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Sandia National Laboratories

Temperature and density analysis and their uncertainties

PRESENTED BY

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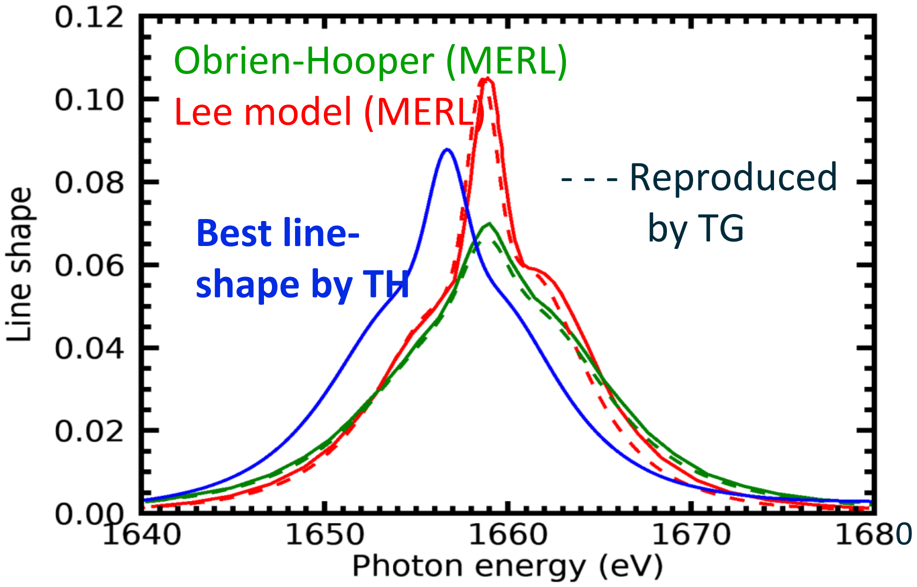
Sample temperature and density need to be reanalyzed due to recent refinements in line shapes and background inference

Line-shape refinements [1,2]

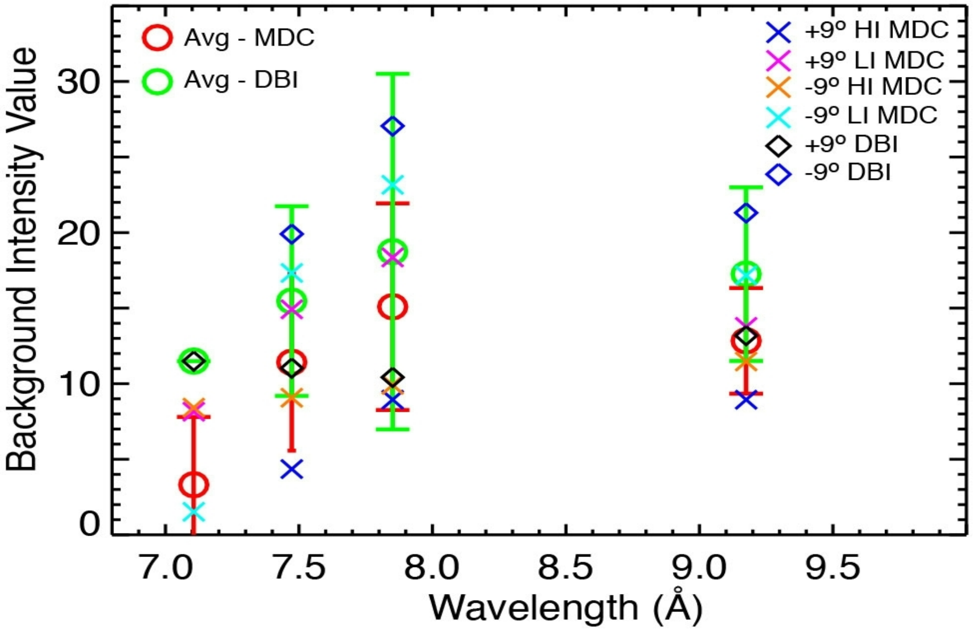
- Electron capture
- Removing 3 approximations



Affects n_e by up to 30%
Affects T_e by a few %

Background refinements [3]

