SAND2014-19484C

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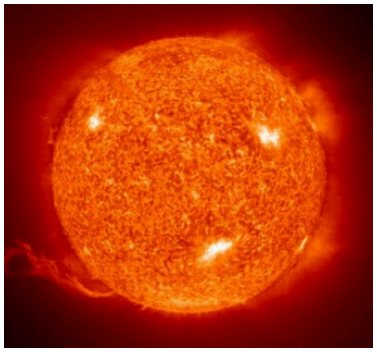

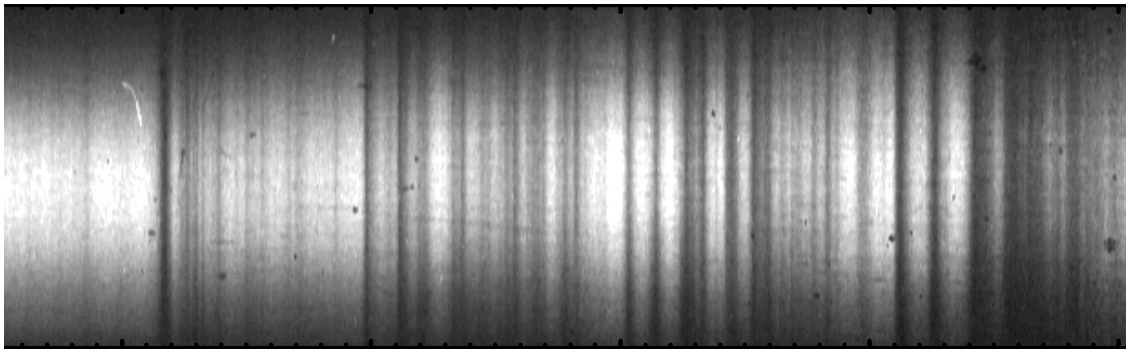

Iron opacity experiments for the solar interior

Taisuke Nagayama

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

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

J.E. Bailey, T. Nagayama, G. Loisel, G.A. Rochau, S.B. Hansen, C. Ball, M. Kernaghan, G.S. Dunham, M.R. Gomez, R.E. Falcon
Sandia National Laboratories, Albuquerque, NM, 87185-1196

A.K. Pradhan, C. Orban, M. Pinsonneault, and S.N. Nahar
Ohio State University, Columbus, Ohio, 43210

C. Blancard, Ph. Cosse, G. Faussurier, J.-C. Pain
CEA, DAM, DIF, F-91297 Arpajon, France

C.A. Iglesias and B. Wilson
Lawrence Livermore National Laboratory, Livermore, CA, 94550

J. Colgan, C. Fontes, D. Kilcrease, and M. Sherrill
Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545

J.J. MacFarlane, I. Golovkin
Prism Computational Sciences, Madison, WI

R.C. Mancini
University of Nevada, Reno, NV

Summary: Z Fe opacity measurements reveal that modeled Fe opacities are underestimated at solar interior conditions

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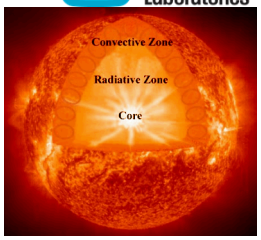
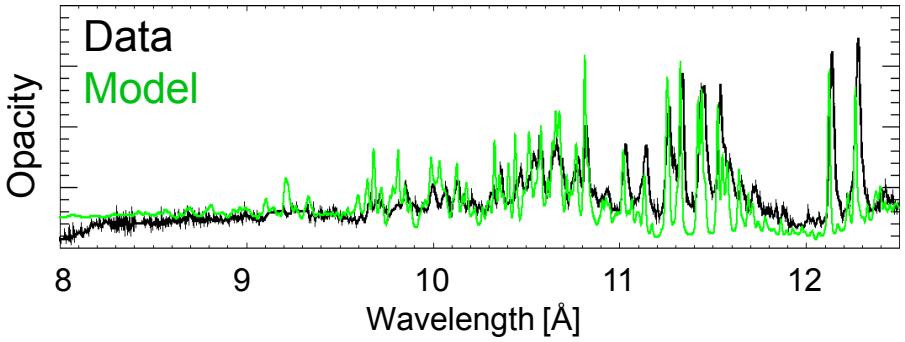
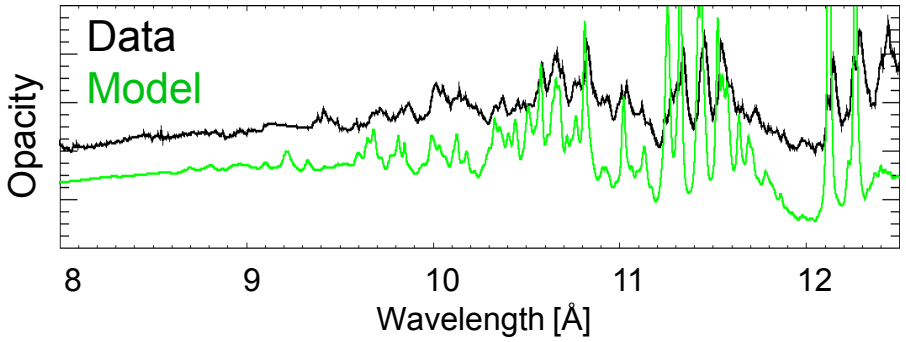


- Fe opacity measurements are important to solve a puzzle with the Sun
- Fe opacity are measured at multiple conditions with SNL Z opacity platform

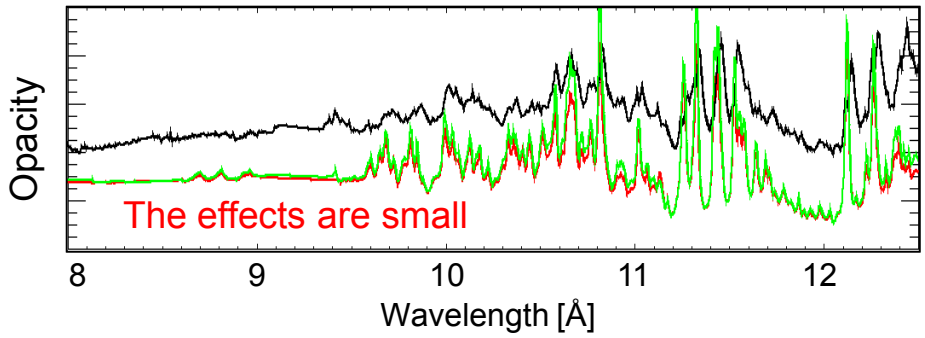
At lower T_e and n_e



At higher T_e and n_e (~ solar interior)

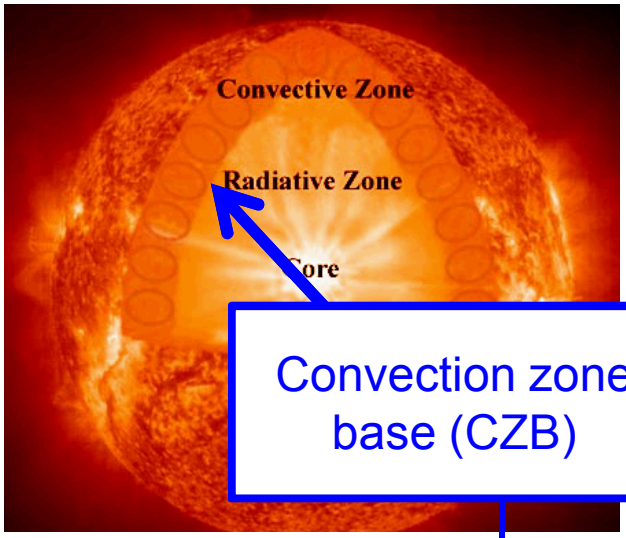


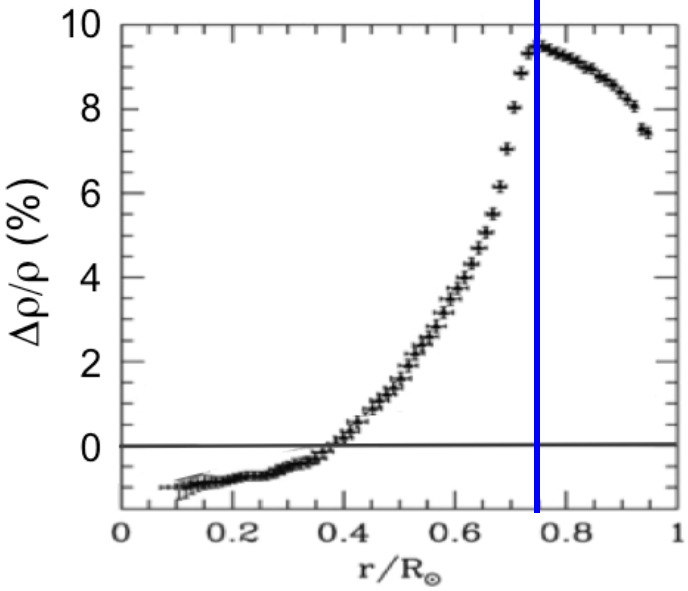
- Various concerns are synthetically investigated
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects



- **The observed discrepancies are likely to be real**
- **Platform is ready to test hypothesis to explain the discrepancies**

Solar models disagree with observation due to mean opacity underestimate





- Simulation: standard solar models

  Input:

  - Opacity
  - Abundance
  - etc

- Observation: Helioseismology

Discrepancies

- $\rho(r)$, $c(r)$, $T(r)$
- CZB location: 13-30 σ

Problem

Simulated mean opacity is somehow lower than observed mean opacity

S. Basu et al, Physics Reports 457, 217 (2008).

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

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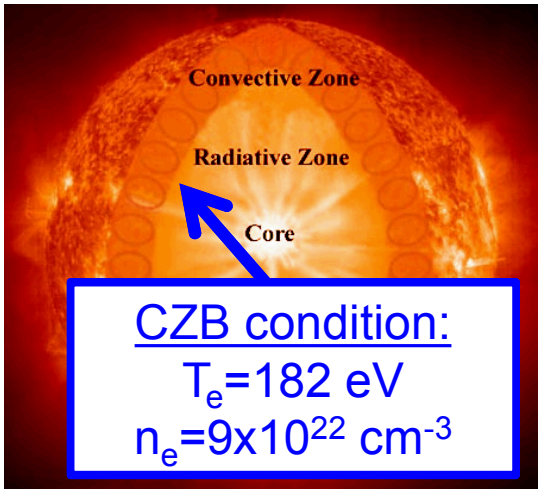
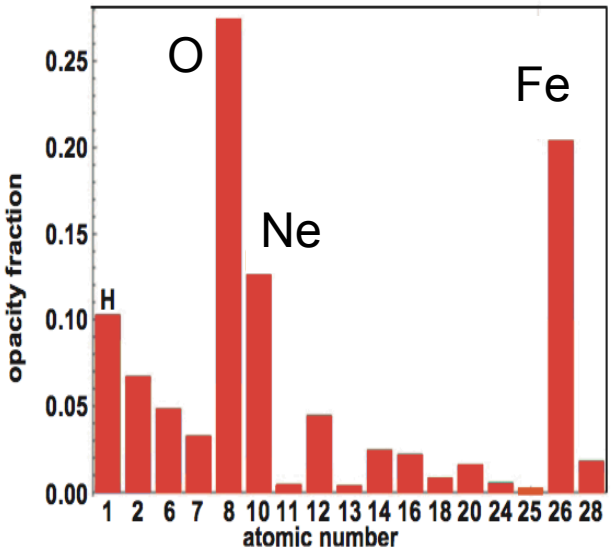
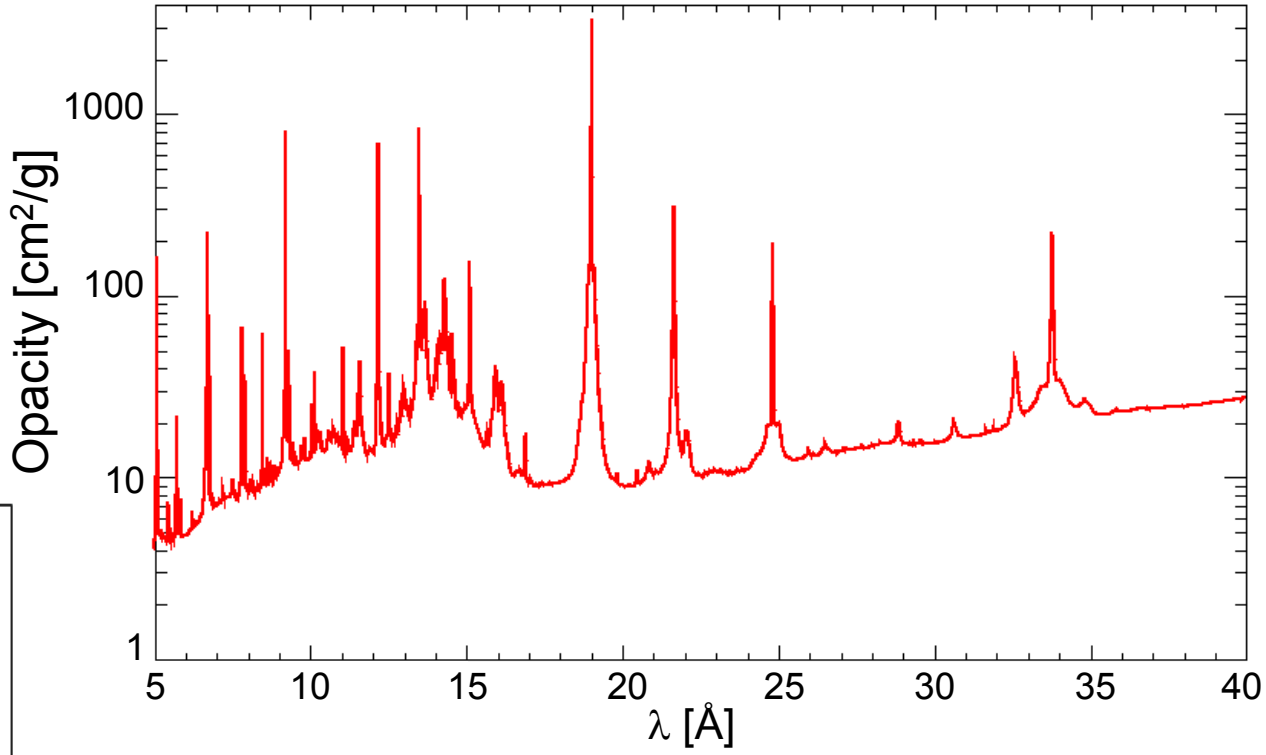




