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Revisiting iron opacity measurements at solar interior temperature

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U.S. DEPARTMENT OF ENERGY NNSA

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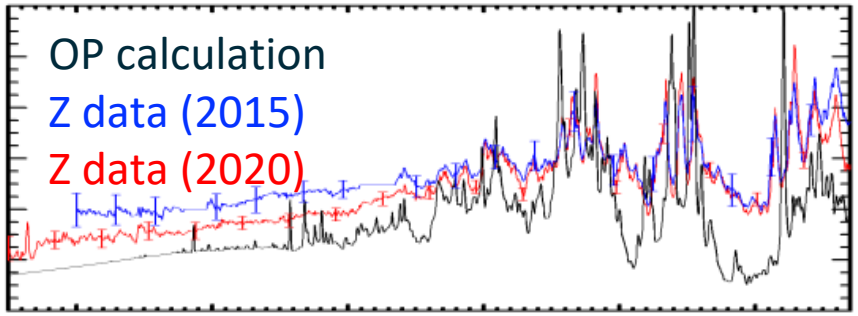
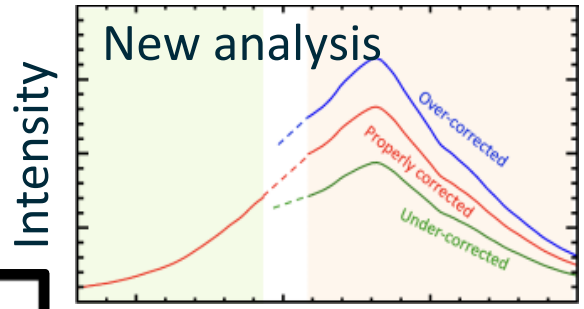
Novel opacity-analysis methods enhance accuracy for Z opacity data

- There is significant disagreement between measured and modeled iron opacity → Is opacity analysis accurate?
- Large volume of backlight-only data enable accurate analysis

  Concern: Backlight-only data were collected over a decade. → Does backlight change over the decade?
- We developed new methods that do not rely on backlight-only data
- 7% transmission accuracy was confirmed through many synthetic-data tests



