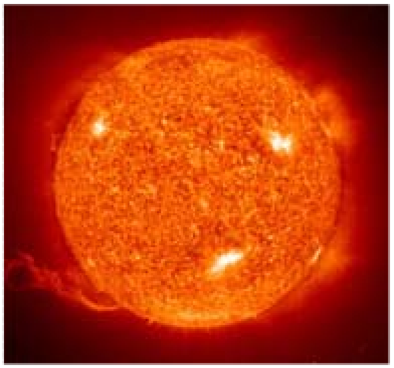
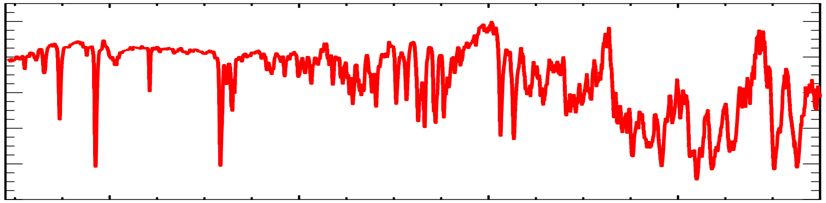
# HEDLP Workshop
# August 26, 2008



## Laboratory Astrophysics at Z: Stellar Interior Opacities



stellar interior iron transitions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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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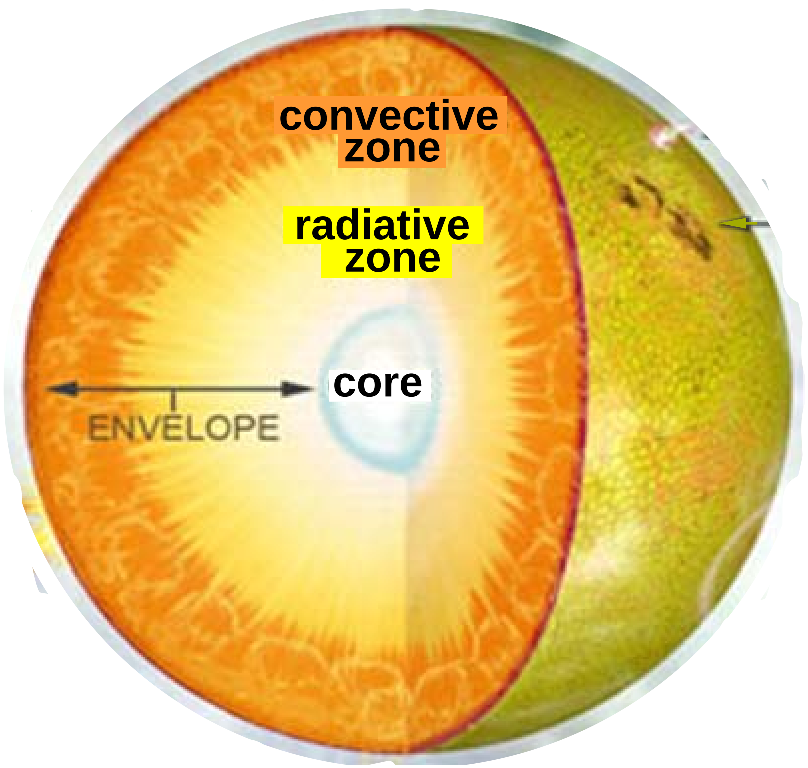
# Modern HED facilities can provide essential stellar physics opacity knowledge

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Stellar structure depends on opacities