CEA OPAS calculation

Solar mixture opacity at Convection Zone Base (CZB)



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

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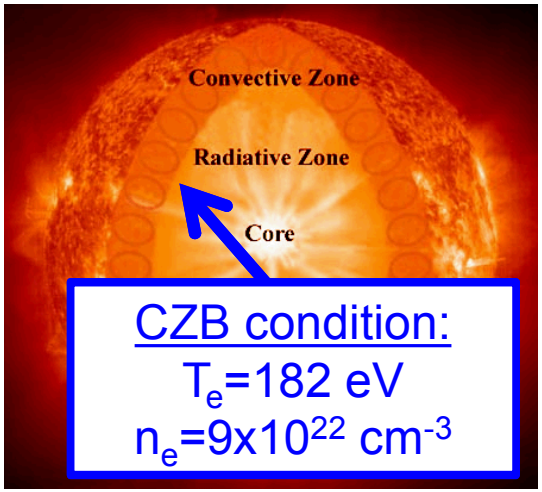
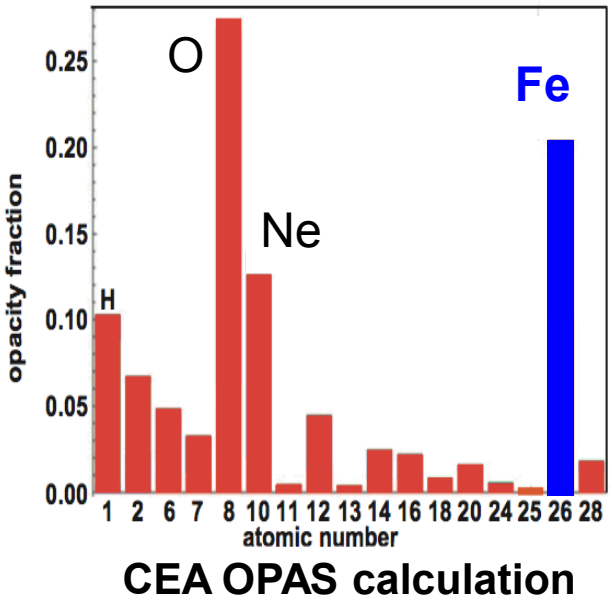
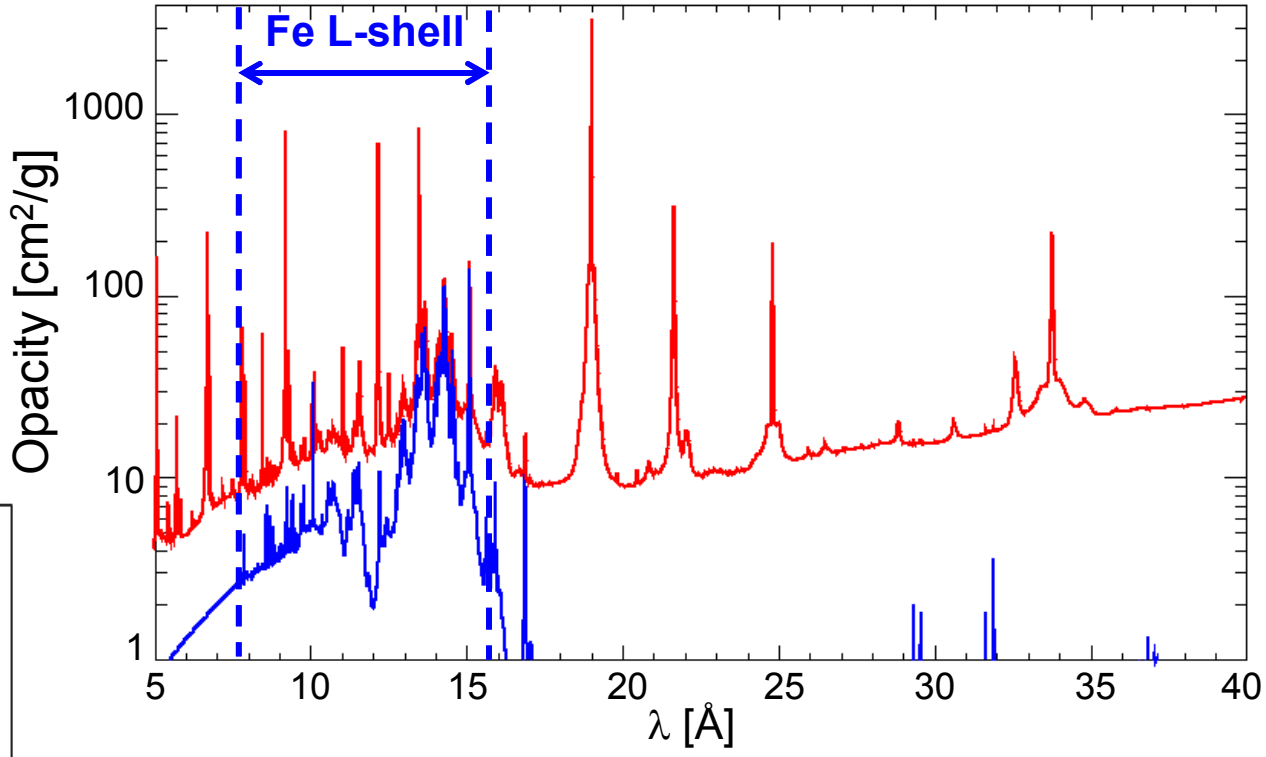




CEA OPAS calculation

Solar mixture opacity at Convection Zone Base (CZB)



- Fe opacity is a likely suspect
  - Significant contribution
  - Most difficult to model

Let's measure Fe opacity at the CZB conditions !

C. Blancard et al, Astrophysical Journal 745, 10 (2011)

Above 150 eV Fe opacities are measured using the Z-Pinch dynamic hohlraum (ZPDH) opacity science platform

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Z-pinch dynamic hohlraum

J.E. Bailey et al, Physics of Plasmas 16, 058101 (2009).

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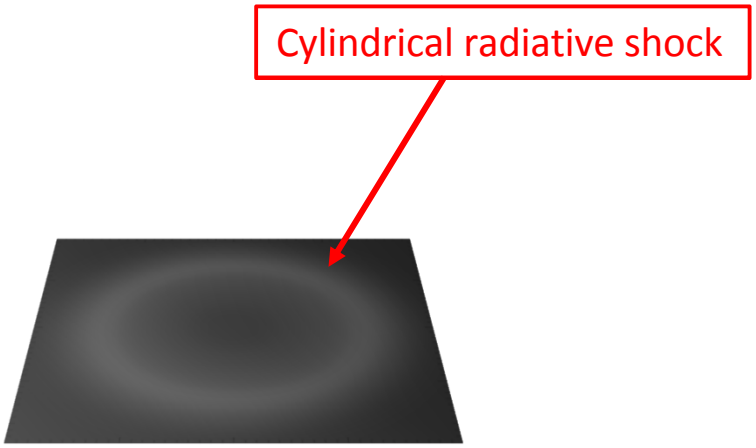

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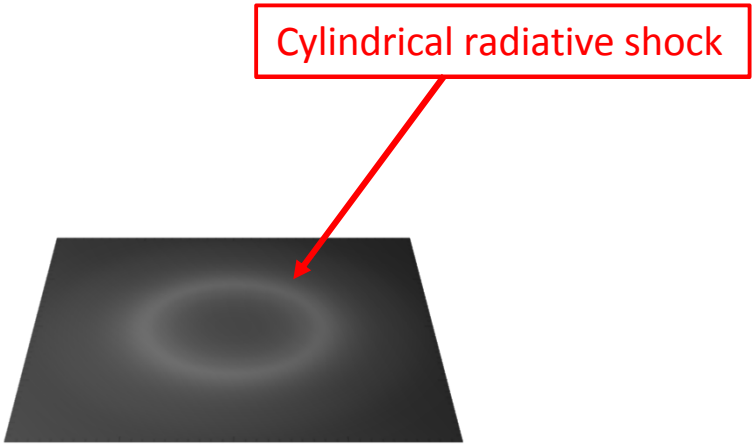

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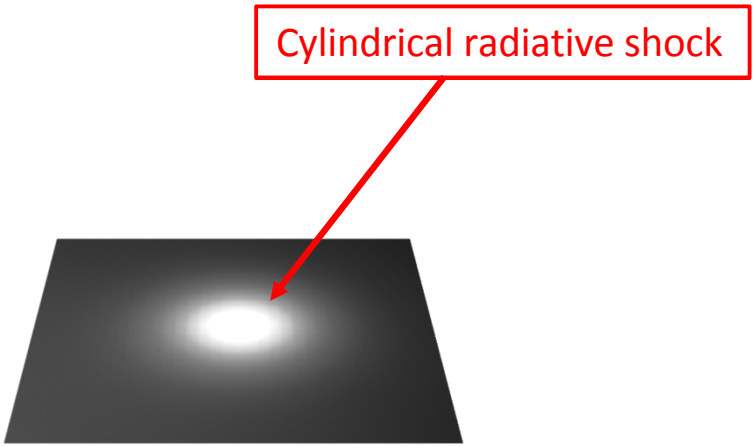

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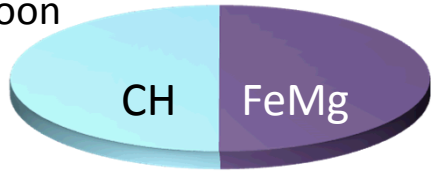
Half-moon sample



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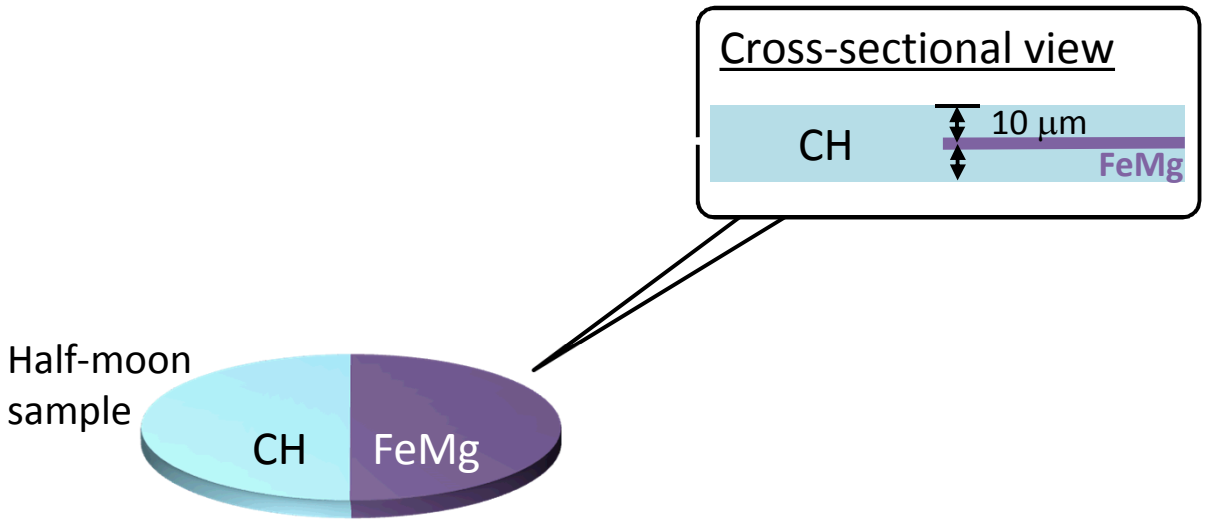

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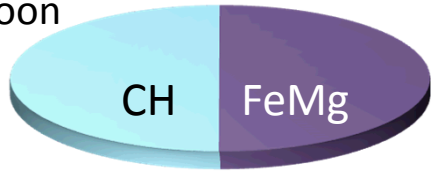

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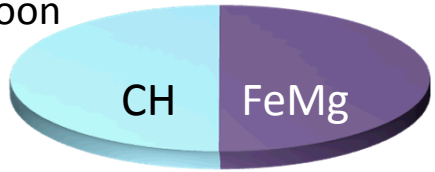

hν > 600eV

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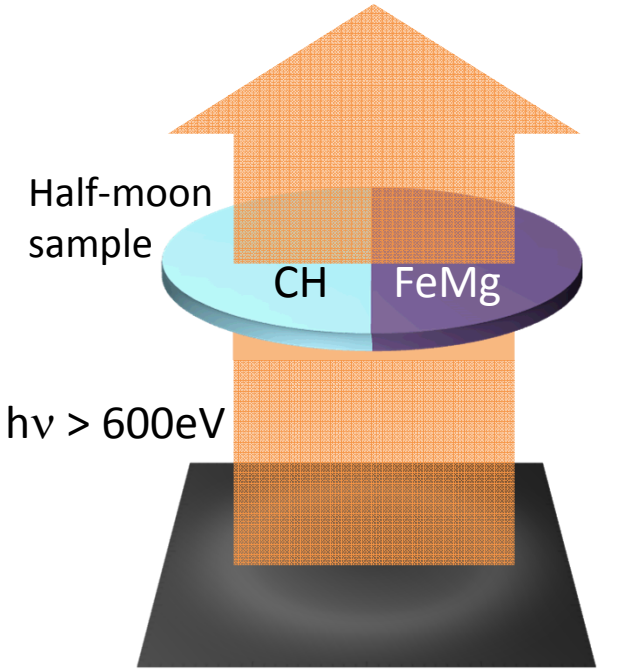

