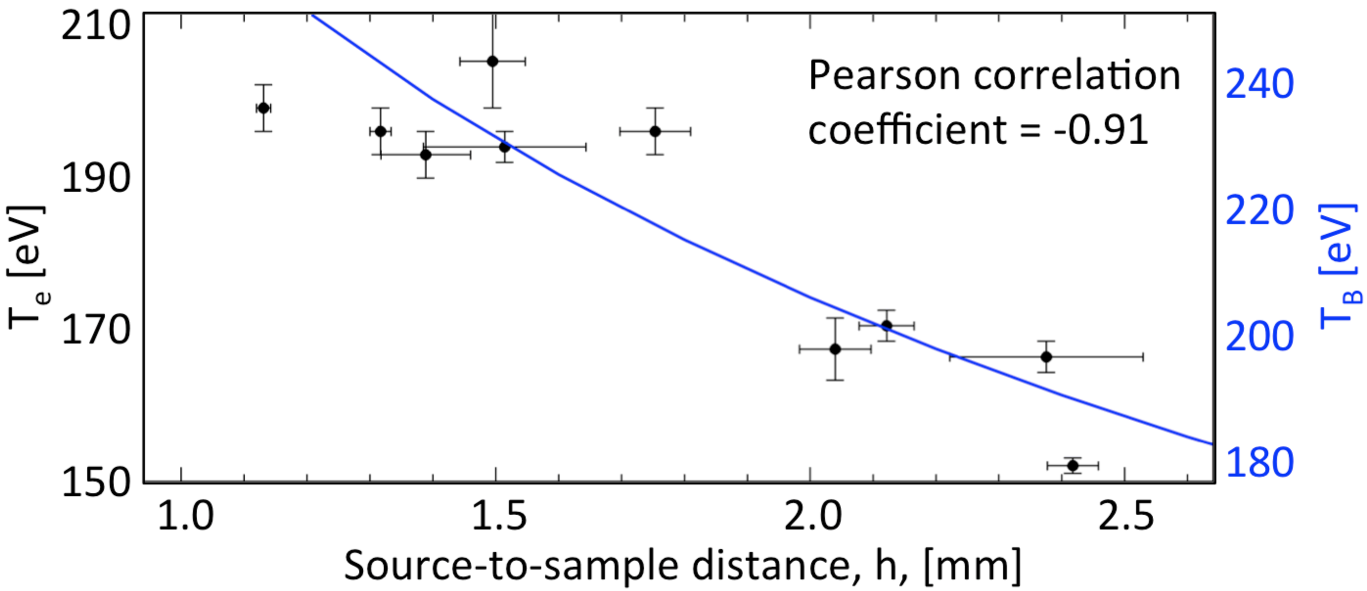

Conclusions:

- Parallax is systematically applied to 10 Fe opacity experiments
- There is a strong correlation between measured Fe temperature, T_e, and measured source-to-sample distance, h
- T_B is modeled brightness temperature as function of distance, h
- Sample temperature is controlled by radiation source geometric dilution