Predictions of the best studied star, our sun, do not agree with observations

Solar structure depends on opacities that have never been measured

<u>Challenge: create and diagnose stellar interior conditions on earth</u>

Z opacity experiments reach T ~ 156 eV

High T enables first studies of iron transitions important in stellar interiors

New generation of HED facilities might simultaneously reach stellar density

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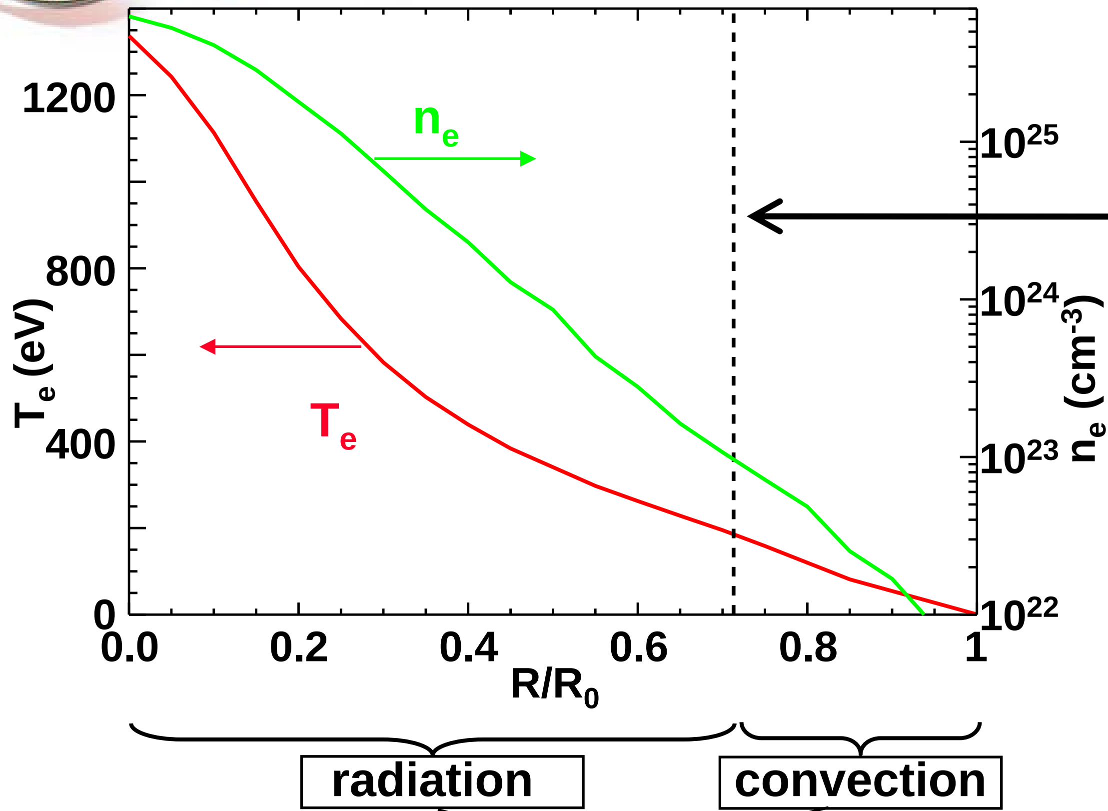
# Modern solar models disagree with observations. Why?




- measured boundary $R_{CZ}$ = 0.713 $\pm$ 0.001
- Predicted $R_{CZ}$= 0.726
- Thirteen $\sigma$ difference

"The CZ problem"

Bahcall et al, ApJ 614, 464 (2004).
Basu & Antia
Physics Reports 457, 217 (2008).

- Boundary location depends on radiation transport
- A 10-20% opacity change solves the CZ problem.
- This accuracy is a challenge – experiments are needed to know if the solar problem arises in the opacities or elsewhere.

