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# Electron density determination in a MgFe dense plasma via Stark broadening analysis

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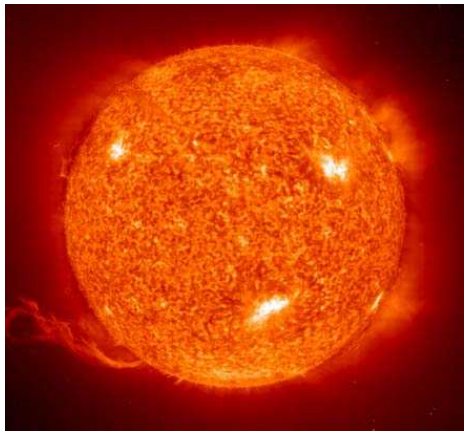
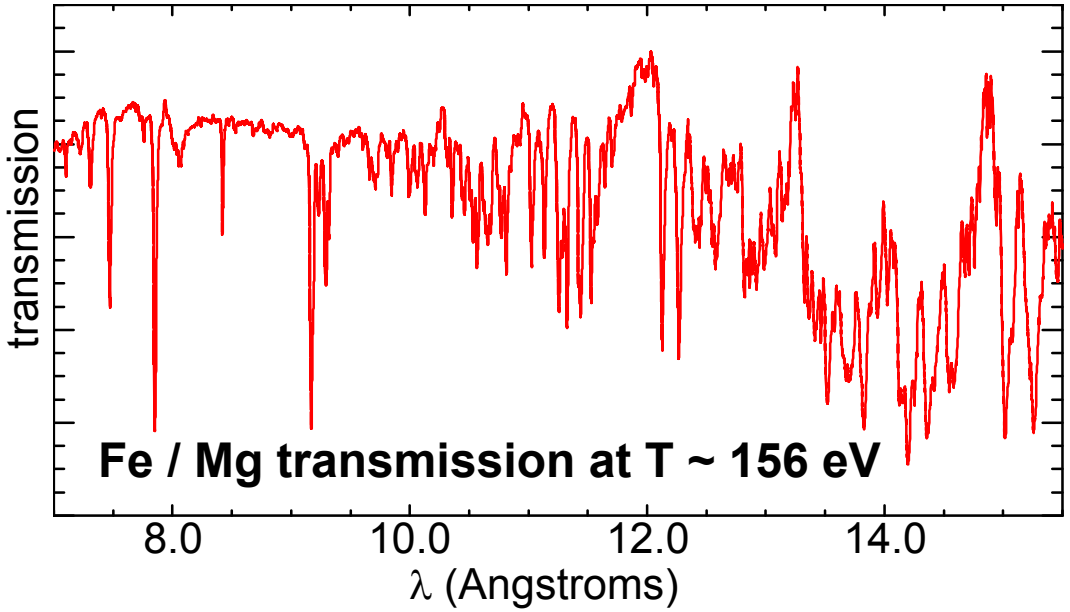
# Laboratory experiments test opacity models that are crucial for stellar interiors



**Emergent radiation depends on opacity**




**Z opacity experiments reach T ~ 156 eV**
**High T enables first studies of transitions important in stellar interiors**
**Measurements establish Z opacity science platform**
**Challenge: how do we diagnose conditions in the absorbing plasma?**
**Idea: Fe is the test element; Mg is the diagnostic element → extract $T_e$, $N_e$**

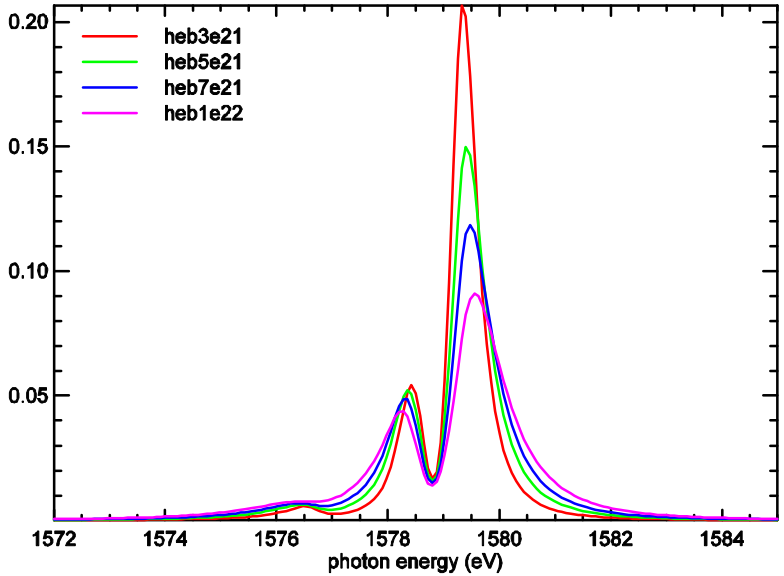
# Use density dependence of Stark broadened Mg absorption line shapes