Q. Why is this result important?

A. It refines the understanding of our measurements!

Parallax results are critical to model heating radiation for each experiment

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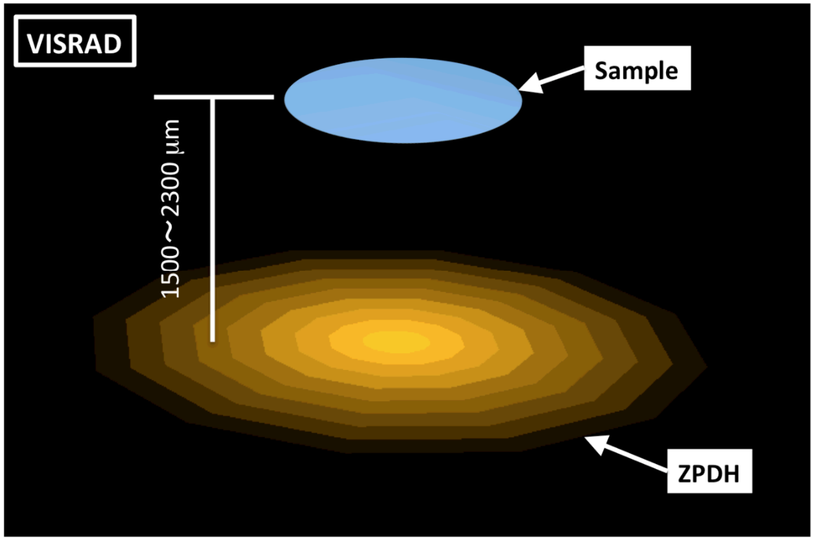
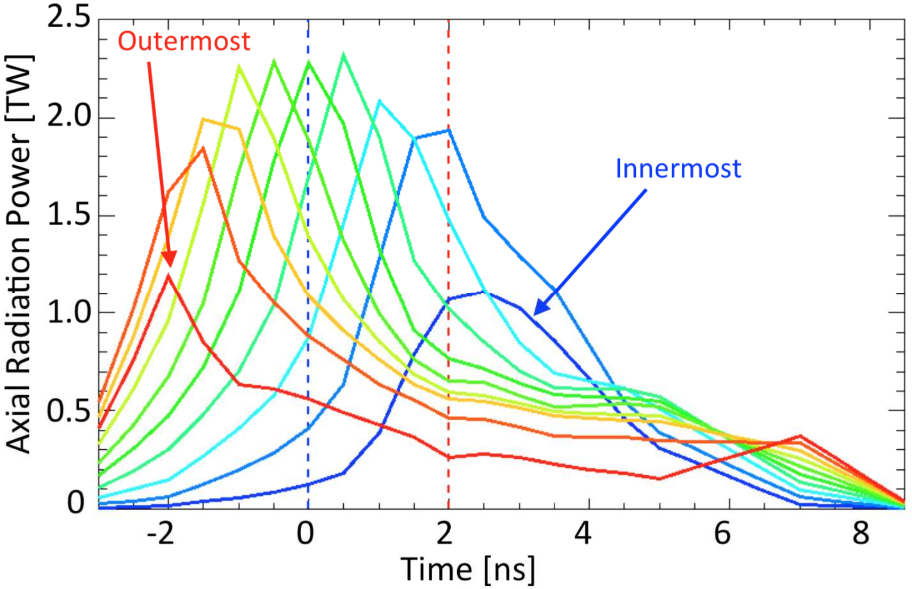
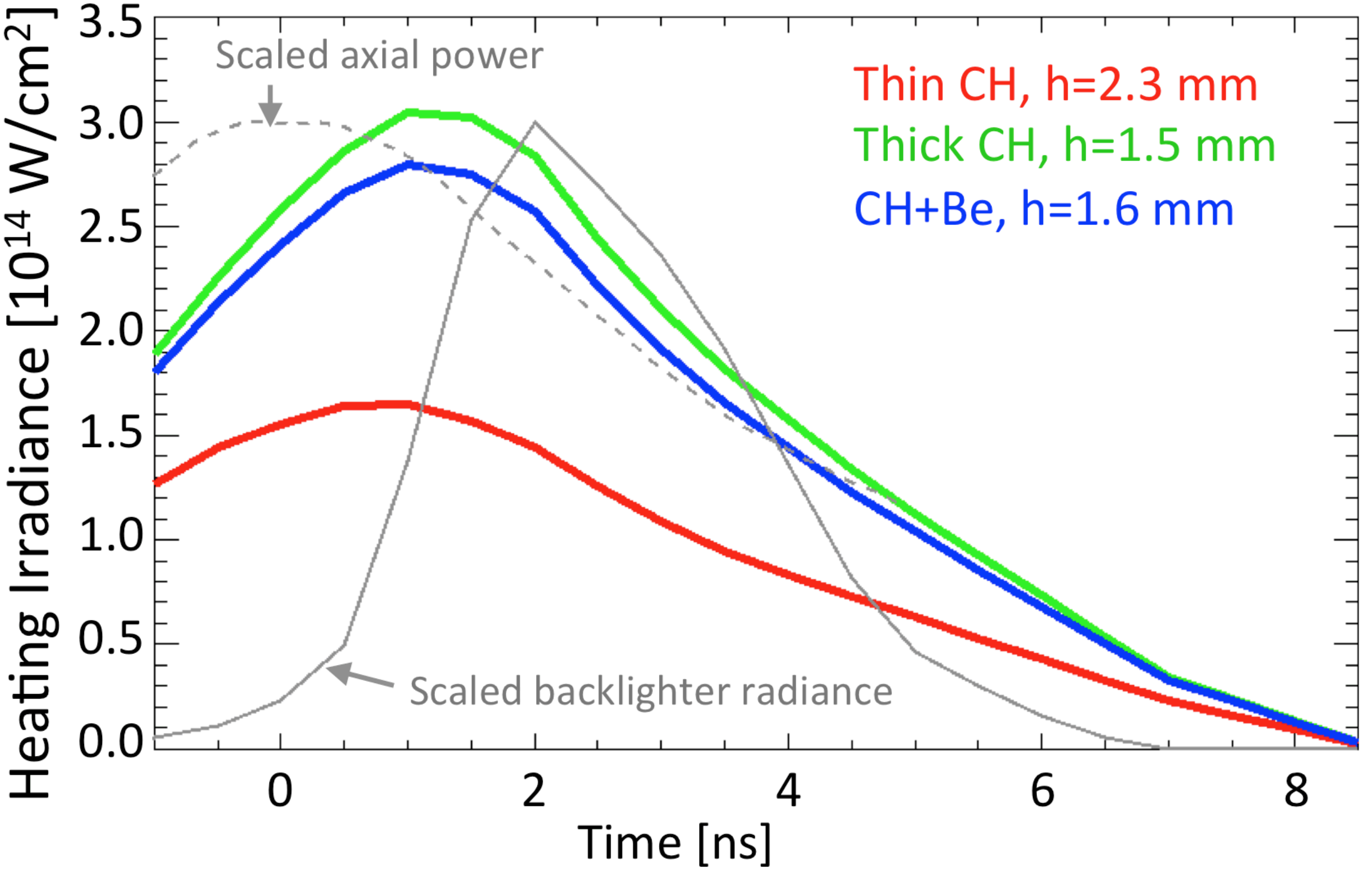