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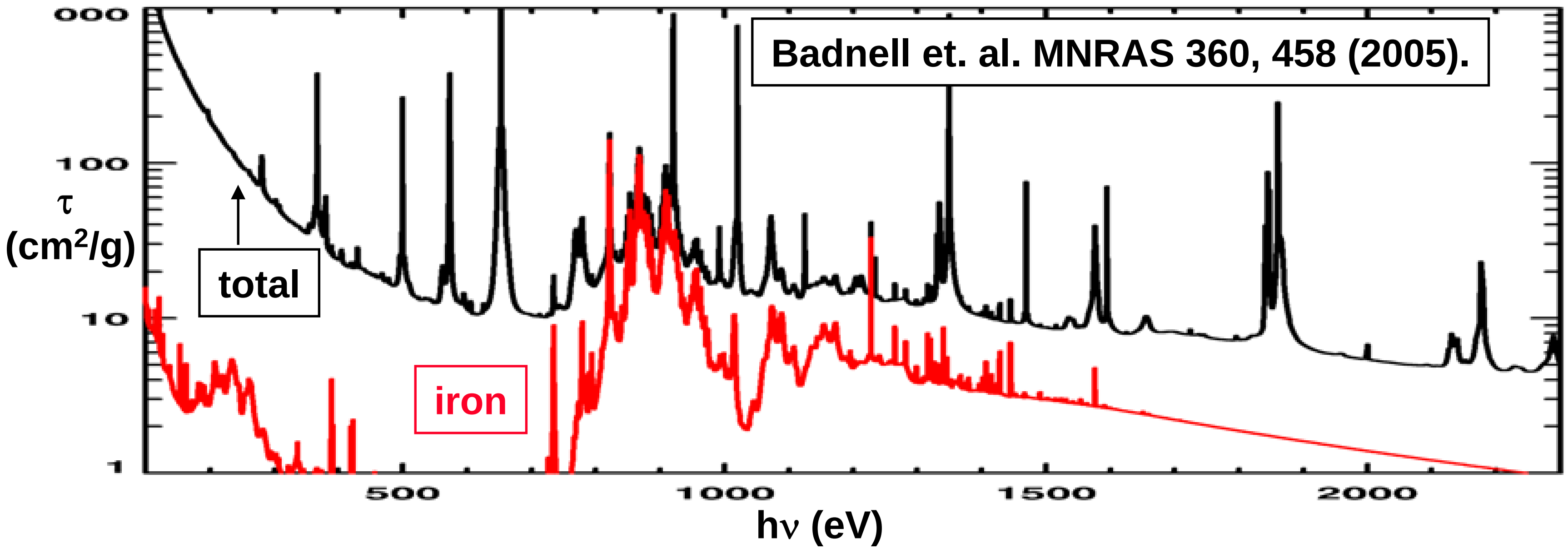
# To understand stars we need accurate opacities for mid-Z atoms at $T_e$ > 150 eV and $n_e > 10^{22}$ cm$^{-3}$

**Opacity Project calculations at bottom of solar convection zone**
**$T_e$=193 eV, $n_e=1x10^{22}$ cm$^{-3}$**




- K-shell oxygen, K-shell neon, and L-shell iron are important at the CZ base
- The complexity of L-shell iron demands special scrutiny
- The importance of any single element is diluted by the mixture

**Example:**
**Changing Fe L-shell by 1.5x causes ~11% change in total mean opacity**

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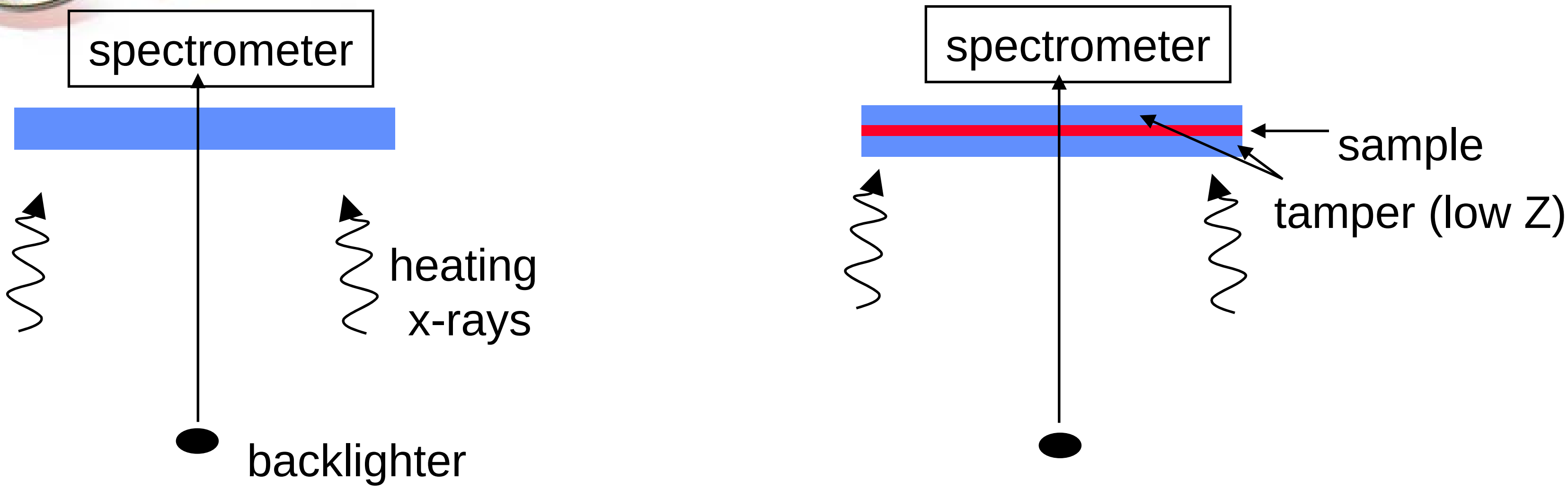
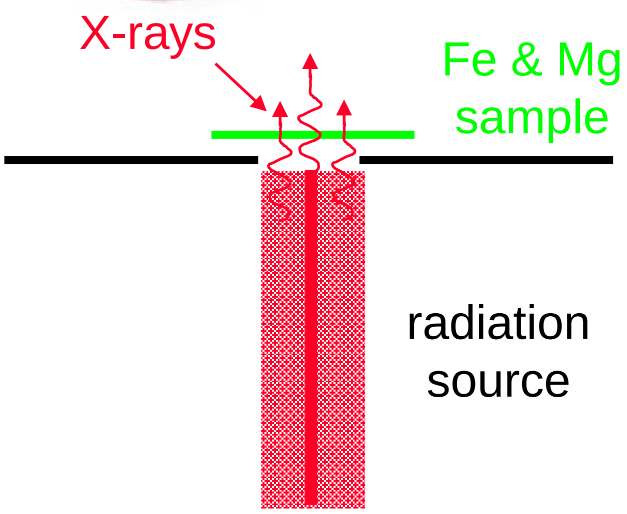
# Opacity experiment challenges grow as temperature and density increase