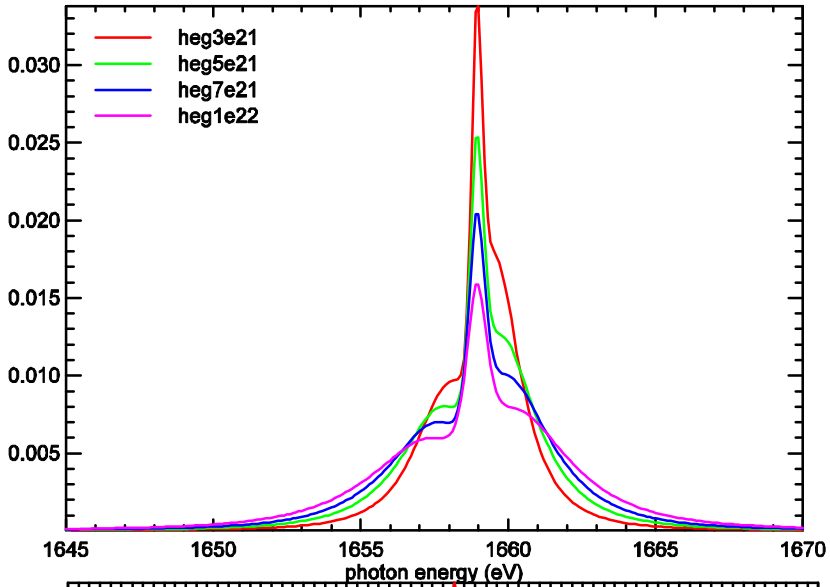
- Calculations: MERL multi-electron line shape model and code[1,2]
- MERL implements the standard Stark broadening theory approximation: consider static ions and dynamic electrons
- Electron broadening: second order quantum mechanical approximation
- Static ion's microfield distribution: APEX approximation[3]
- Important property: Stark broadened line shapes are mainly dependent on plasma density
- Mixing between adjacent manifolds of different principal quantum numbers is included
- Also included: natural and Doppler broadening effects

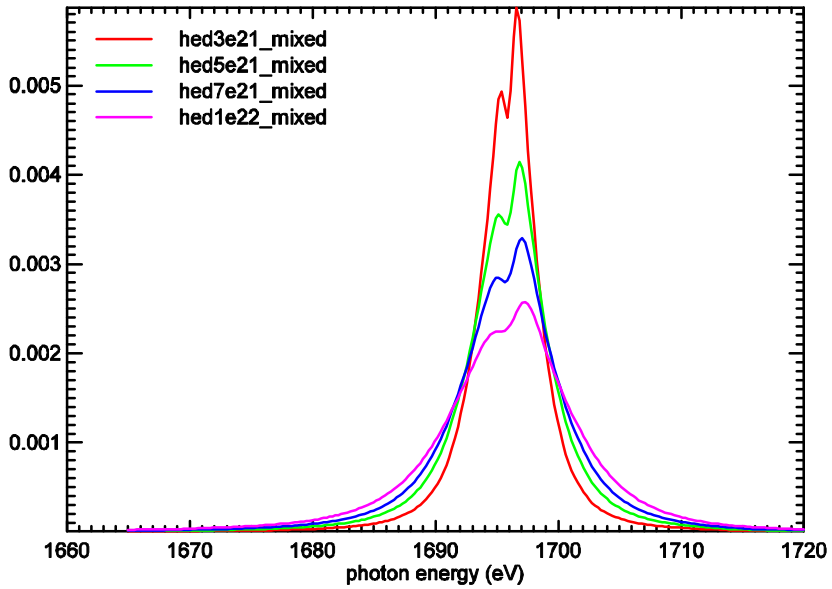
[1]L.A. Woltz and C.F. Hooper, Jr., Physical Review A **38**, 4766 (1988)
[2]R.C. Mancini, D.P. Kilcrease, L.A.Woltz, C.F. Hooper, Jr., Computer Physics Communications **63**, 314 (1991)
[3]C.A Iglesias, H.E. DeWitt, J.L. Lebowitz, D. MacGowan, W.B. Hubbard, Physical Review A **31**, 1698 (1985)