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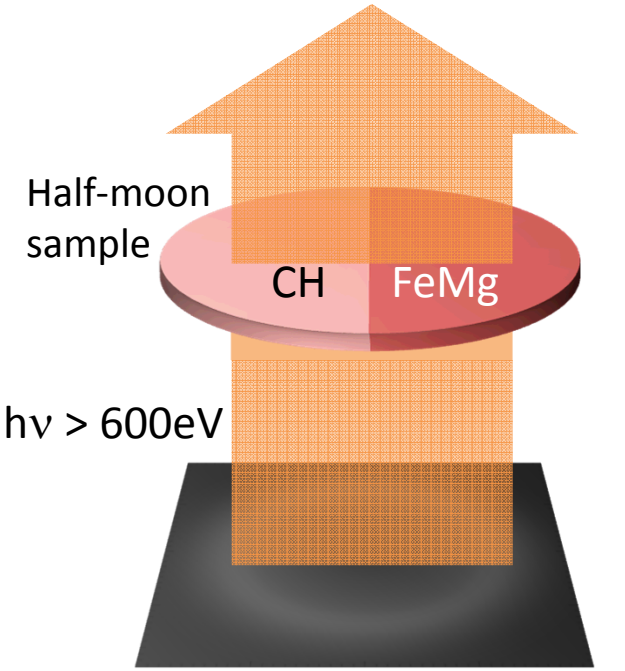

Z-pinch dynamic hohlraum

- Heating to uniform conditions:

  ZPDH radiation

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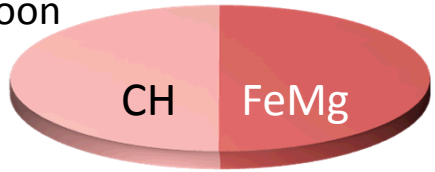

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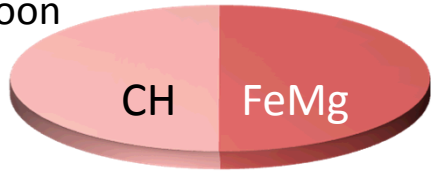

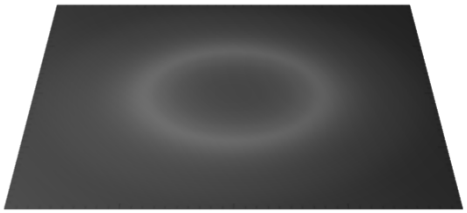

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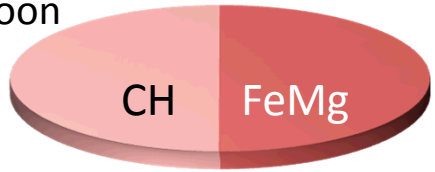

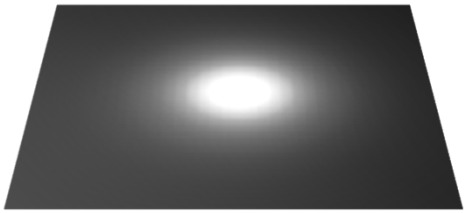

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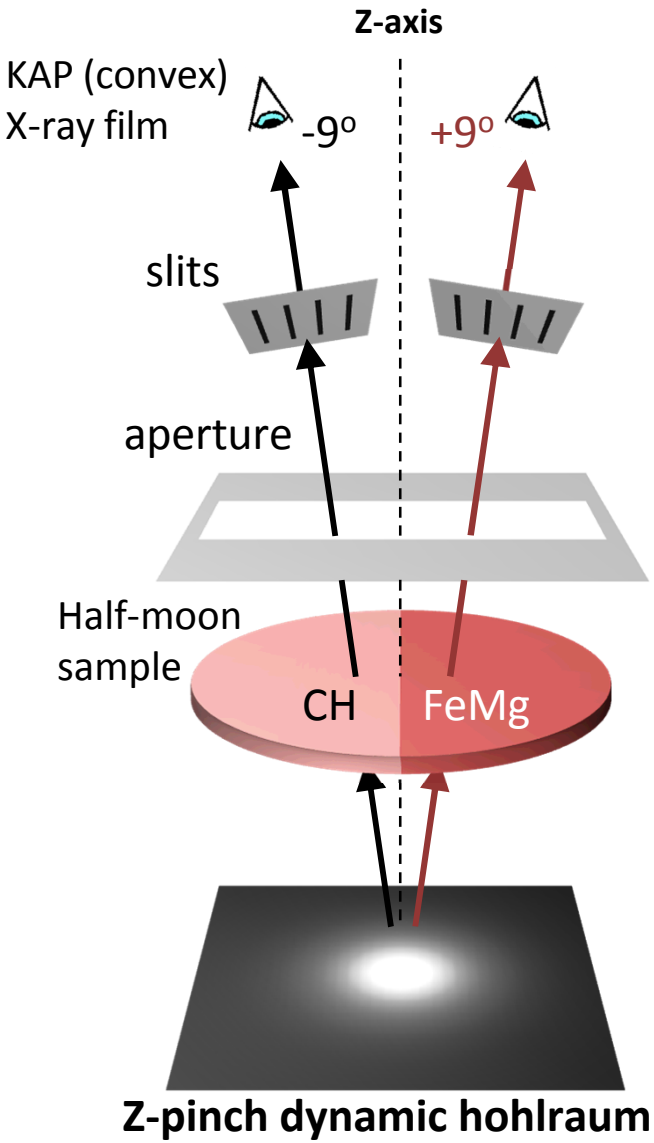

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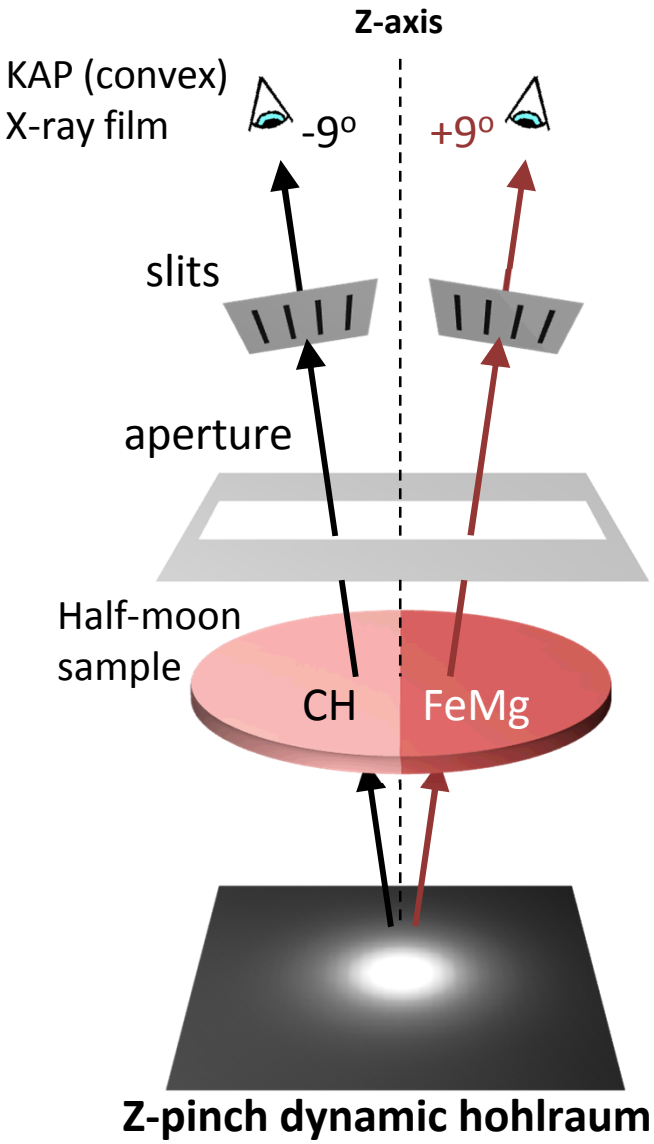

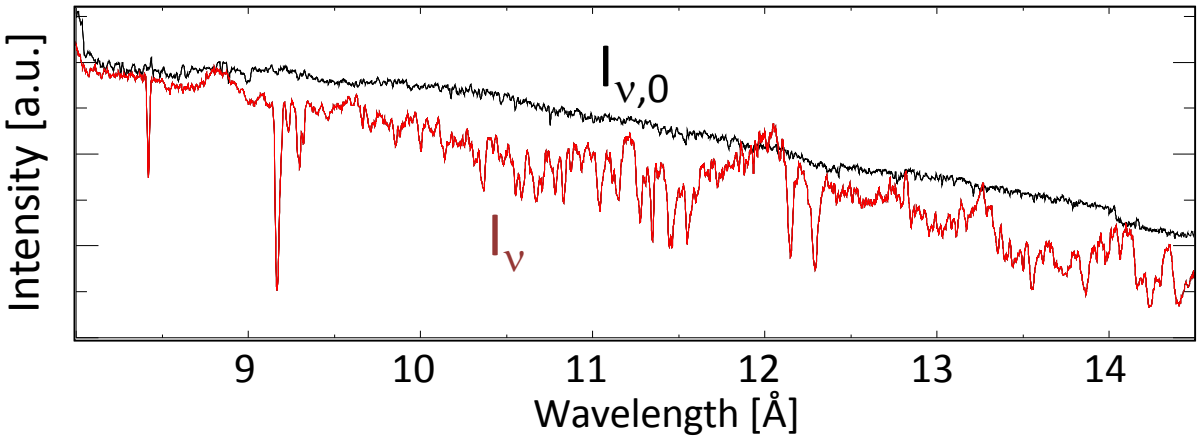

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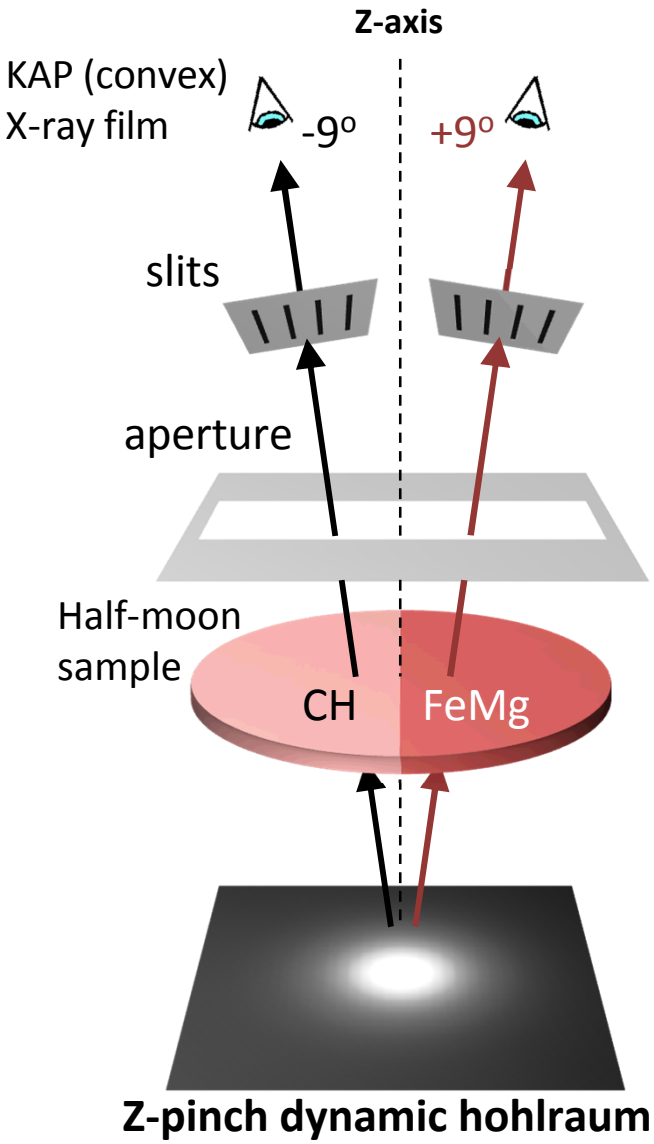

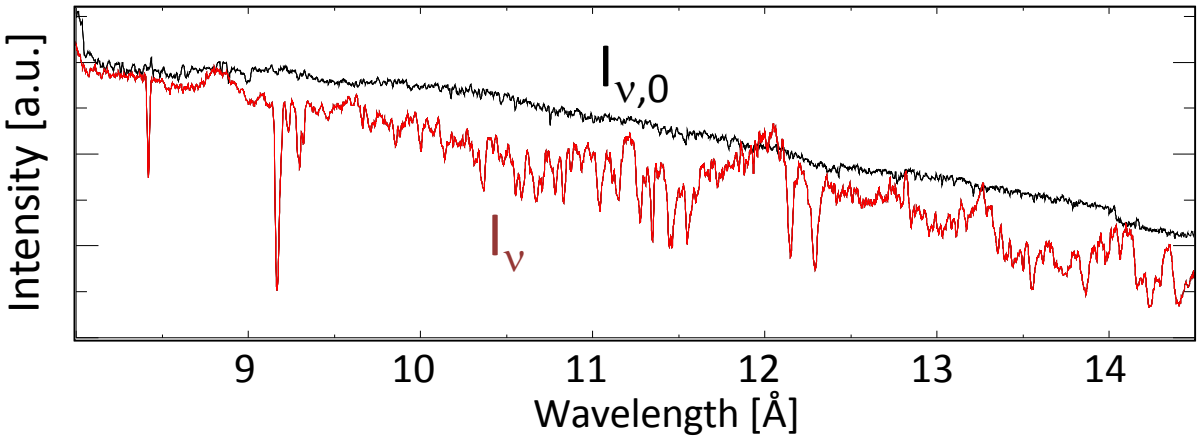

- Heating to uniform conditions:

  ZPDH radiation

- Transmission:

  $T_\nu = I_\nu / I_{\nu,0}$

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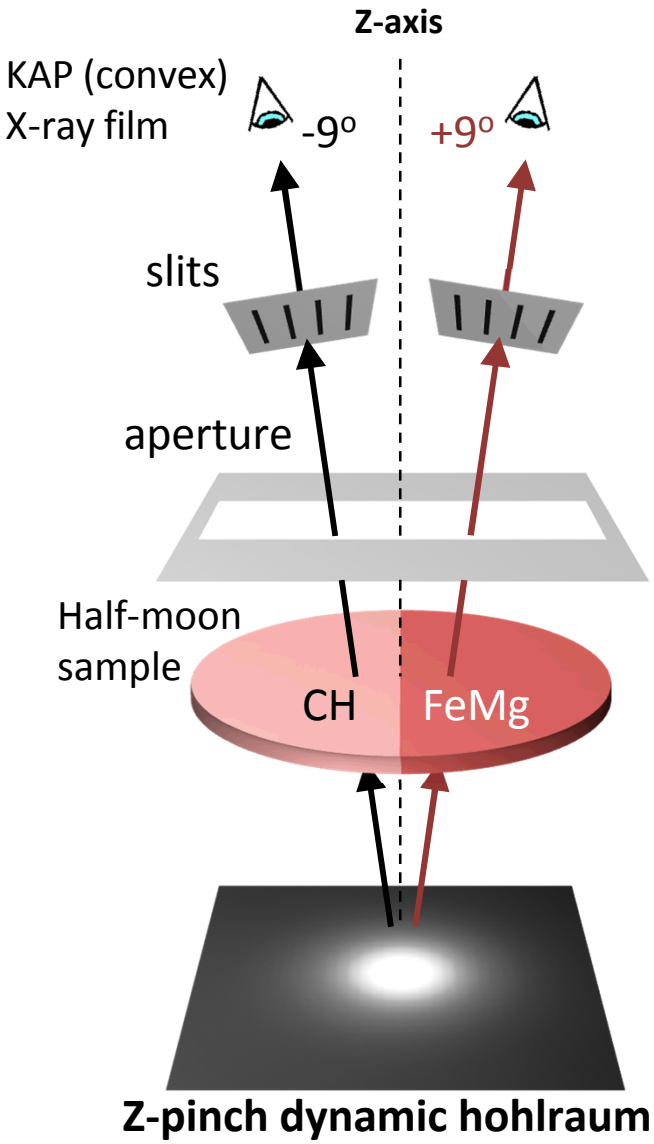

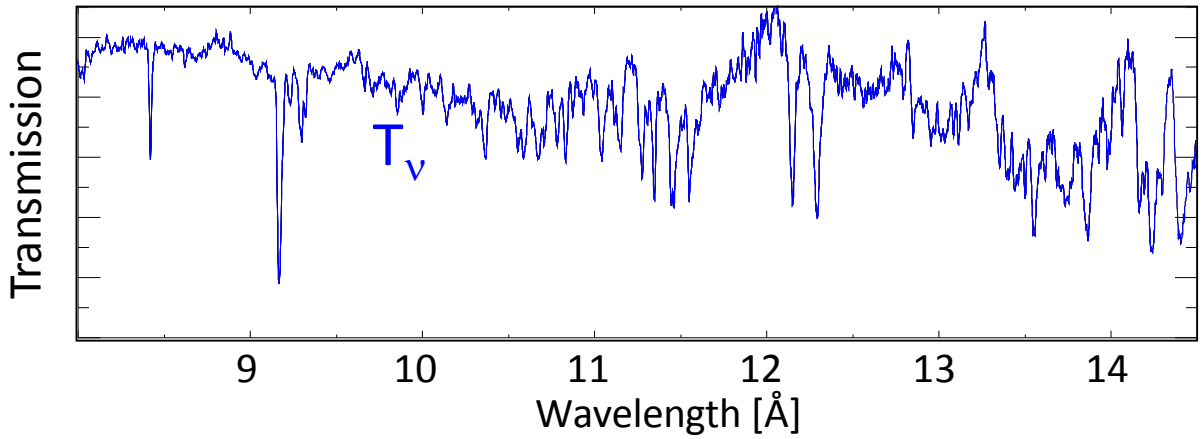

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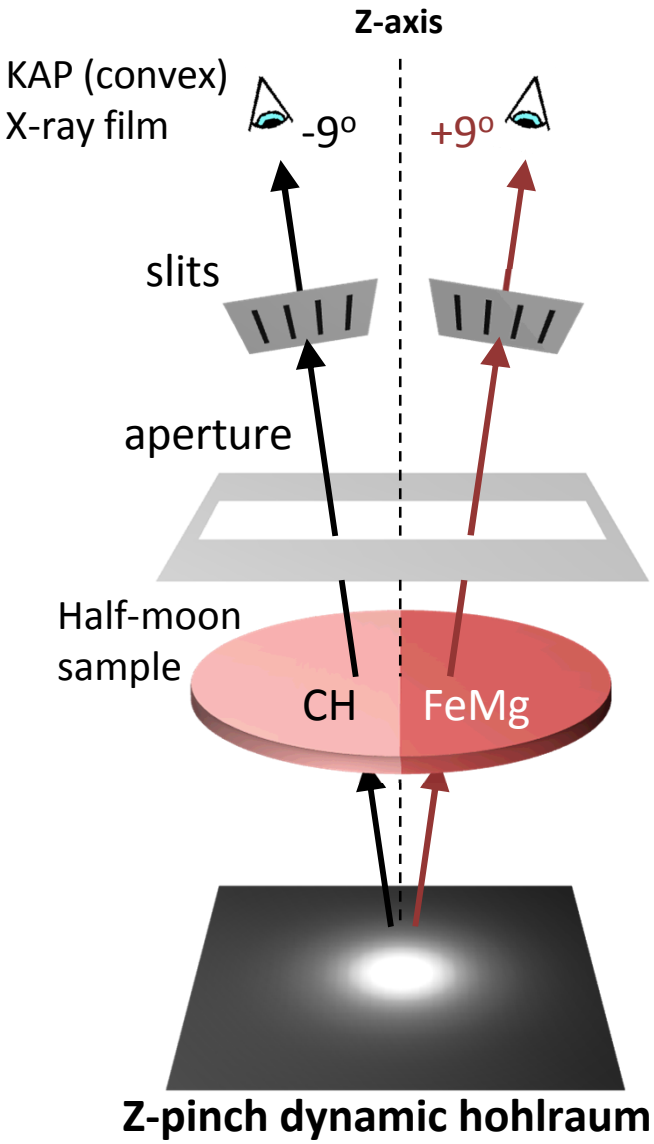

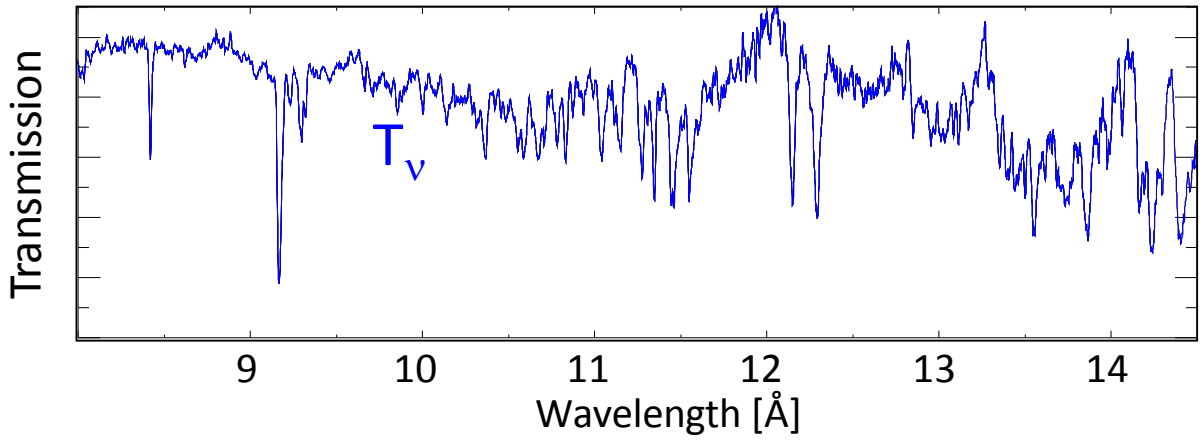

- Heating to uniform conditions:

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  $\kappa_\nu = -\ln(T_\nu)/\rho L$

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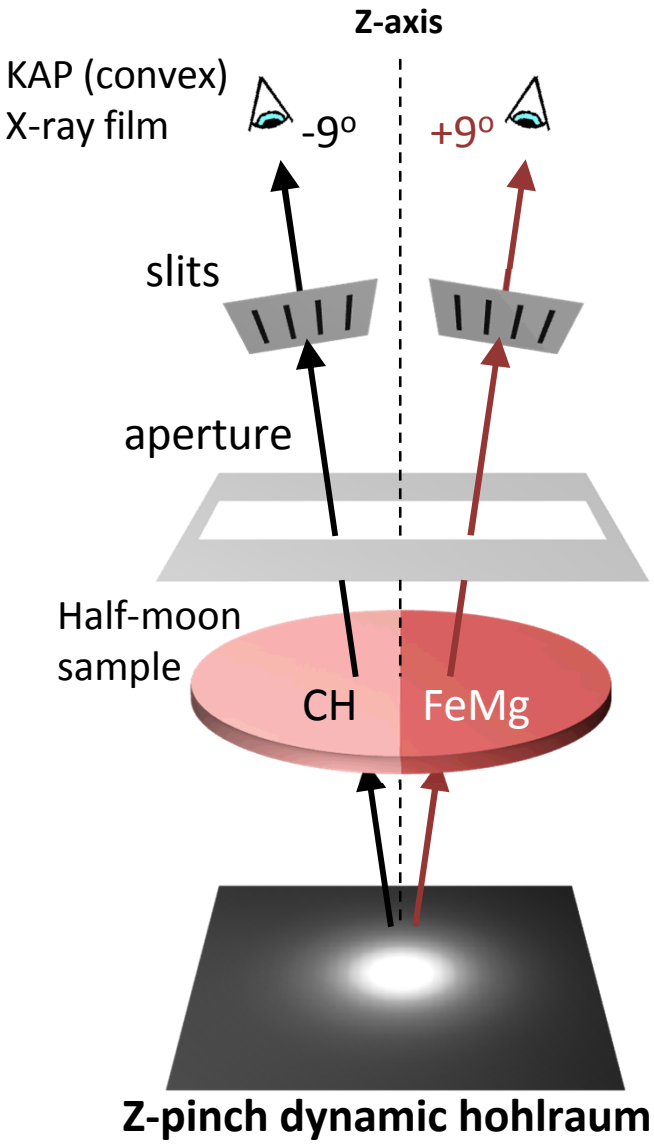