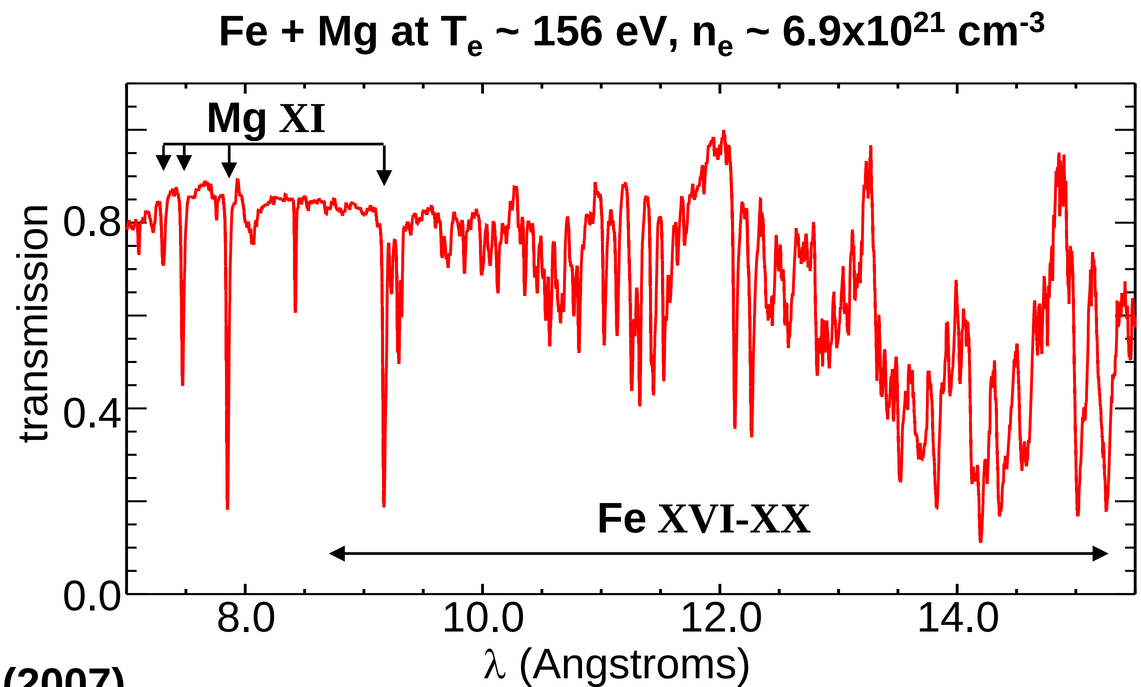



Comparison of unattenuated and attenuated spectra determines transmission
**T = exp –{κρx}**

<u>At high temperature:</u>
More energy in heating x-rays is required to produce uniform conditions
A brighter backlighter is required to overwhelm the self emission