- Method1: Dual backlight intensity (DBI)
- Method2: Modal-data comparison (MDC)

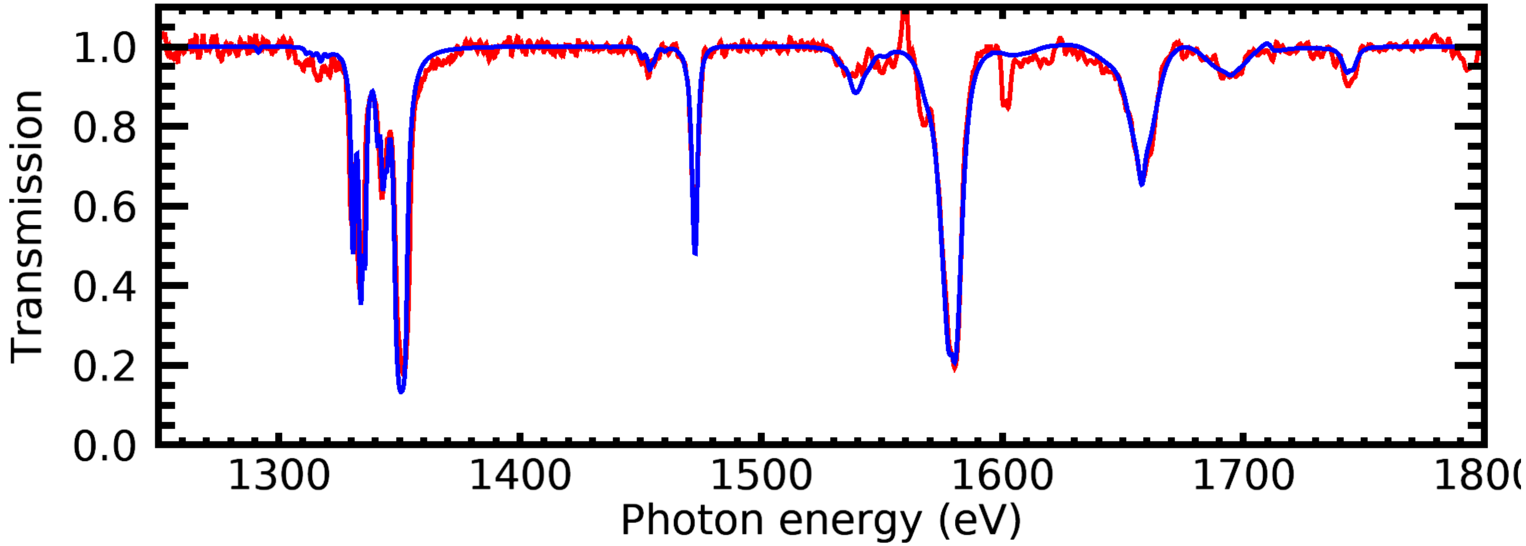


Affect both n_e and T_e for strong lines (e.g., Heβ)

Need to revisit Te and ne analysis, but let's revisit analysis method itself

[1] Gomez et al PRL (2020), [2] Gomez et al submitted to PRL, [3] Dunham et al accepted by RSI

I've been analyzing all lines simultaneously and infer T_e, n_e, ρL, and background simultaneously



z2624
Fe at anchor2

T_e = 179.7±0.5 eV (0.2%)

n_e = (3.53±0.05)x10^{22} eV (1.4%)

ρL = (6.2±0.1)x10^{-5} g/cm^2 (1.6%)

background = 6.0±0.6 J/sr/Å (10%)

Final fits look great, but this analysis produces too small uncertainties, raising concern in uncertainty quantification

Uncertainties inferred from χ^2 analysis (or Bayesian analysis) are often too small when *assumptions* are inappropriate

Assumptions

- Experiment and data reduction are perfect
- Background treatment is perfect
- Uncertainty is dominated by random noise
- Plasma condition is spatially and temporally uniform
- Spectral model is perfect
    - Atomic data are perfect
    - Line-broadening model is perfect
    - Continuum lowering is perfect

Whenever the assumptions are invalid, the analysis shows inconsistency.
→ This inconsistency artificially reduce uncertainty.