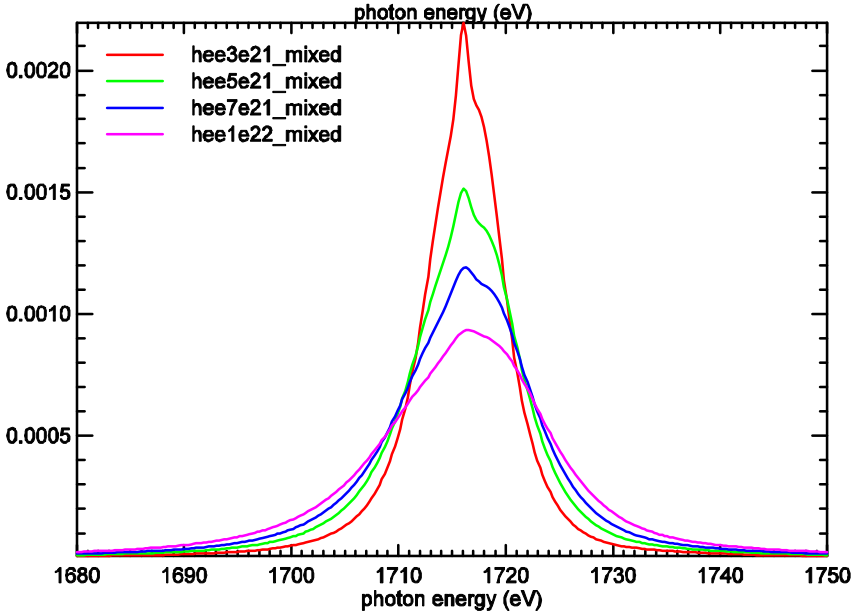
# $N_e$ sensitivity of Mg He-like absorption line shapes

Absorption lines correspond to transitions from n=1 to n = 3 (heb), 4 (heg), 5 (hed), 6 (hee)