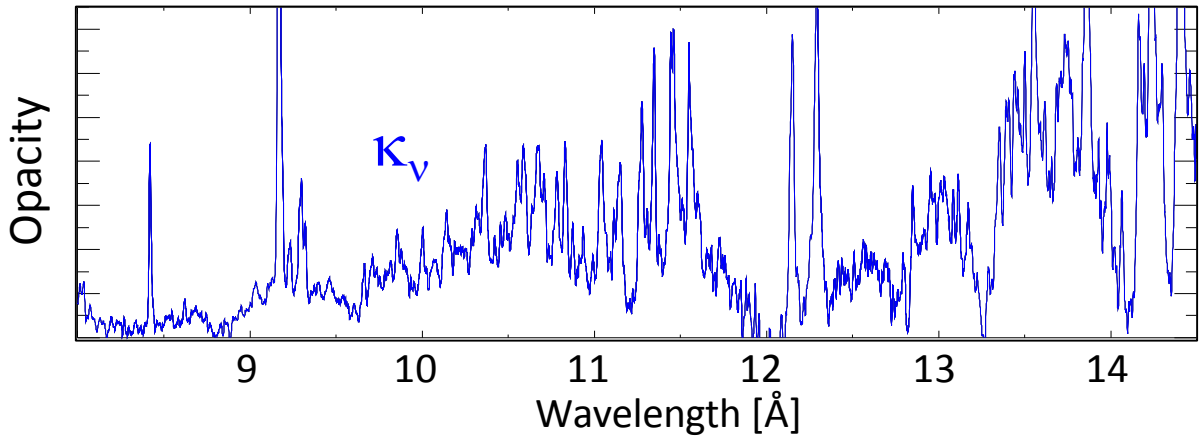

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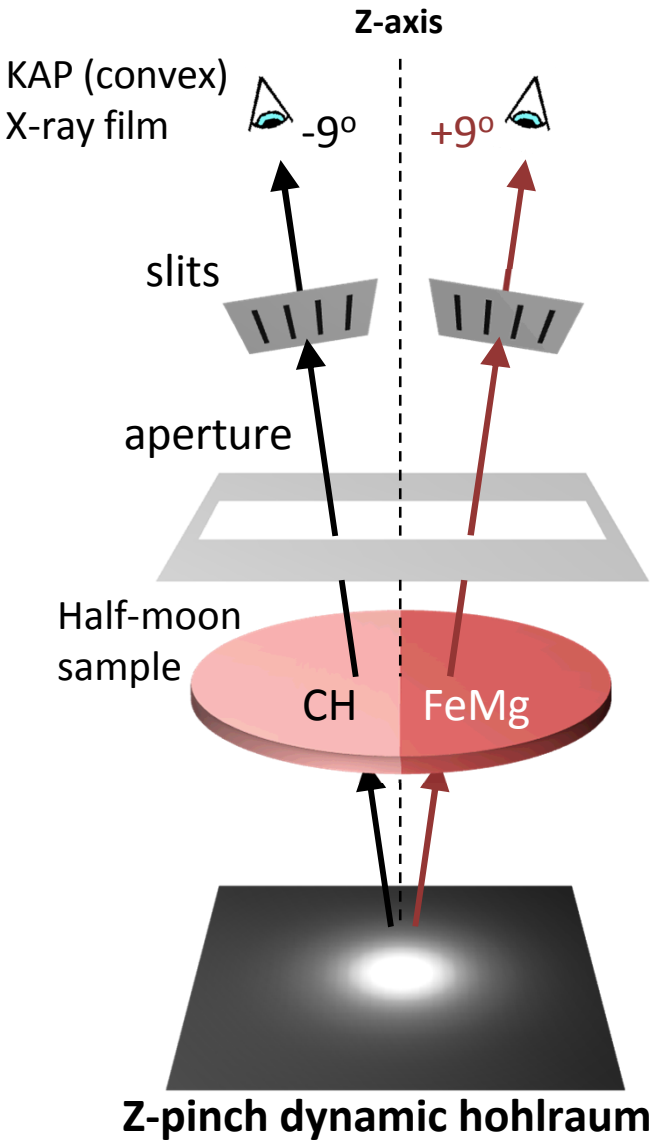
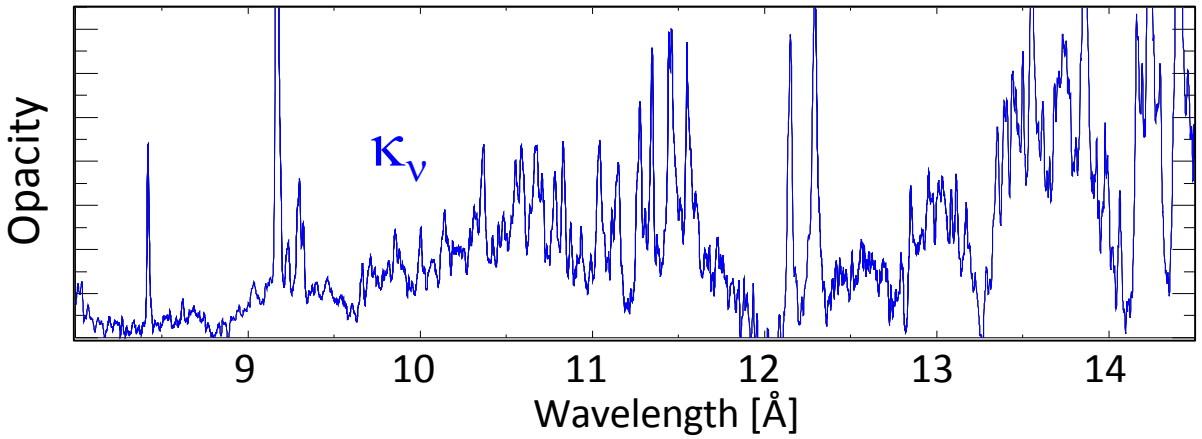


Z-pinch dynamic hohlraum



- Heating to uniform conditions:

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- Transmission:

  $T_\nu = I_\nu / I_{\nu,0}$

- Opacity:

  $\kappa_\nu = -\ln(T_\nu)/\rho L$

- Plasma conditions:

  Mg K-shell spectroscopy

J.E. Bailey et al, Physics of Plasmas 16, 058101 (2009).

Modeled opacity agrees with the data at lower T_e and n_e (CZB: 185 eV, 9e22 e/cc)

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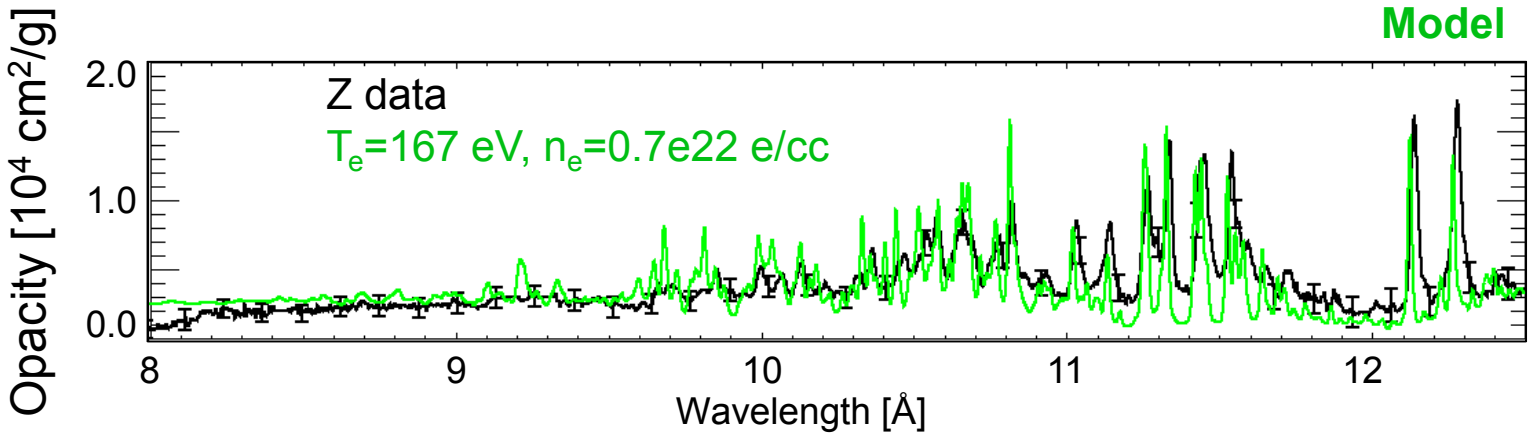
Thin CH



J.E. Bailey et al, Phy Rev Lett 99, 265002 (2007)

Model-data agreement deteriorates as T_e and n_e increase approaching the CZB conditions (185 eV, 9e22 e/cc)

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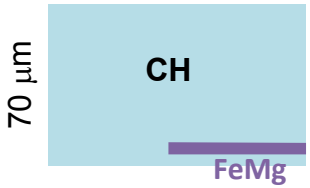
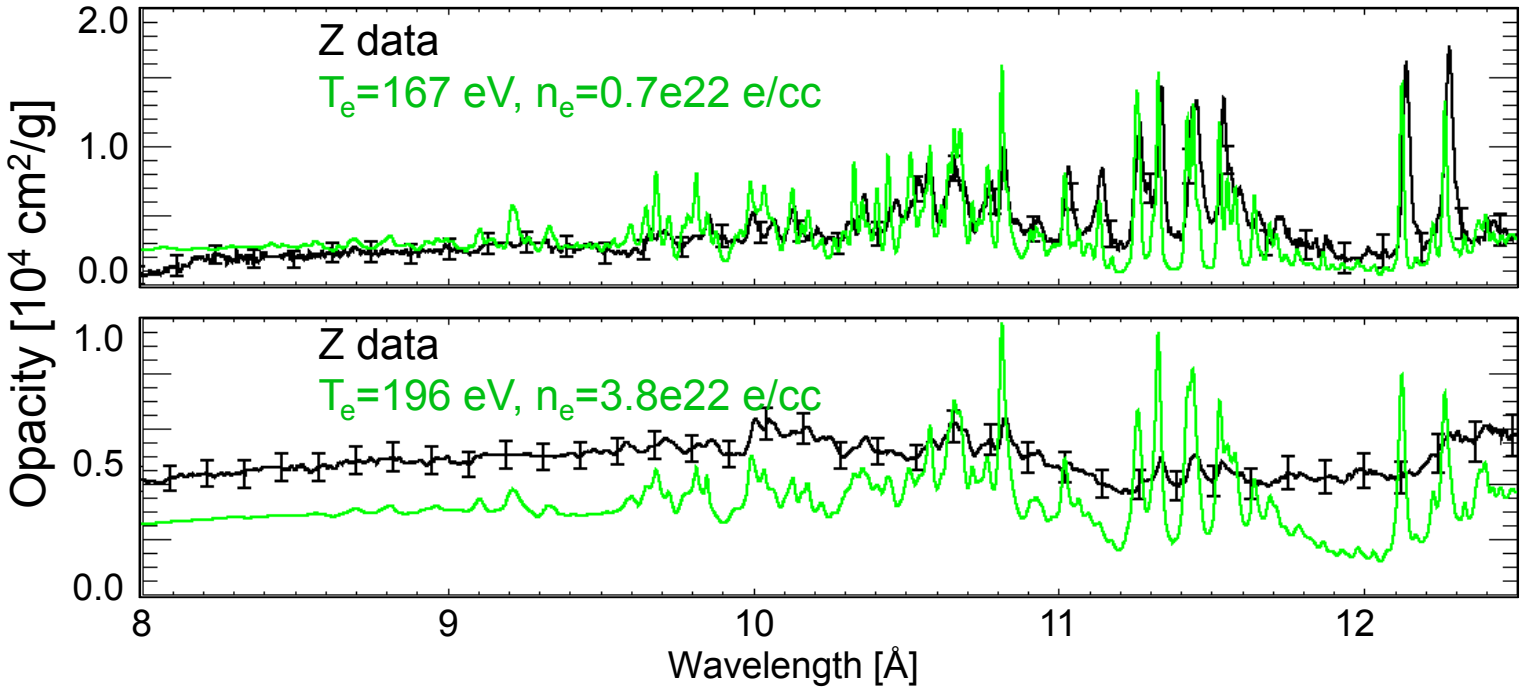
Model

Thin CH

Thick CH





Model-data agreement deteriorates as T_e and n_e increase approaching the CZB conditions (185 eV, 9e22 e/cc)

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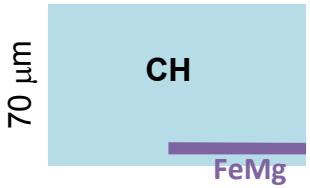
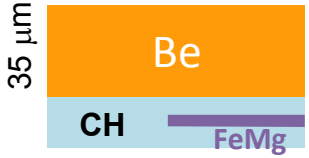
Model

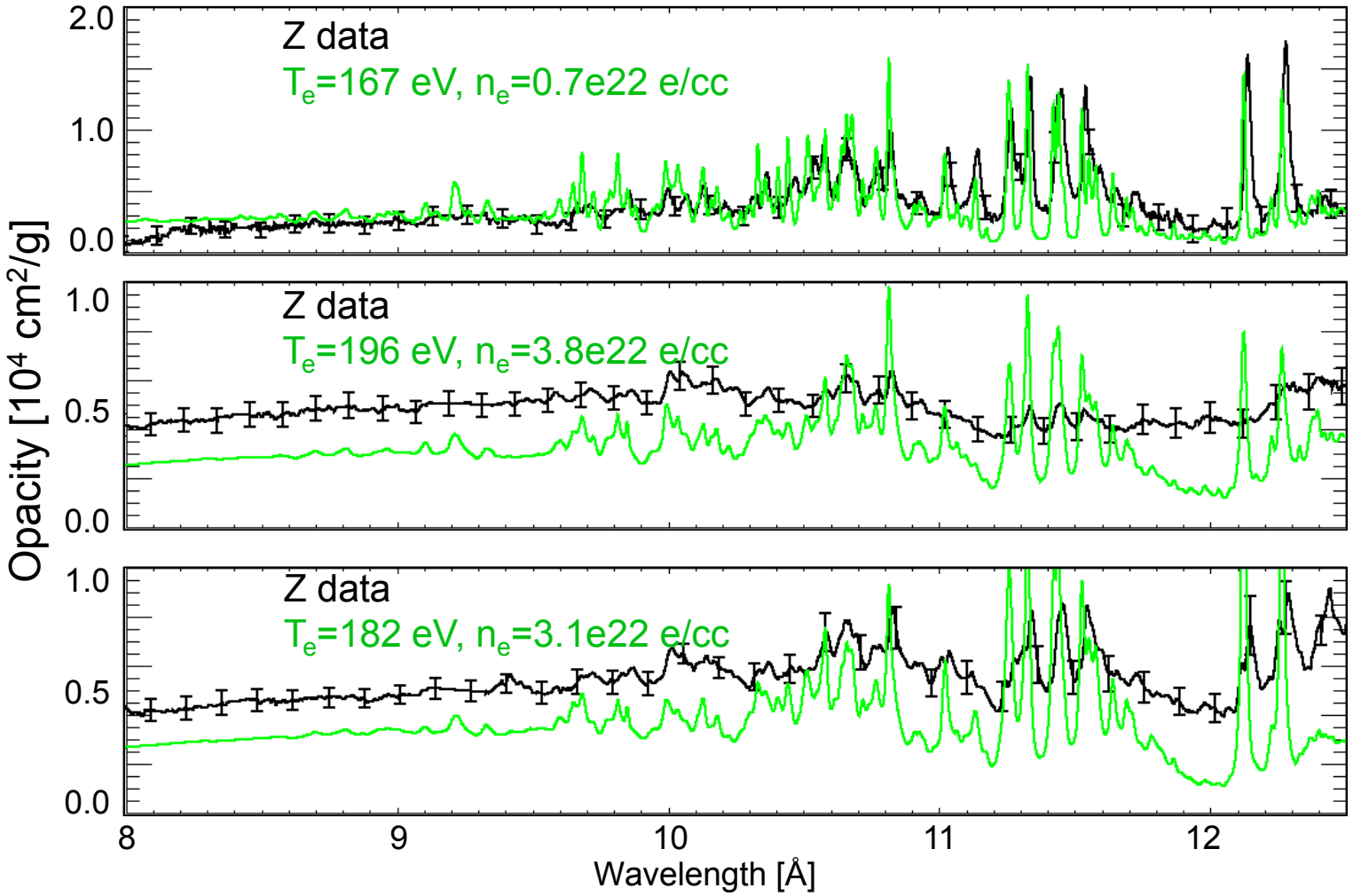
Thin CH

Thick CH



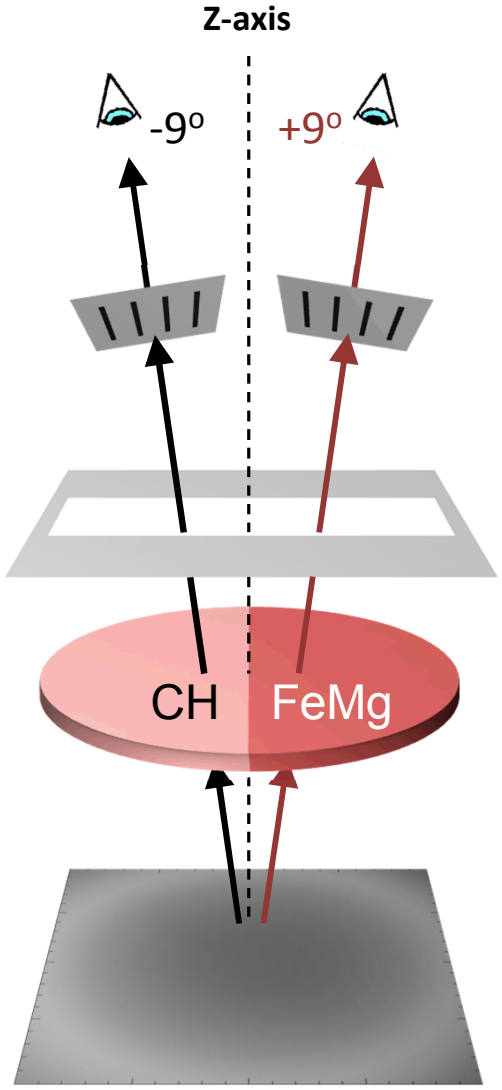
CH+Be





Experiments need to be scrutinized for potential systematic uncertainties.

Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics



Z-pinch dynamic hohlraum

- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics

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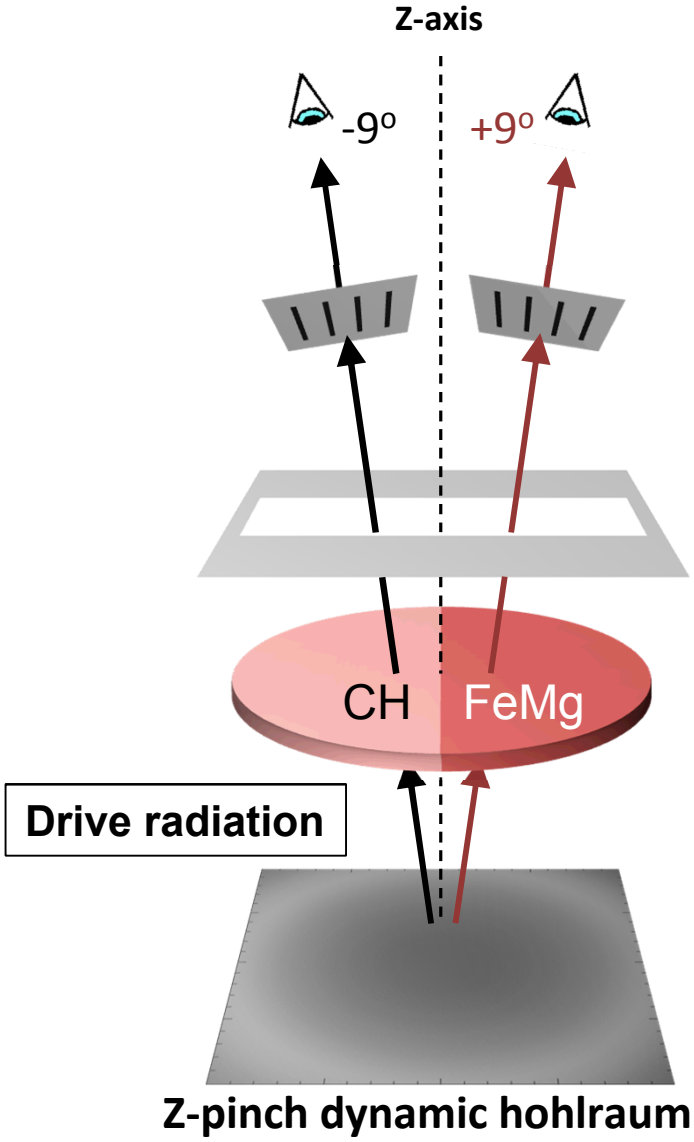
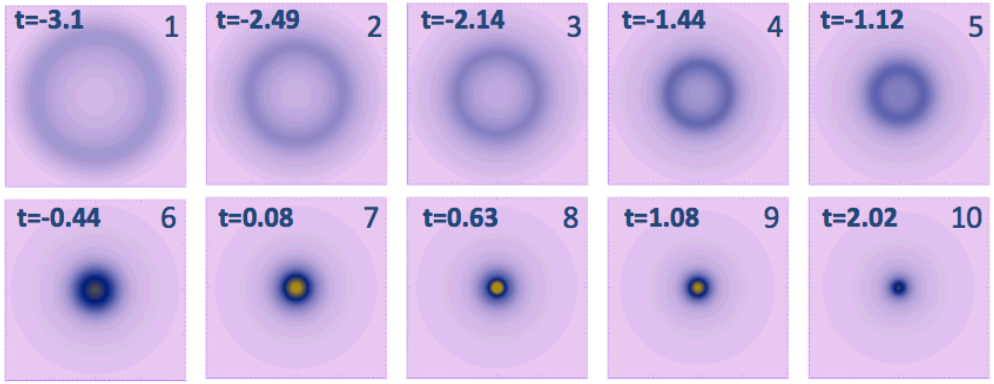


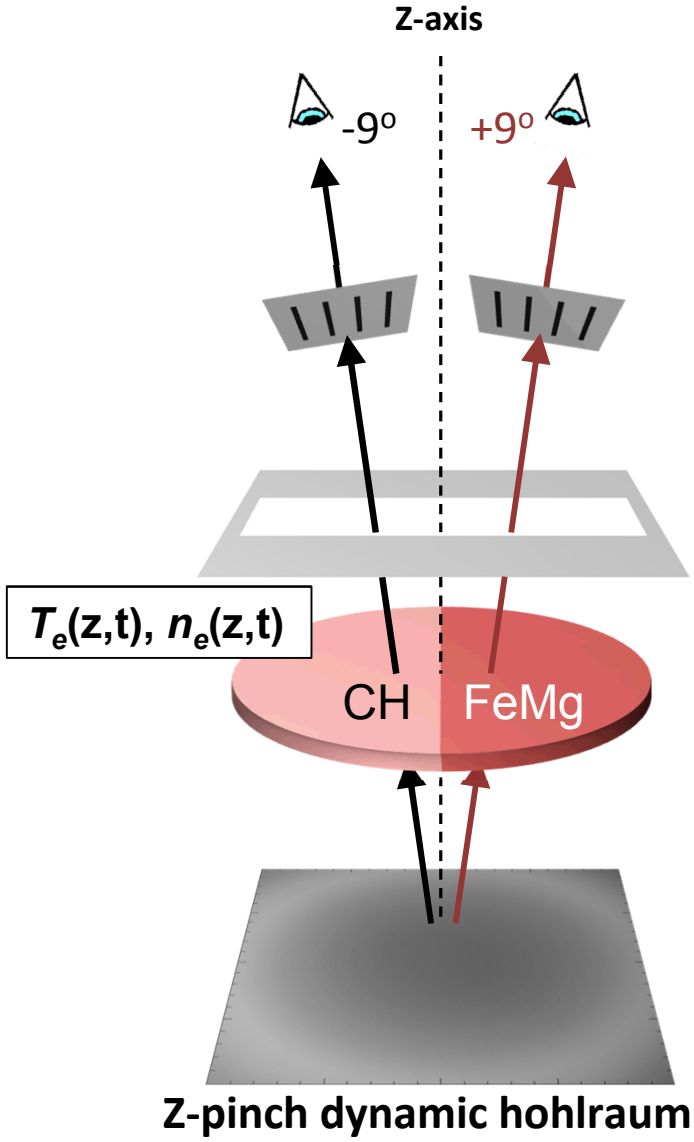
- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Drive radiation: VISRAD

- 3D view factor code, VISRAD
- Gated pinhole images of ZPDH

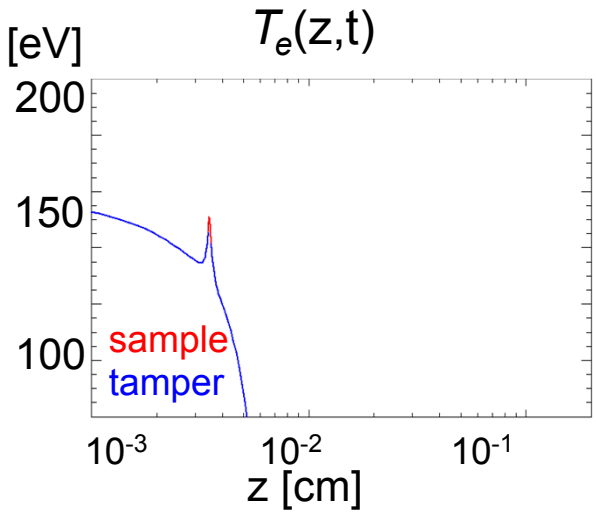


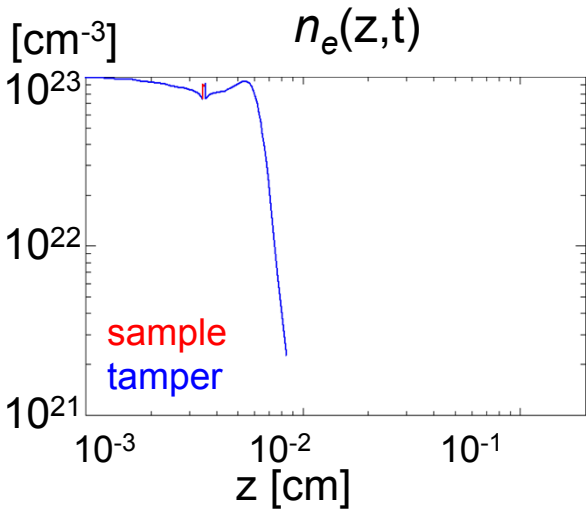
Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics



- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Hydrodynamics: 1D Lagrangian, HELIOS





Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics

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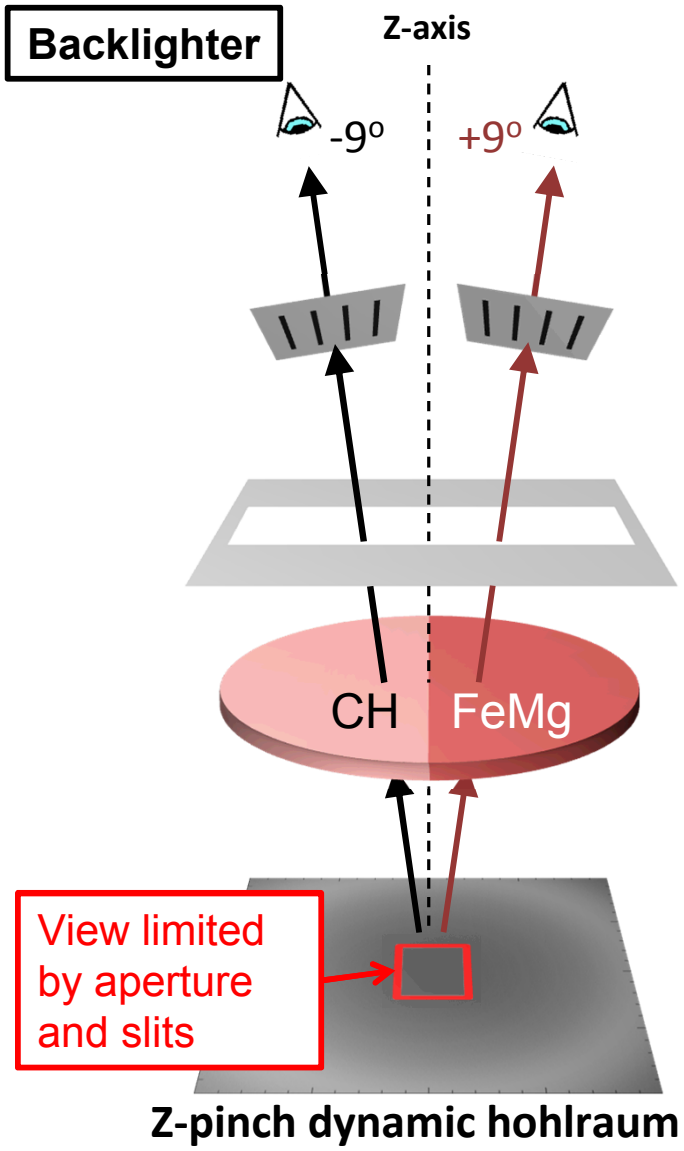
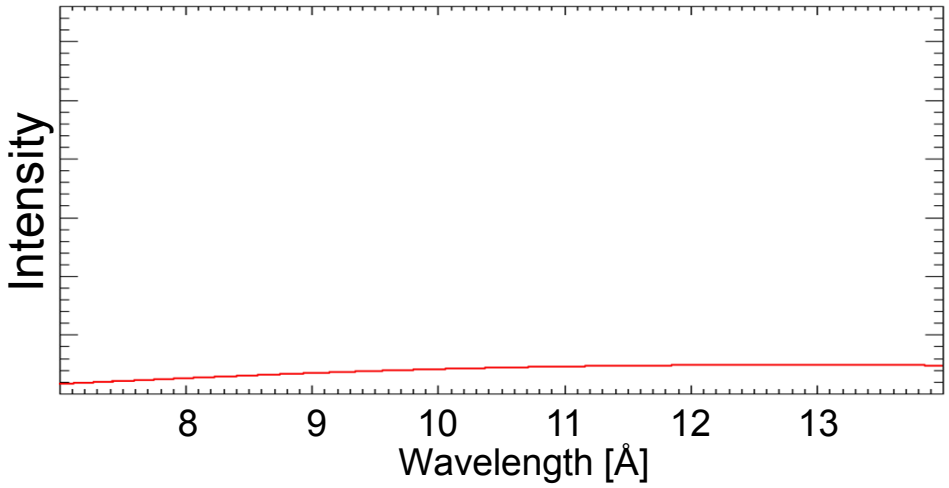
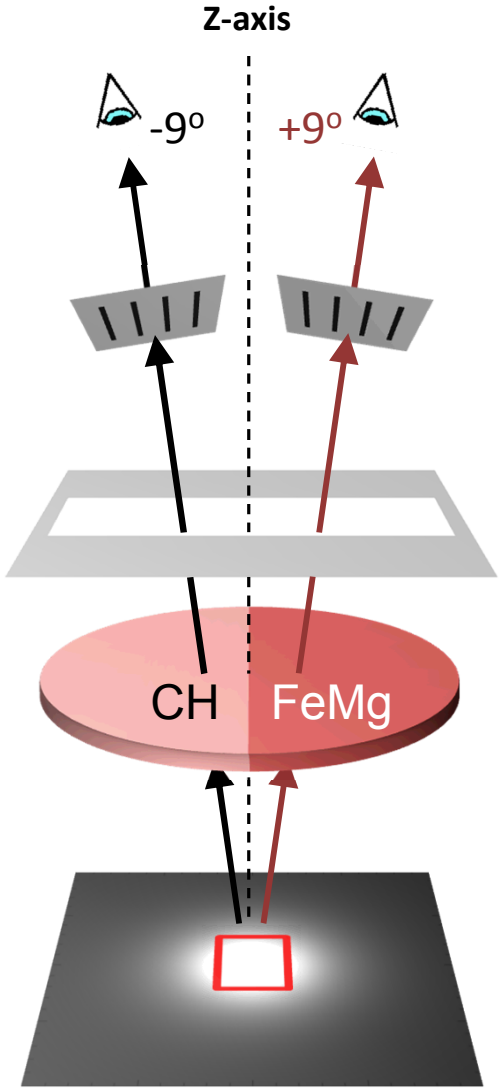


- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Backlighter: Gated pinhole images



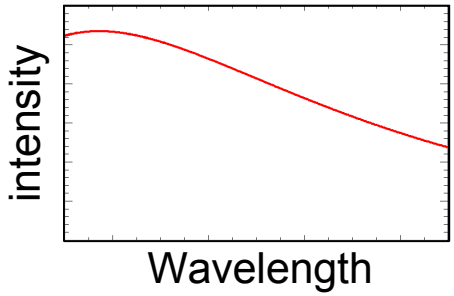
Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics



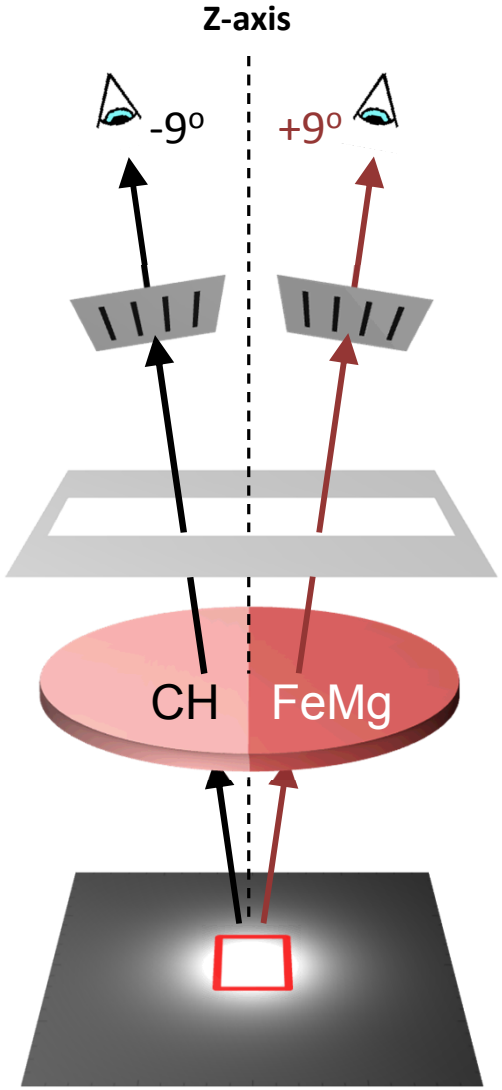
Z-pinch dynamic hohlraum

- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Radiation Transport

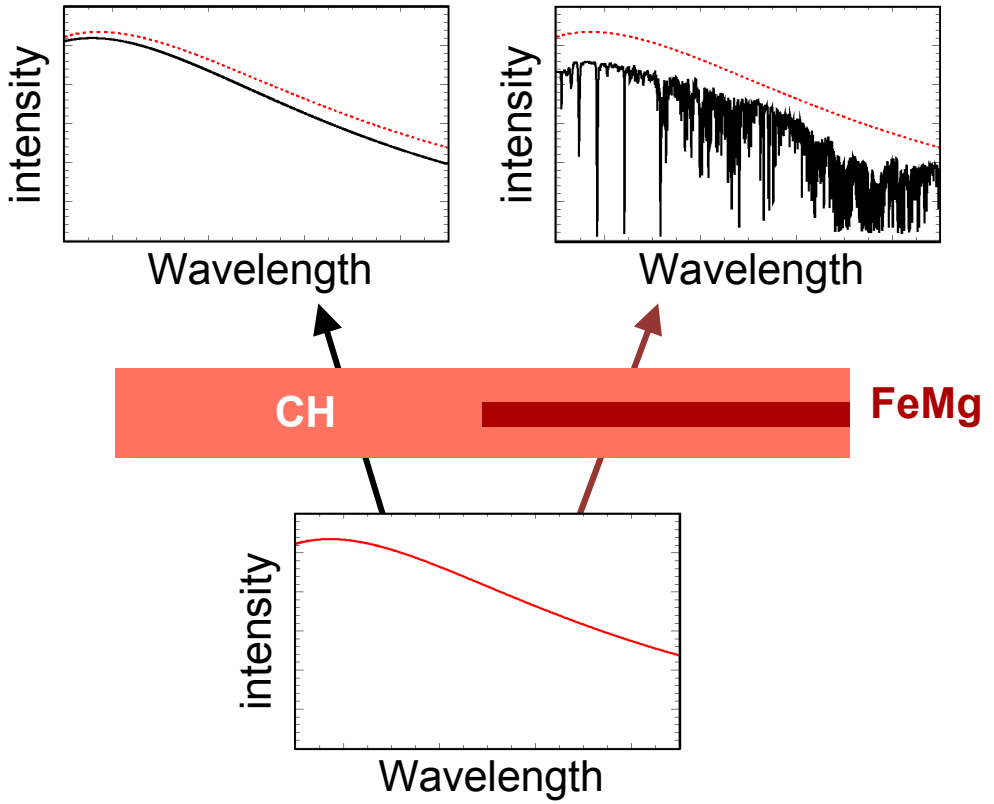


Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics

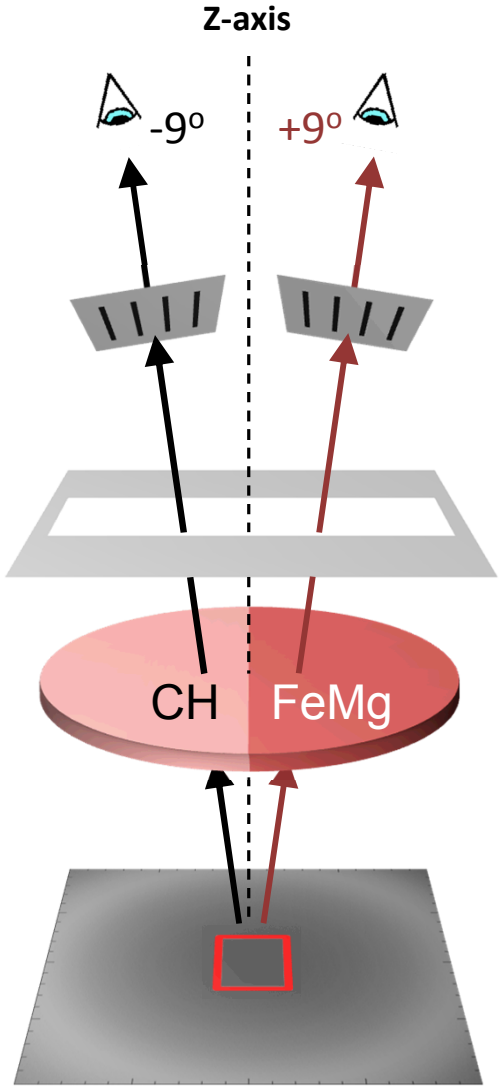


- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Radiation Transport

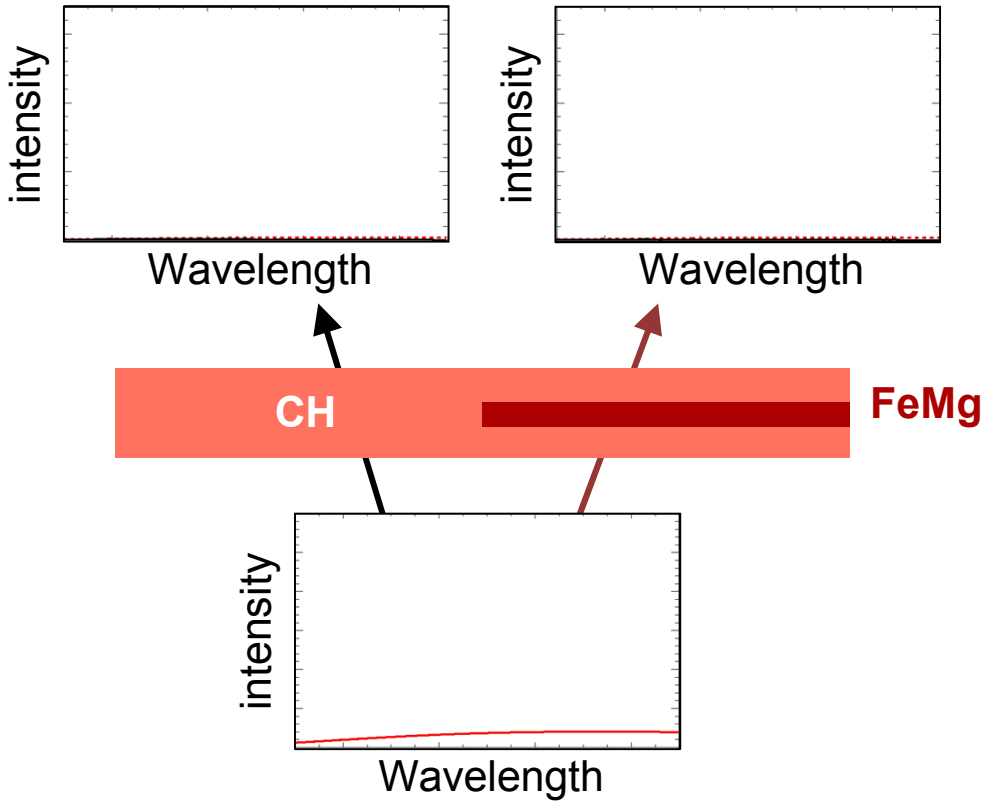


Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics



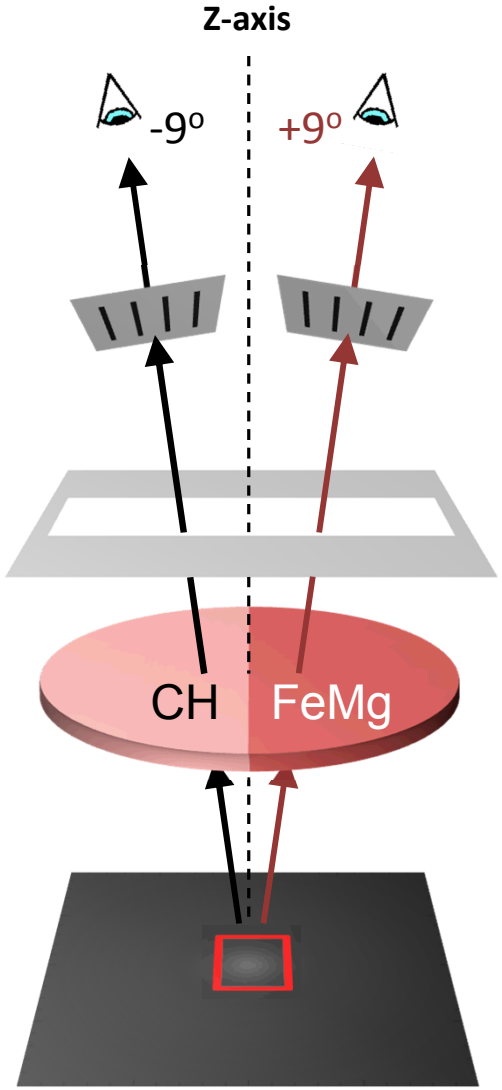
- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Radiation Transport