- Define geometry of ZPDH radiation source and the sample
- Different sample-source distance for different target configuration
- Assign power time history of each ring of the ZPDH radiation source
- 3D view factor code (VISRAD) calculates the heating radiation on the sample for each target configuration

VISRAD: J.J. MacFarlane, Journal of Quantitative Spectroscopy and Radiative Transfer 81, 287 (2003)

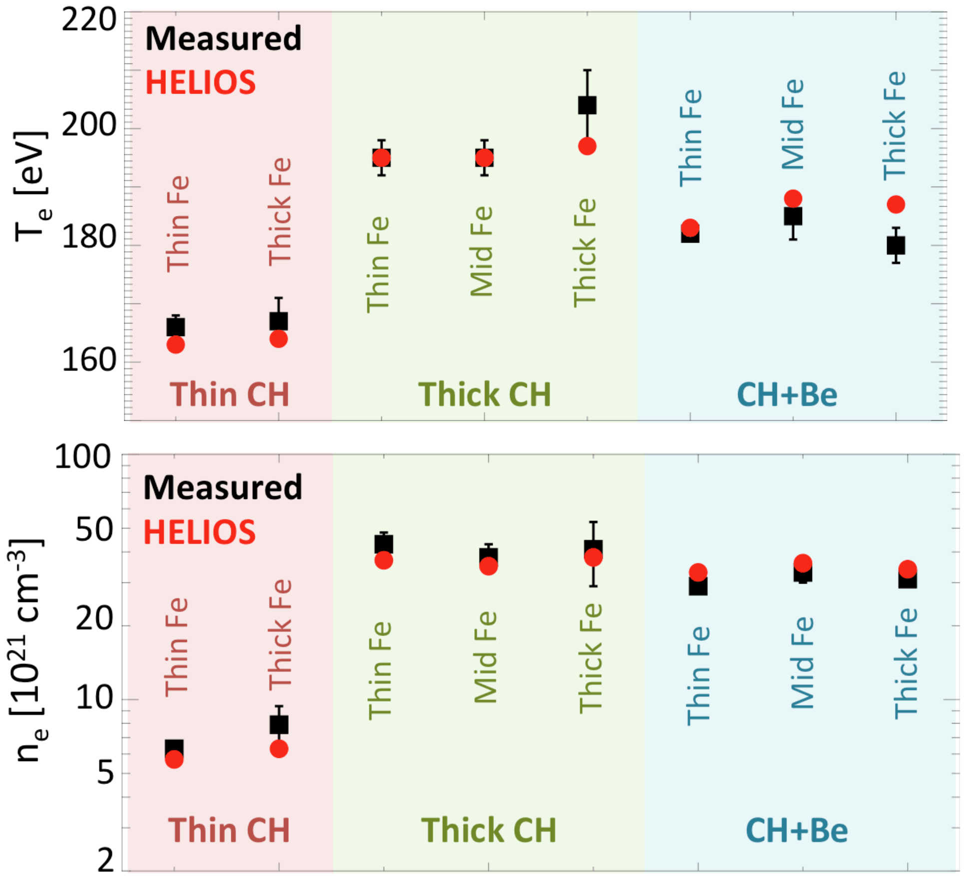
Heating radiation time history depends on sample-source distance