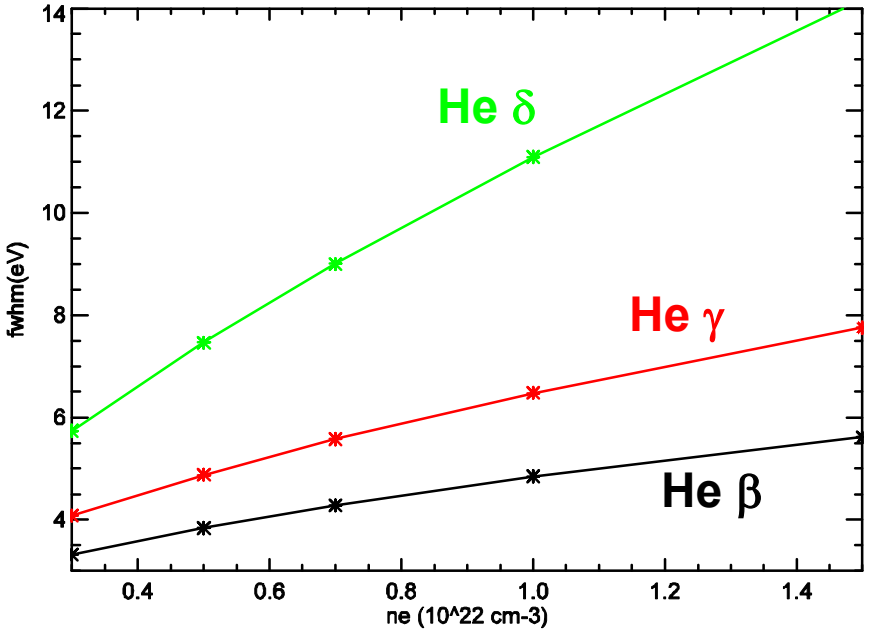



# Density dependent width "survives" instrumental broadening effect

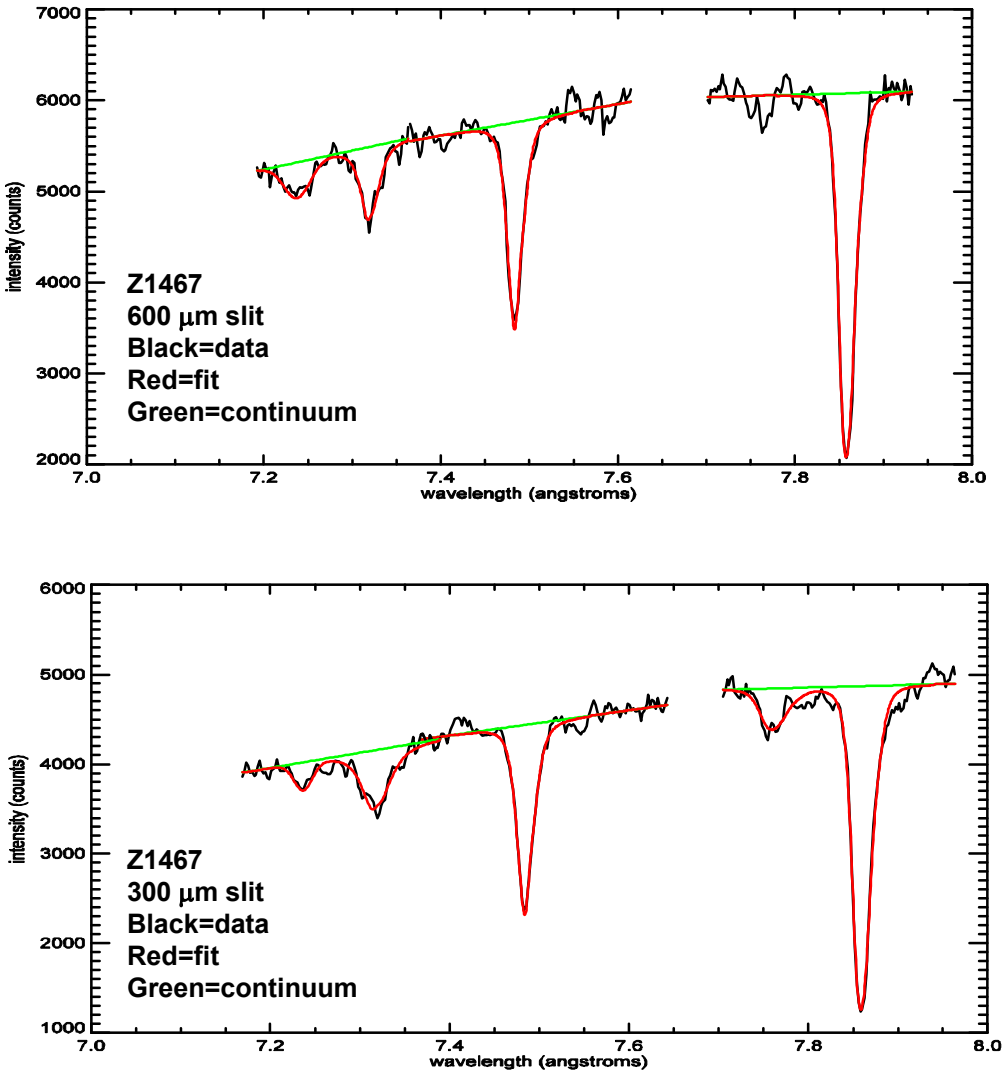
- After convolution with the instrumental function ($\lambda/\Delta\lambda \approx 700$) specific line shape details are washed out
- However, the density dependent width and an overall shape asymmetry still "survive"




- The density analysis relies mainly on heb (1-3), heg (1-4) and hed (1-5) lines
- Absorption line shapes are used to compute photon-energy dependent optical depth $\tau_\nu$, which also depends on areal-density
- But He-like Mg ground state population is weakly dependent on temperature, for the temperature range of interest
- In turn, this still renders the transmission line profile ($\sim e^{-\tau}$) density dependent