# Z opacity experiments reach T ~ 156 eV, two times higher than in prior Fe research

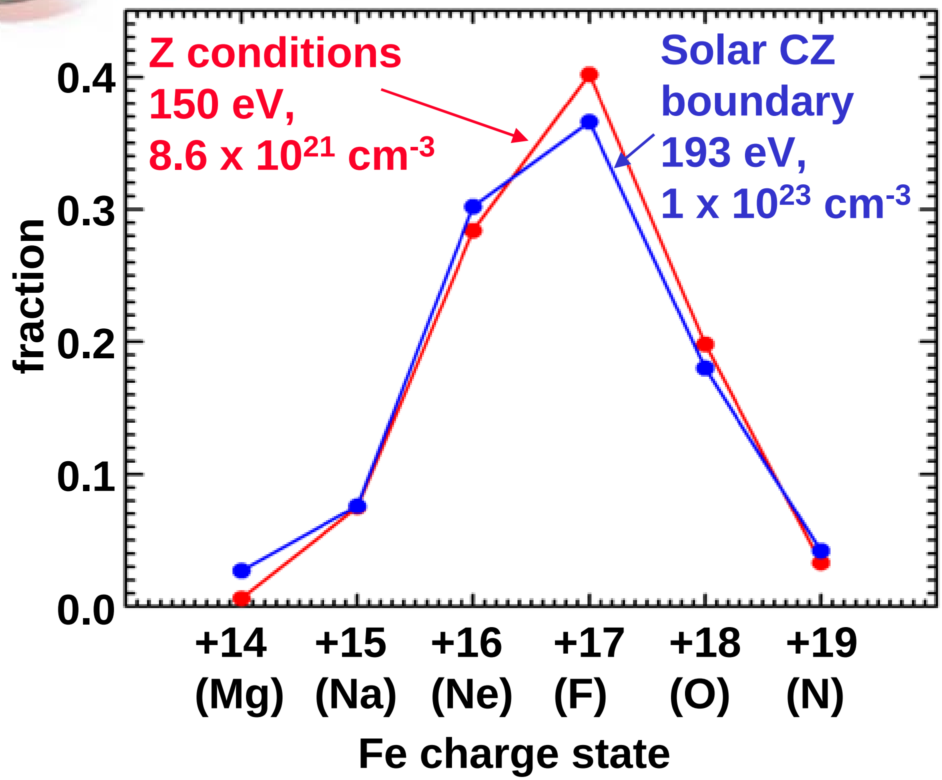



J.E. Bailey et al., PRL 99, 265002 (2007)

- **Mg is the "thermometer", Fe is the test element**

# Opacity experiment priority: produce the charge states found in stellar interiors




The charge state distribution depends on $T_e/n_e$ and it strongly affects both bound-bound and bound-free transitions

- Transitions in Fe with L-shell vacancies are important in the sun
- Laboratory experiments must produce high enough temperatures to ionize Fe into the L shell