- Axial radiation power, heating radiation, and backlighter are computed from the same ZPDH radiation source

- Their peak timings are different due to the geometric dilution and the observable area

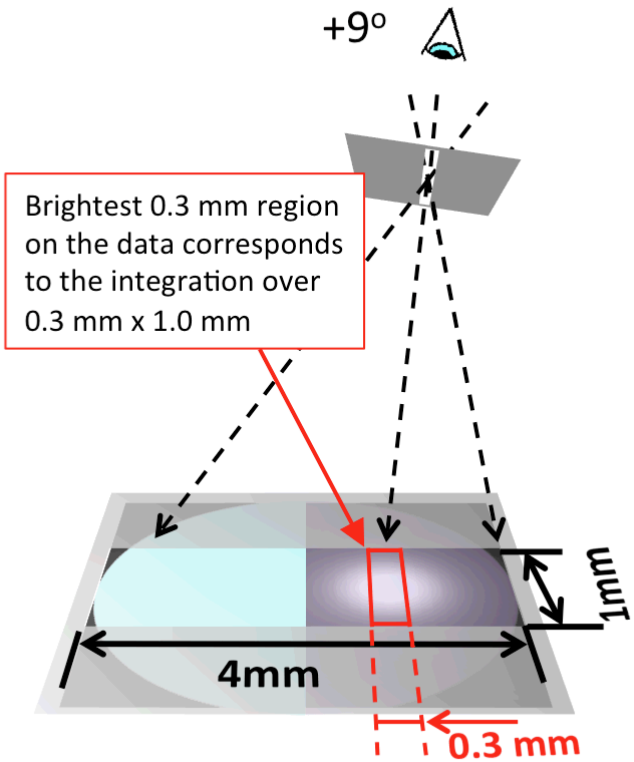
HELIOS simulations reproduced measured conditions for different Fe opacity experiments