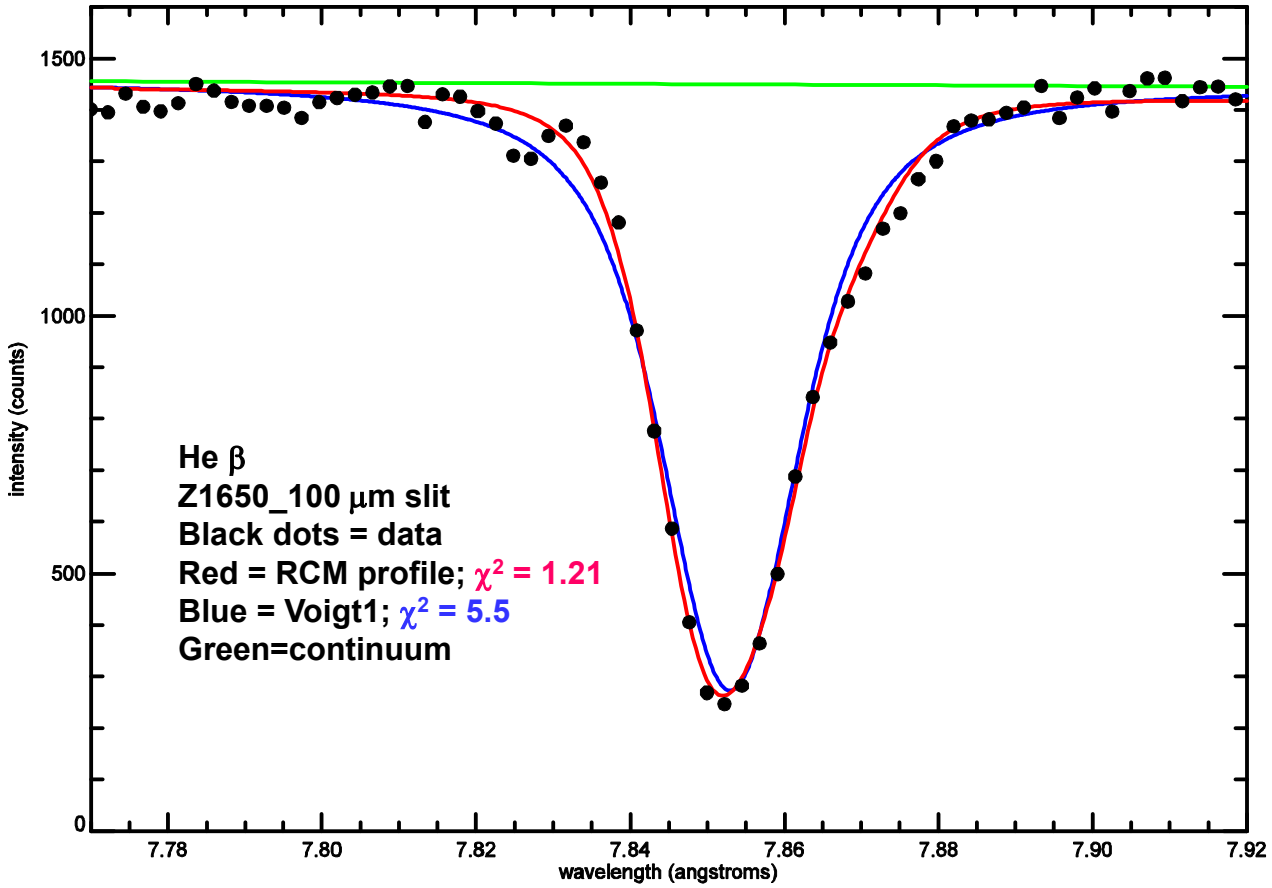
# Data is systematically analyzed using ROBFIT

- Detailed line shapes are used in the spectral analysis code ROBFIT[1] to fit each absorption feature
- The code self-consistently fits absorption spectral features and continuum in order to produce the optimal fit to the data
- A weighted least-square method is employed to track the best fit, and uncertainties are determined from the error matrix evaluated at the minimum of the $\chi^2$ surface[1]