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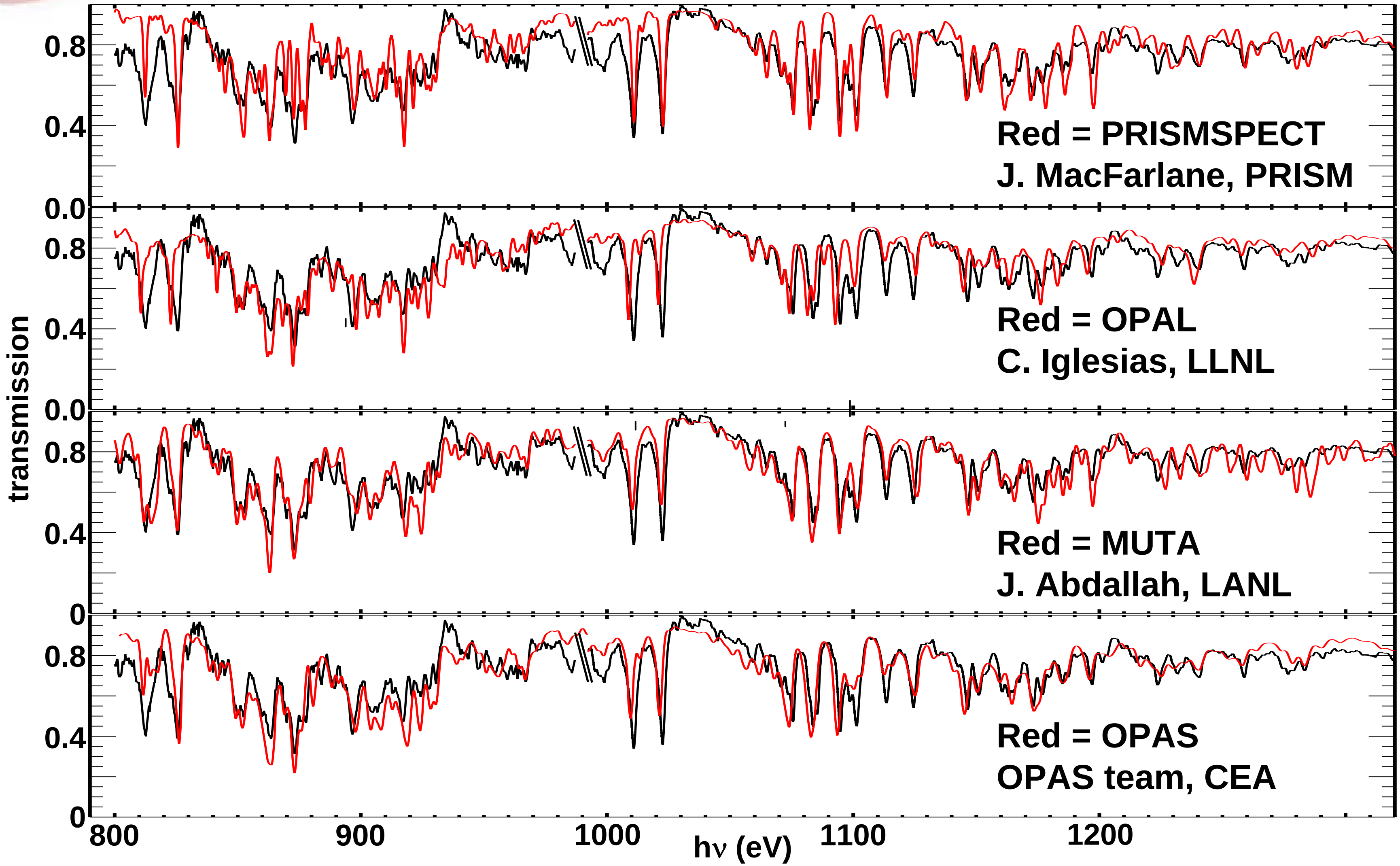
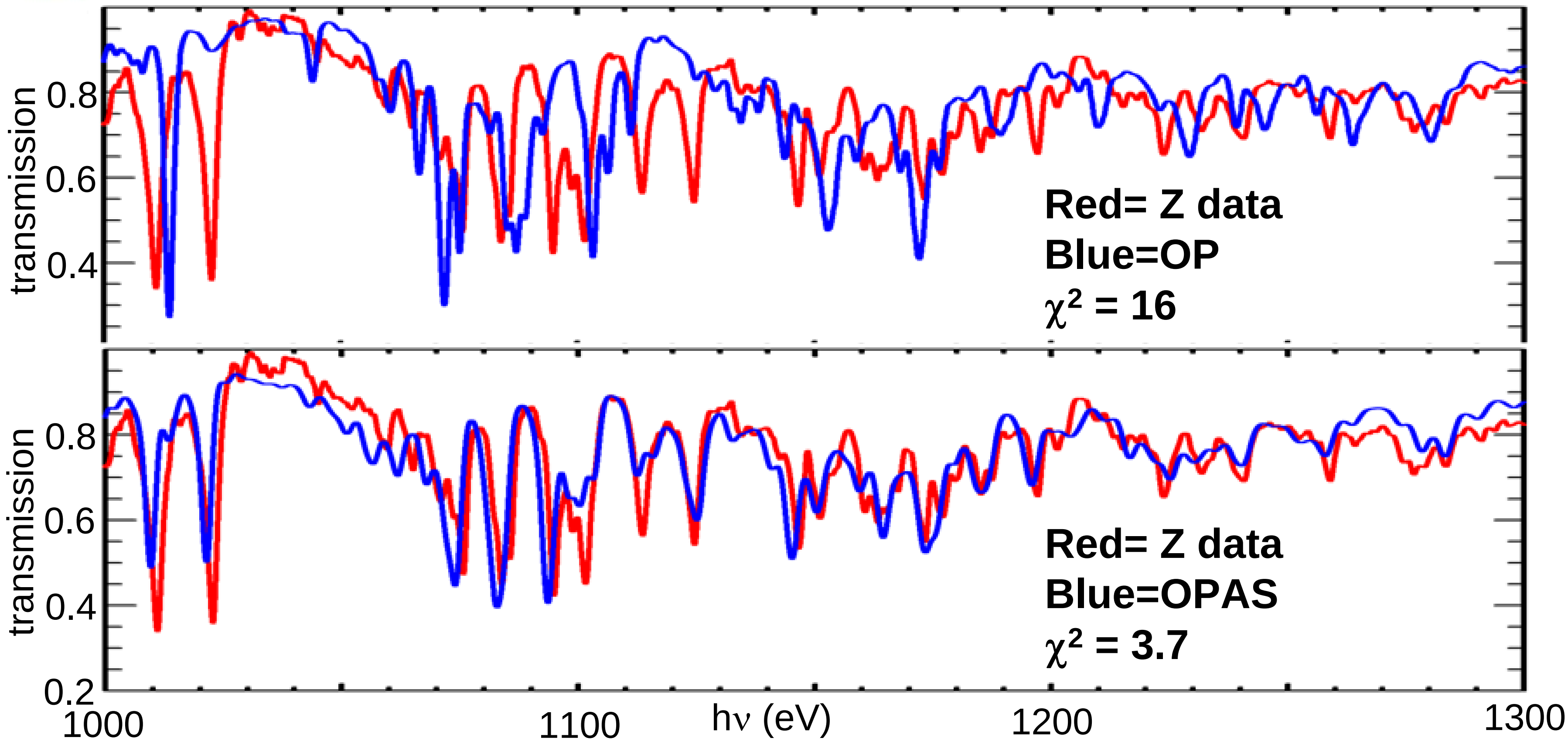
# Modern detailed opacity models are in remarkable overall agreement with the Fe data