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Assumptions		*Reality*
- Experiment and data reduction are perfect	→	We know they are not perfect
- Background treatment is perfect	→	We don't know where background is from
- Uncertainty is dominated by random noise	→	There are systematic uncertainties
- Plasma condition is spatially and temporally uniform	→	There is axial gradient that changes with time

- Spectral model is perfect
  - Atomic data are perfect
  - Line-broadening model is perfect
  - Continuum lowering is perfect
	→	Different spectral model gives different answers → Nagayama HEDP (2016)

Whenever the assumptions are invalid, the analysis shows inconsistency.
→ This inconsistency artificially reduce uncertainty.

Jim took more conservative approach in 2008*

<u>Different lines suggest different n_e</u>

- Heβ → 9.6×10^{21} cm^{-3}
- Heγ → 6.1×10^{21} cm^{-3}
- Heδ → 4.9×10^{21} cm^{-3}

→ $(6.9 \pm 1.7) \times 10^{21}$ cm^{-3}

<u>Different line ratios suggest different T_e</u>

- Lyα/Heβ Lyα/Heγ Lyα/Heδ
- Lyβ/Heβ Lyβ/Heγ Lyβ/Heδ

→ 156±6 eV

Since they give inconsistent results, he averaged them together.

Key question: Don't we get more accurate result if we analyze them together?

→ Answer depends on:

- If they are giving consistent answers

- If not, why they are giving inconsistent answers

All line analysis under this circumstance results in *some average* with very small uncertainties

<u>Individual analysis:</u>

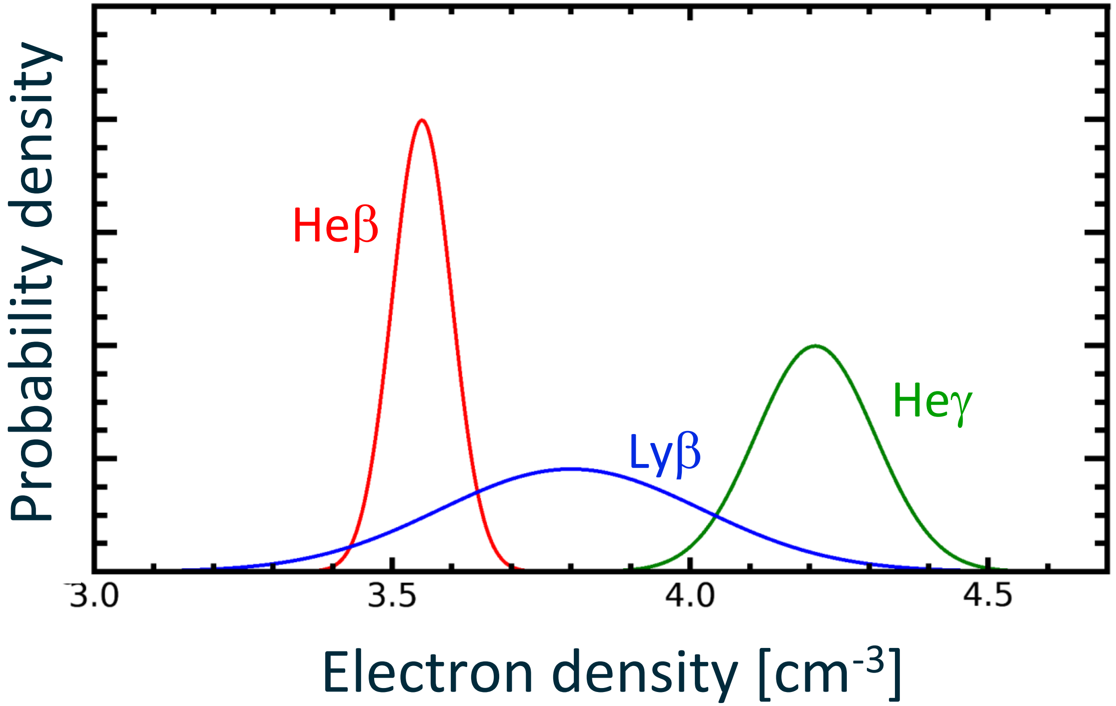
Heb: (3.55±0.05)e22 (1.4%)
Heg: (4.21±0.10)e22 (2.4%)
Lyb: (3.80±0.22)e22 (5.8%)

<u>Simultaneous analysis:</u>

Heb, Heg, Lyb together

(3.68±0.04)e22 (1.1%) cm^{-3}

What's happening?