T. Nagayama et al, Phys Plasmas 21, 056502 (2014)

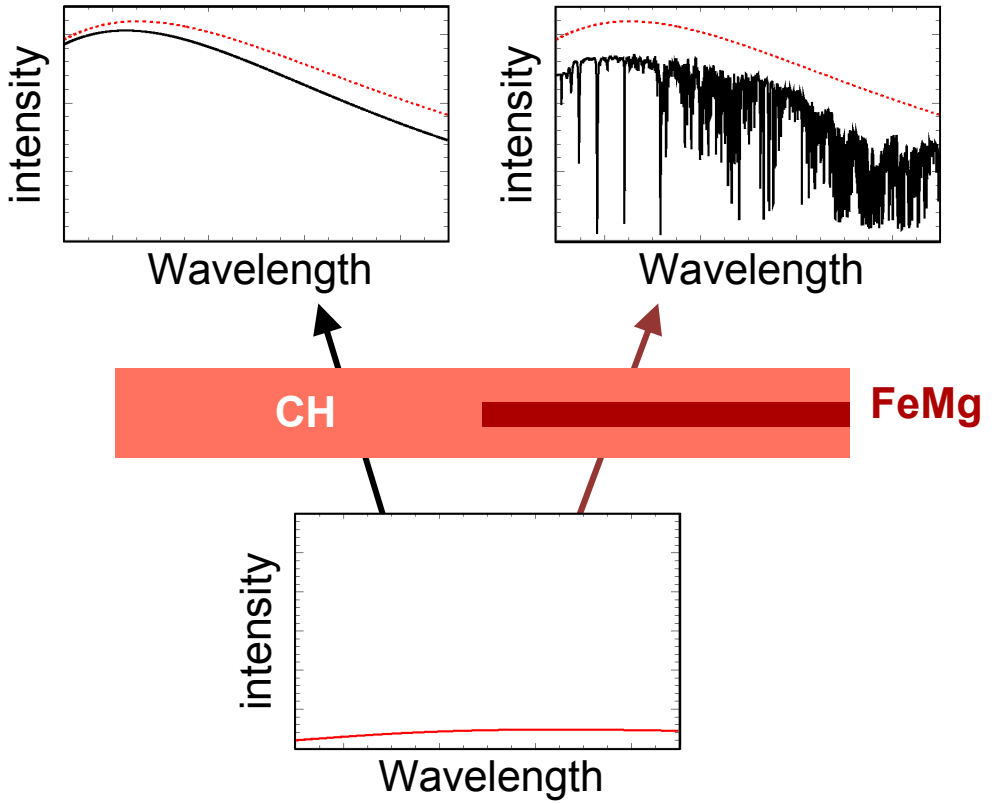
Systematic uncertainties are synthetically investigated accounting for sample/backlighter dynamics



Z-pinch dynamic hohlraum

- Concerns
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects

Radiation Transport



T. Nagayama et al, Phys Plasmas 21, 056502 (2014)

Investigated concerns do not explain the observed discrepancies

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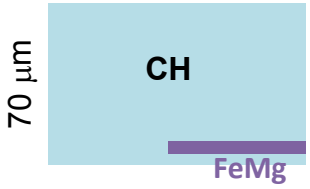
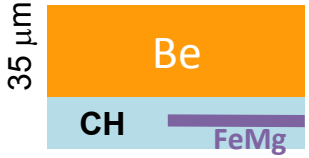
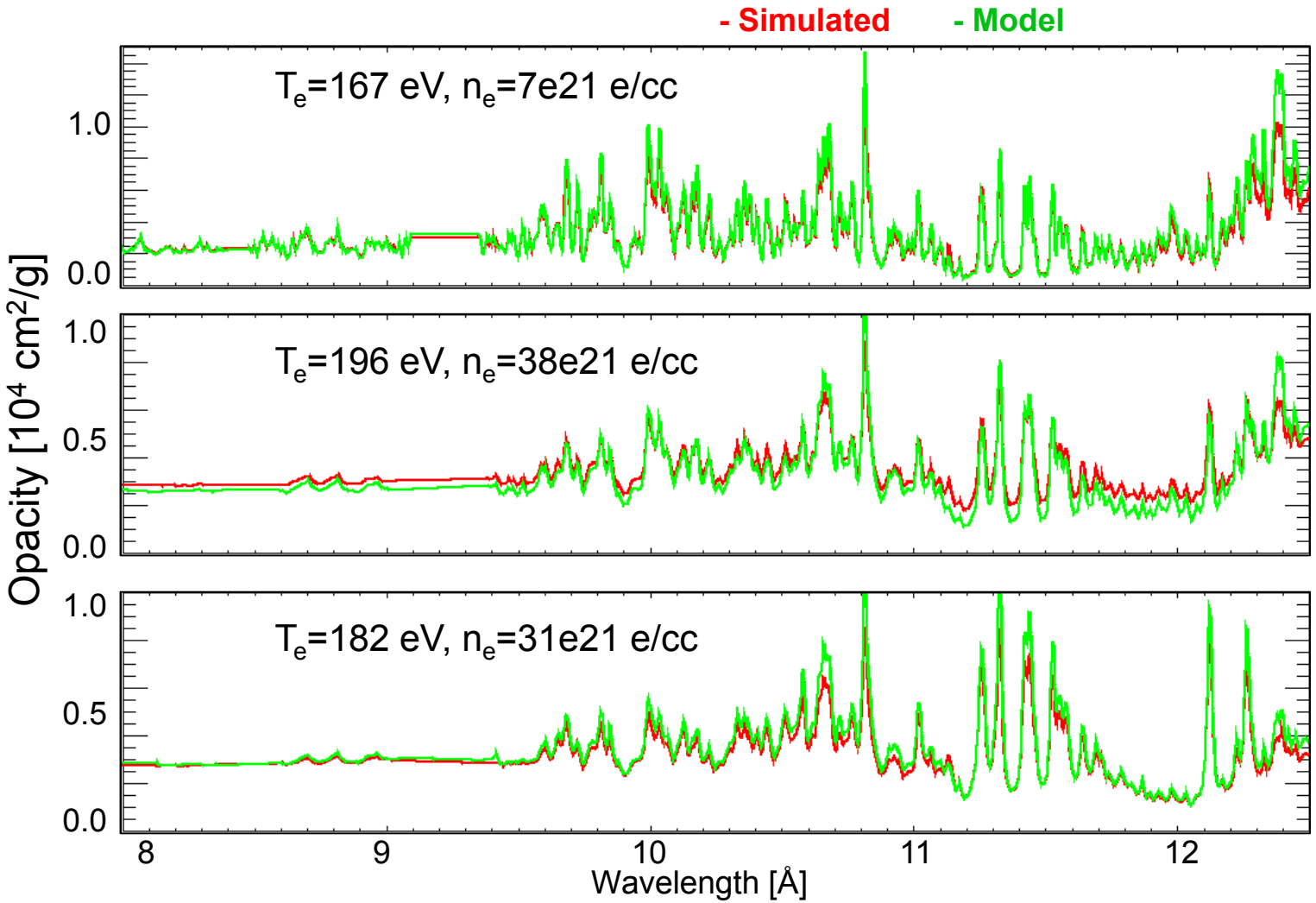
Thin CH

Thick CH



CH+Be





Investigated concerns do not explain the observed discrepancies

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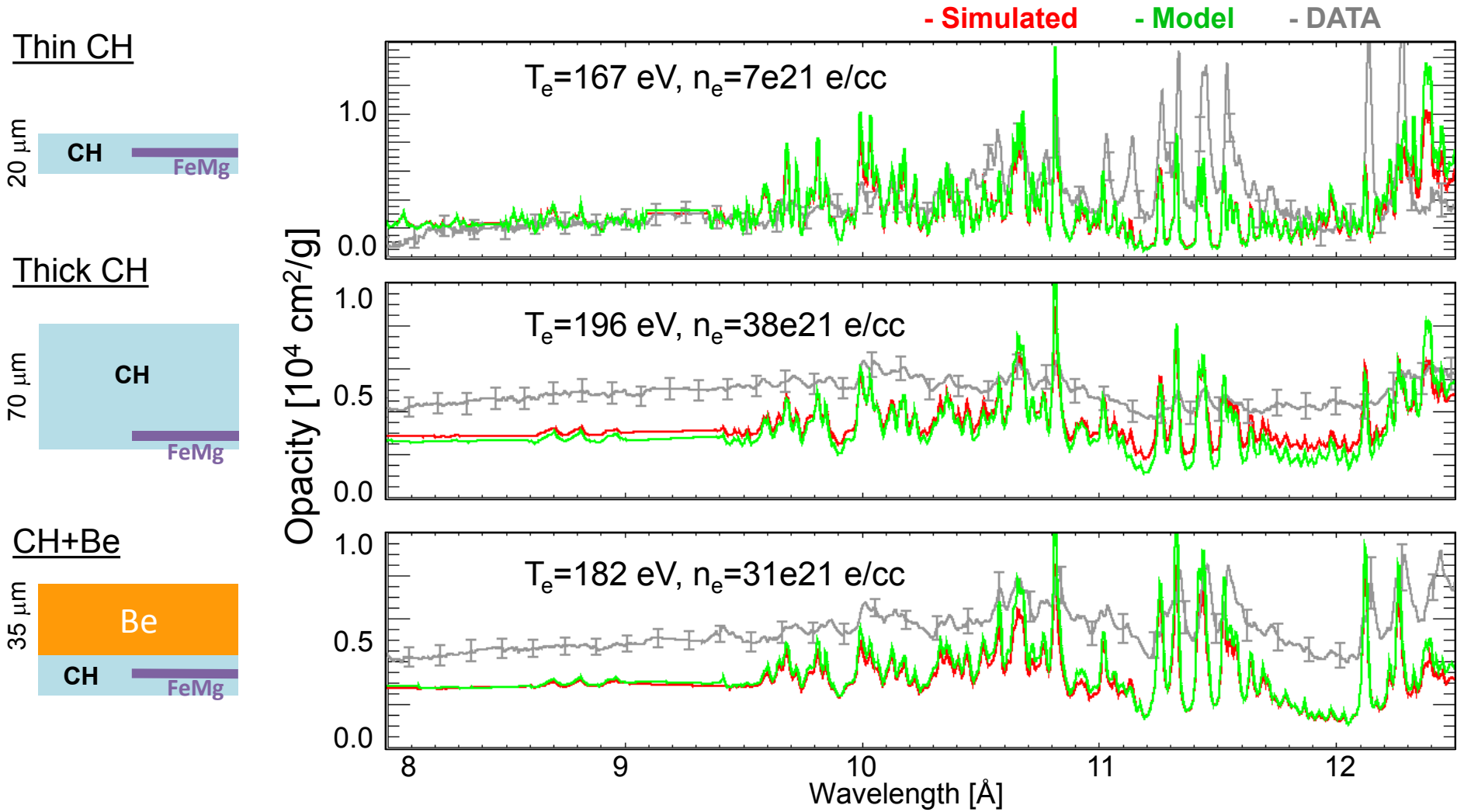

Self-emission, tamper effects, and time- and space-integration effects do not explain the observed discrepancies

Summary: Z Fe opacity measurements reveal that modeled Fe opacities are underestimated at solar interior conditions

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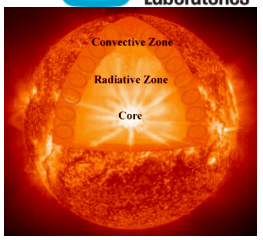
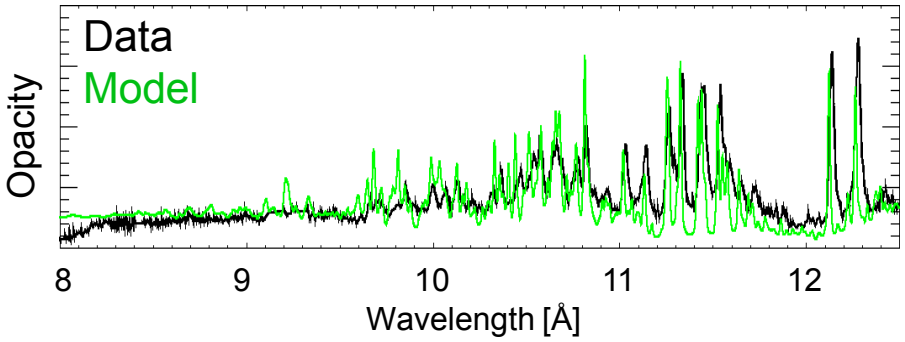
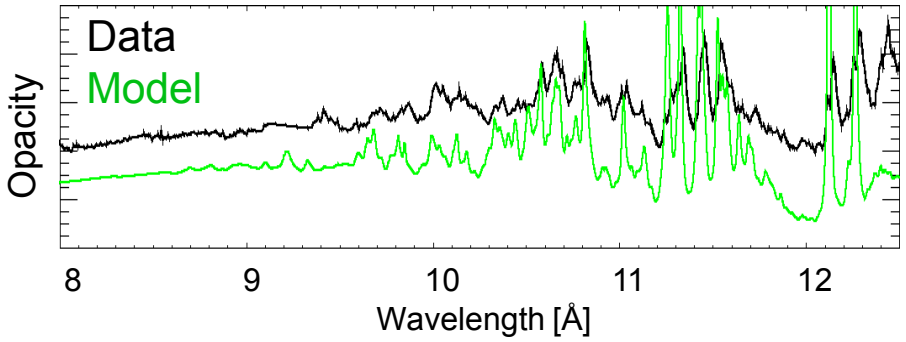


- Fe opacity measurements are important to solve a puzzle with the Sun
- Fe opacity are measured at multiple conditions with SNL Z opacity platform

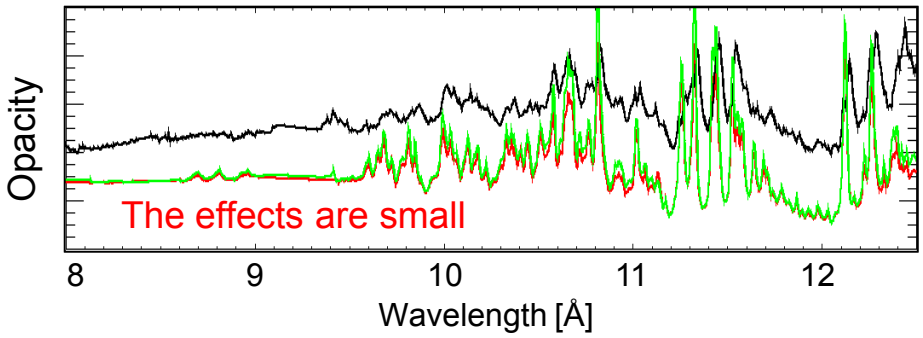
At lower T_e and n_e



At higher T_e and n_e (~ solar interior)



- Various concerns are synthetically investigated
  - Self-emission
  - Tamper effects
  - Time- and space-integration effects



- **The observed discrepancies are likely to be real**
- **Platform is ready to test hypothesis to explain the discrepancies**