# The OP model used in solar research predicts Fe L-shell opacity that is too low at Z conditions




**OP Rosseland mean is ~ 1.5x lower than OPAS at Z conditions.**
**If this difference persisted at solar conditions, it would solve the CZ problem**

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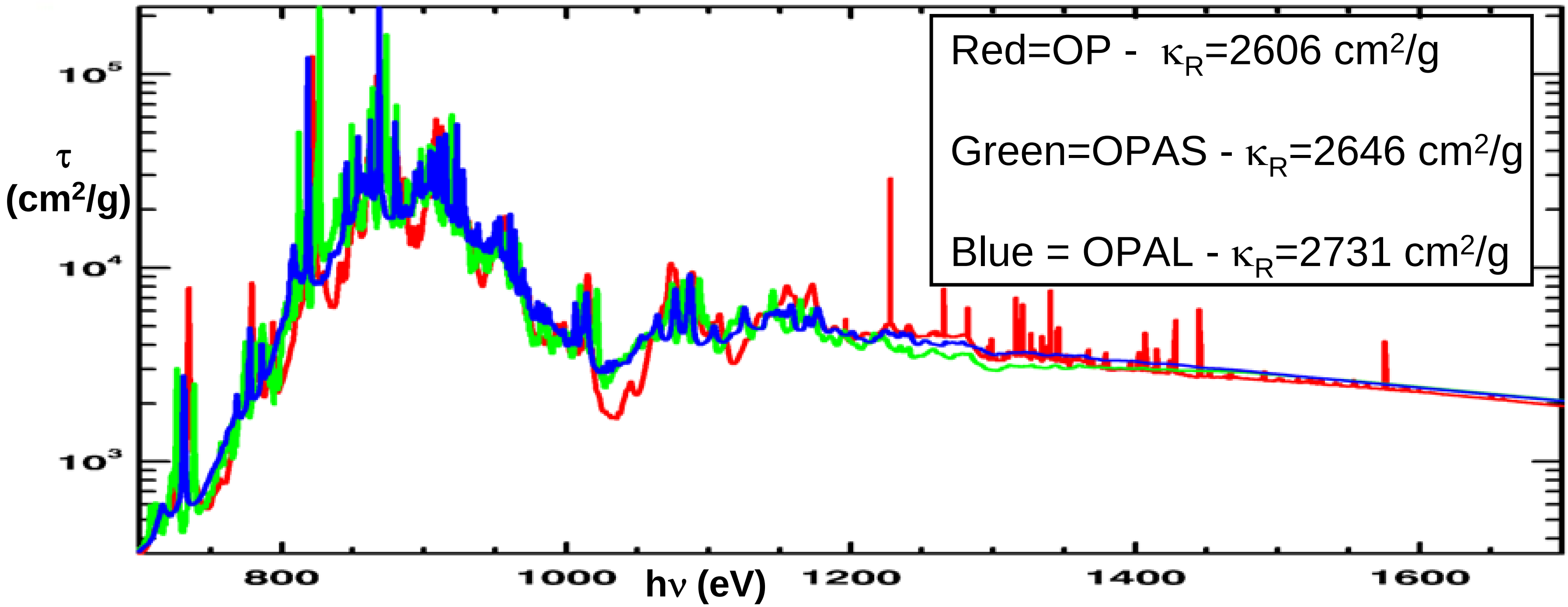
# Discrepancies at Z conditions raise a caution flag for solar opacities