Both χ^2 and Bayesian analyses use the likelihood and thus can introduce this artificial underestimate of uncertainty *when model is inappropriate*

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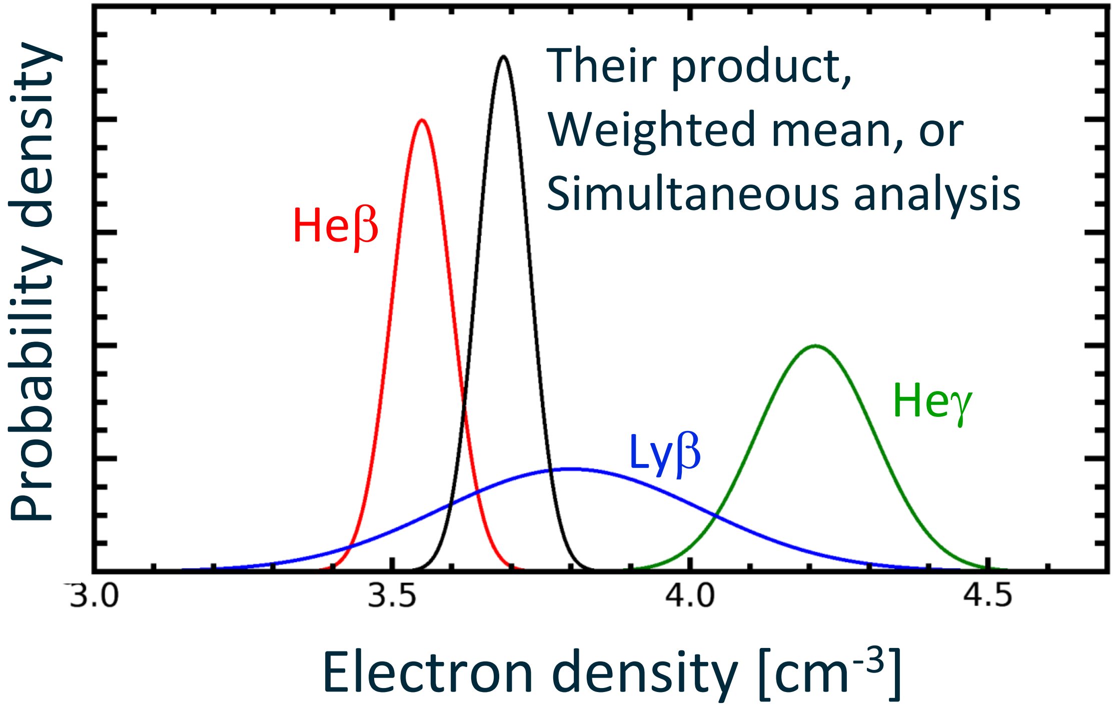

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*z2588 CCP10a

Our new approach quasi-isolate various dependencies, include inconsistencies into the parameter uncertainties

Step1: Background: Determine and subtract background from the data

Step2: n_e**:** Analyze Mg Heβ, Heγ, Lyβ line widths

Step3: ρL**:** Analyze Mg Heβ and Heγ line depths

Step4: T_e**:** Analyze 11 line ratios

Advantage:

- **This accounts for various uncertainties including uncertainty due to assumptions**
- **We may able to identify issues from too large uncertainties**

Pros and cons for each approach

Individual analysis:

Pros:
- Physics we rely on is clear --> More insightful
- Account for inconsistencies into uncertainty

Cons:

- Harder to account correlation between parameters and between objectives

Simultaneous analysis

Pros:
- Account for correlation between parameters and between objectives
- Statistically more accurate if dominant source of uncertainty is statistical noise

Cons:
- Physics we rely on is less clear --> Less insightful
- Cannot account for inconsistencies into uncertainties