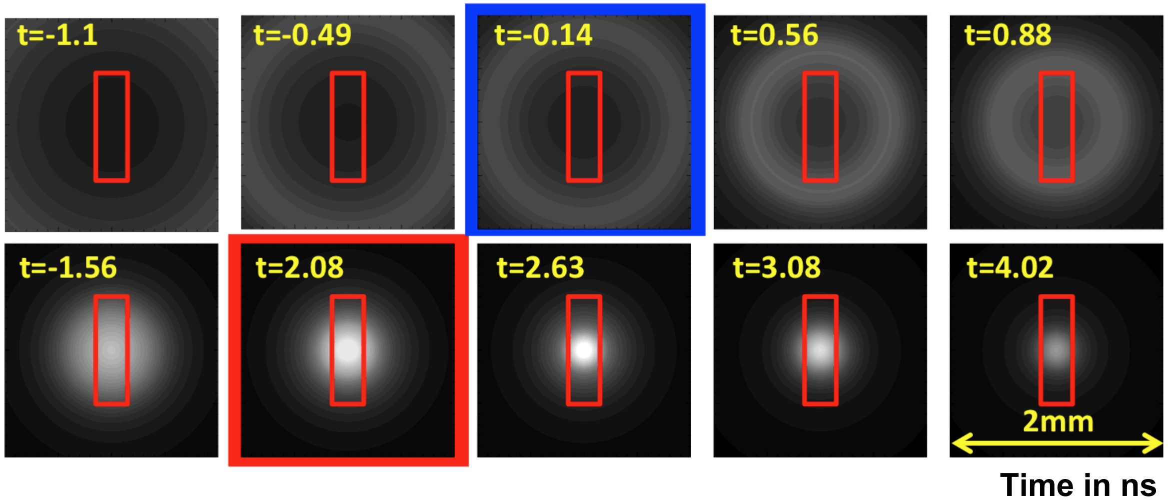


- Sample hydrodynamics are computed with 1D Lagrangian hydrodynamics code, HELIOS
- HELIOS simulations are post-processed to simulate measured spectra
- FeMg T_e and n_e are inferred from the simulated Mg spectra
- Inferred conditions from the simulated spectra agree well with those from the measured spectra

We can synthetically investigate various time- and space-dependent effects on our measurements by post-processing the hydrodynamic simulation results.

Backlighter time history is modeled





$$B_\nu(t) = \frac{1}{A} \iint B_\nu^{Planckian}\left(T_r(x,y,t)\right) dx\, dy$$

- Detector view is limited to 0.3 mm x 1.0 mm by aperture and the slit
- Calibrated intensity images are converted to radiation temperature maps, $T_r(x, y, t)$
- Backlighter at each time is computed by averaging Planckian radiation over 0.3 mm x 1.0 mm on $T_r(x, y, t)$

Simulating measured spectra by solving radiation transport on the hydrodynamic simulation results

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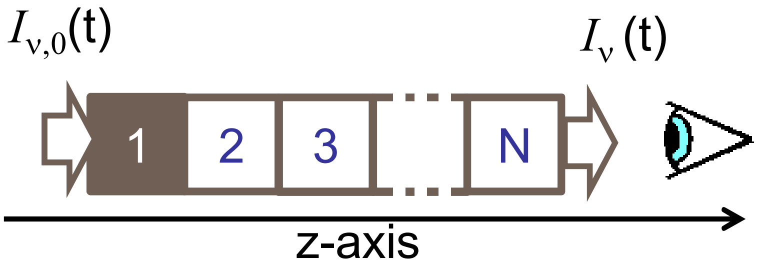
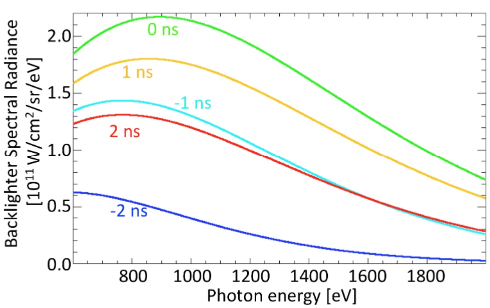


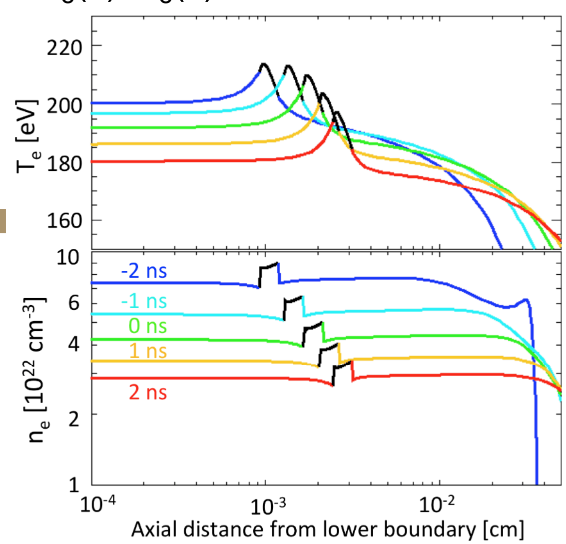
$$I_{\nu,i} = I_{\nu,i-1} T_{\nu,i} + \frac{\varepsilon_{\nu,i}}{\kappa_{\nu,i}} \left(1 - T_{\nu,i}\right)$$

Emergent spectra are computed taking into account the backlighter and spatial gradients at each time