**<u>At the base of the convection zone (T=193 eV, $n_e=10^{23}cm^{-3}$):</u>**
**Iron frequency-dependent opacities possess some differences.**
**But Rosseland mean opacities are not significantly different, even though they disagree at Z conditions.**
**Why?**

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# Experiments at higher density are a logical next step in stellar opacity research

We need to overcome the desire of the sample to expand when it is heated!

Increased tamping

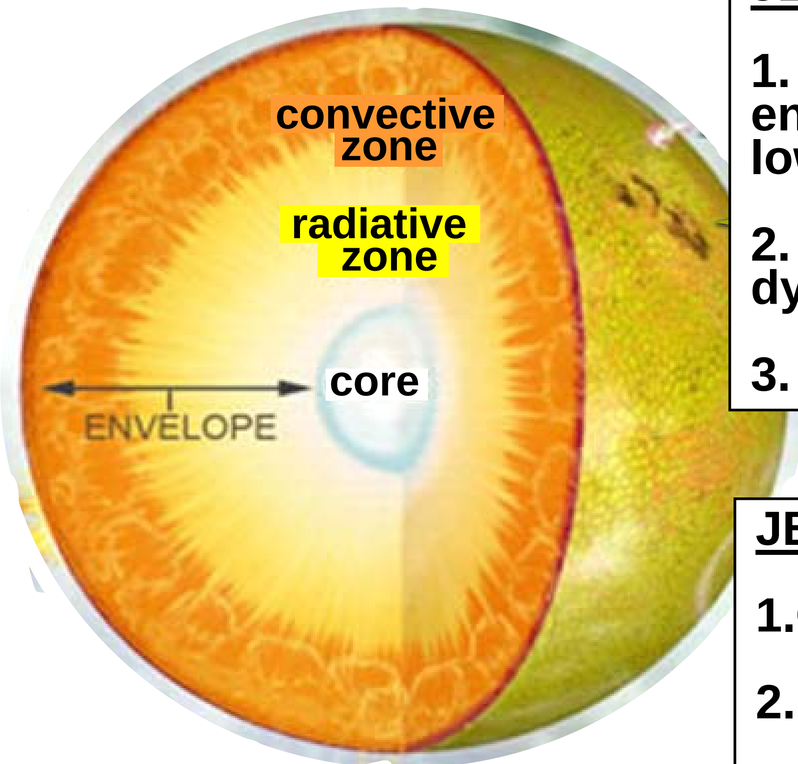
Employ large low Z samples with dilute Fe concentration

Deliberately shock sample

Probe dynamic hohlraum interior

**All options will likely require the greater heating x-rays and brighter backlighting available on the refurbished Z or the NIF**

# Modern HED facilities can provide essential stellar physics opacity knowledge

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**JB's Prioritized list of new research for stars:**

1. Iron L shell at density and temperature high enough to test Stark broadening and continuum lowering physics ($n_e$ ~ $10^{22}$ $cm^{-3}$, $T_e$ ~ 160 eV).

2. Effect of mixed low-Z and mid-Z elements (ion dynamics, influence on wavefunctions)

3. Oxygen and neon.

**JB's Prioritized list of new research for IFE:**

1.Cu and Ge L shell

2. Effect of mixed low Z and mid Z