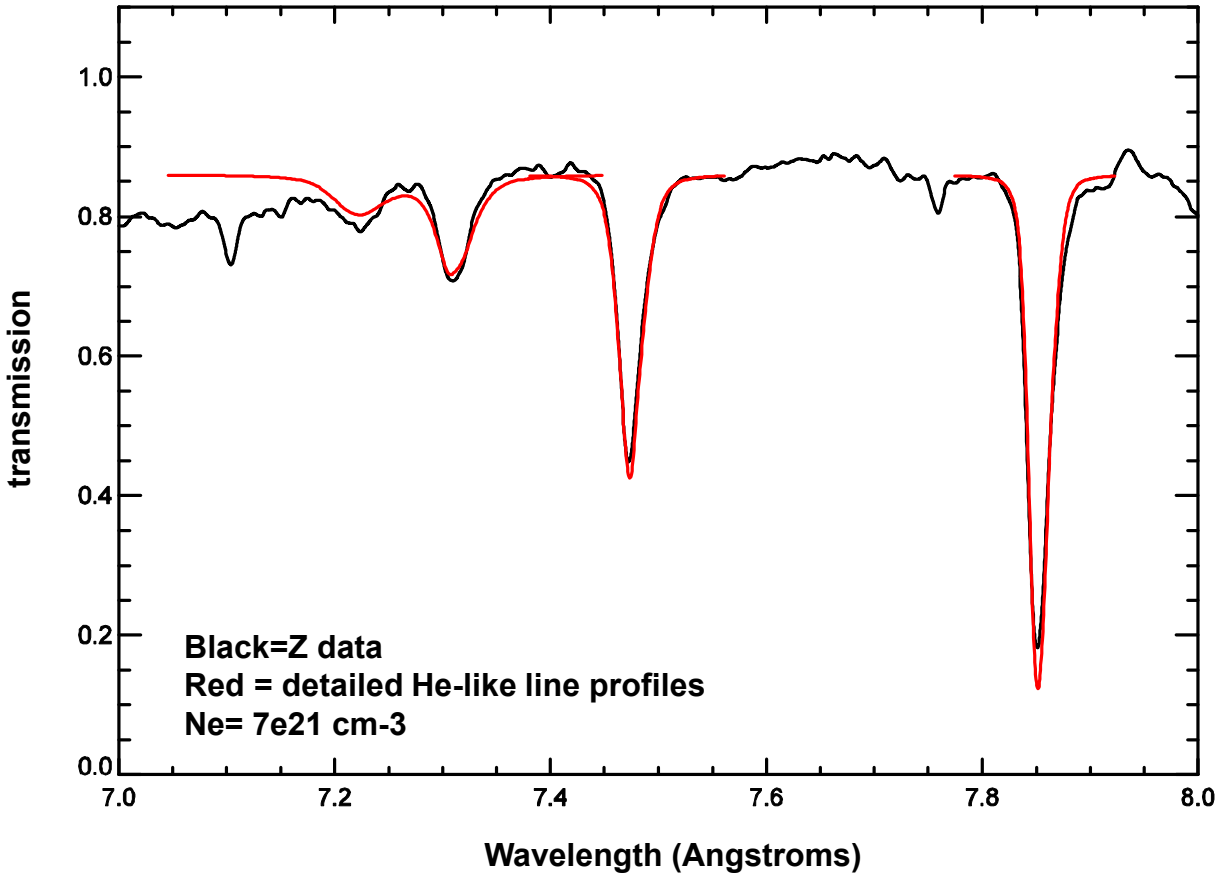

[1] *The Theory and Operation of Spectral Analysis Using ROBFIT* by R.L. Coldwell and G.J. Bamford, American Institute of Physics (1991)

# Data quality is good enough to sort out differences between theory fits




- Weighted-least-square fits based on customized/detailed line shapes and generic Voigt line shapes yield fits that are statistically different by a factor of over 4

# Consistency check: fit all absorption features simultaneously




- To check the consistency of the fits to individual line shapes a composite fit is displayed for a single density from the data analysis; small discrepancies are within the uncertainty of Ne = $6.9\times10^{21}$ $cm^{-3}$ +/- 25%

# Conclusions

- A database of Stark-broadened absorption line shapes has been computed for He-like Mg transitions, taking into account perturbations due to plasma electrons and ions
- The density dependence of these line shapes has been employed to determine the electron density in an opacity experiment where Fe was the test element while Mg was the diagnostic element
- Data was systematically analyzed using the spectral analysis code ROBFIT
- The use of a set of customized/detailed line shapes in ROBFIT has permitted a reliable inference of the plasma density together with rigorous estimates of the uncertainties

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