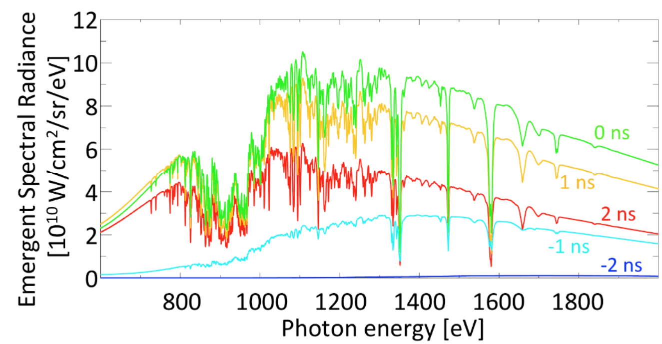
$I_{\nu,0}$ at t=-2,-1, 0, 1, 2 ns



T_e(z), n_e(z) at t=-2,-1, 0, 1, 2 ns



I_{ν} at t=-2,-1, 0, 1, 2 ns

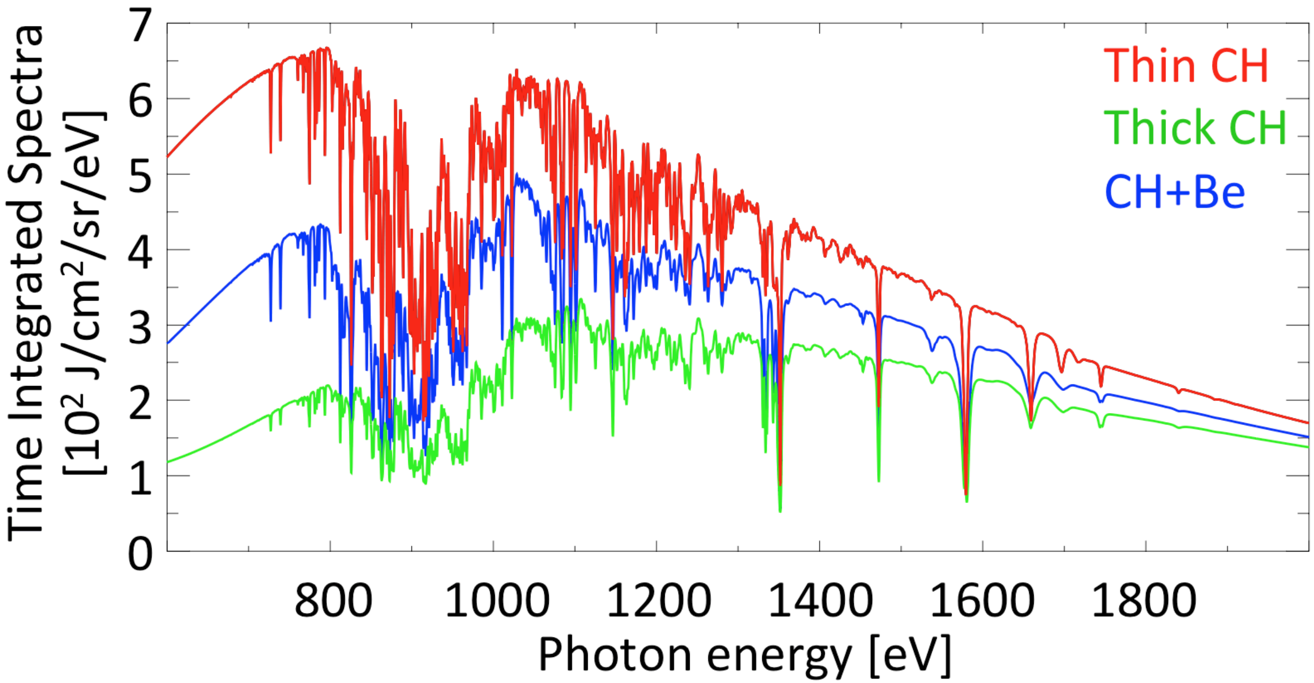


※ t is with respect to backlighter peak

Radiation transport discussed in Appendix of T. Nagayama et al, Physics of Plasmas 21, 056502 (2014)

The simulated measured spectra include various effects

- Heating radiation with 3D view factor
- Axial and temporal plasma gradients
- FeMg self-emission/attenuation
- Tamper self-emission/attenuation
- Backlighter time history taking into account ZPDH radiation spatial variation



<u>Many issues can be synthetically investigated:</u>

1) Time-integrated FeMg/tamper self-emission effects,
2) Potential overheating on the tamper only side,
3) Time-integrated effects on the absorption features
4) Non local thermal equilibrium

Work in progress!