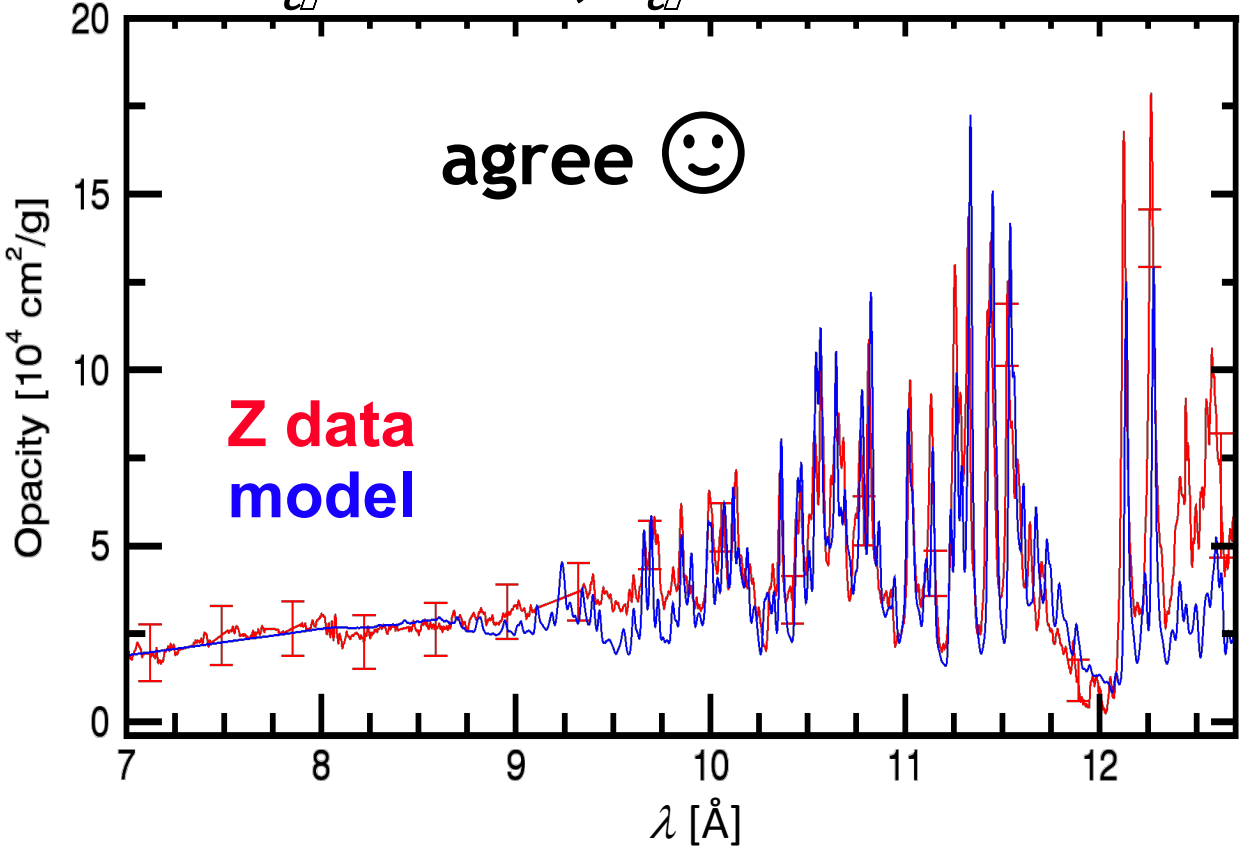


We are working on re-analysis of all iron data from ~40 experiments and quantifying its impact on the solar problem

We measured iron opacity at multiple conditions and found severe disagreement with models at solar temperatures

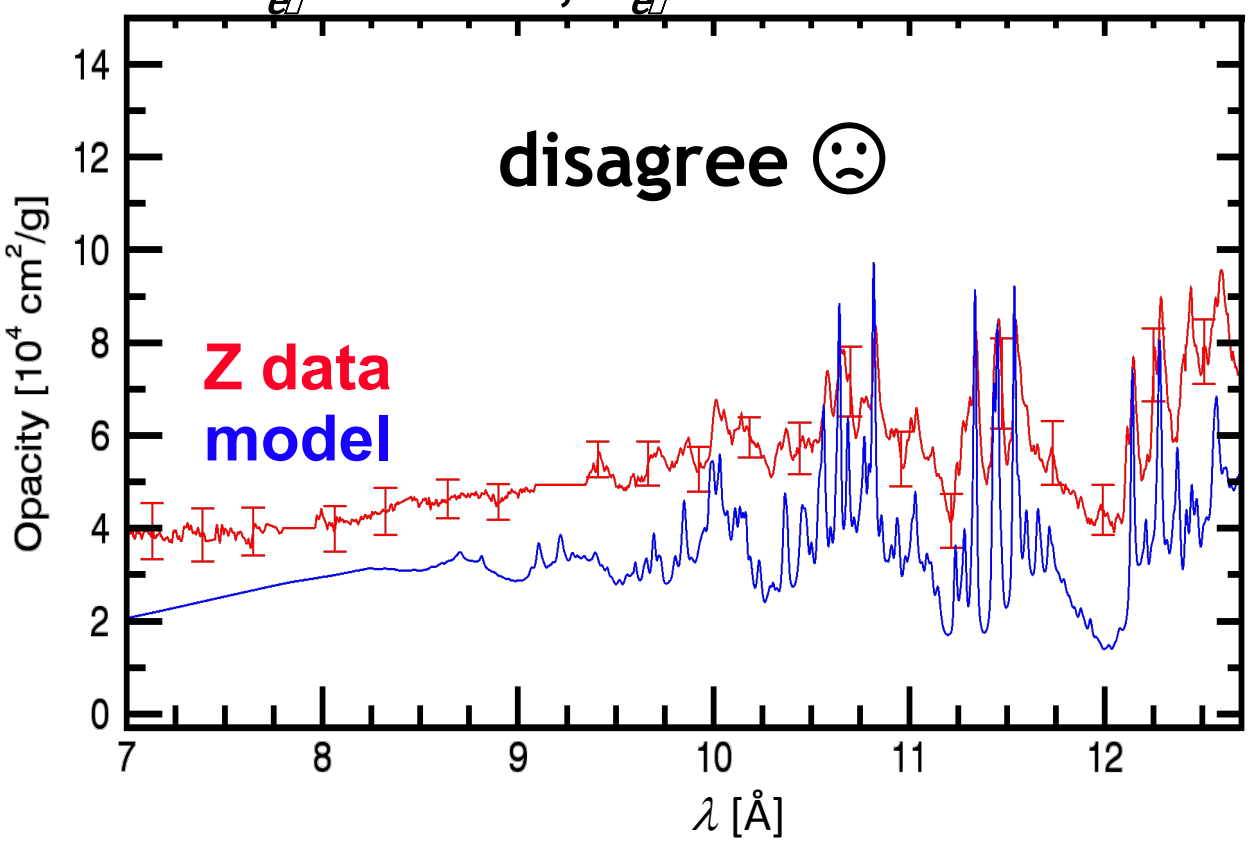
Anchor 1

T_e = 156 eV, n_e = 6.9×10^{21} cm^{-3}



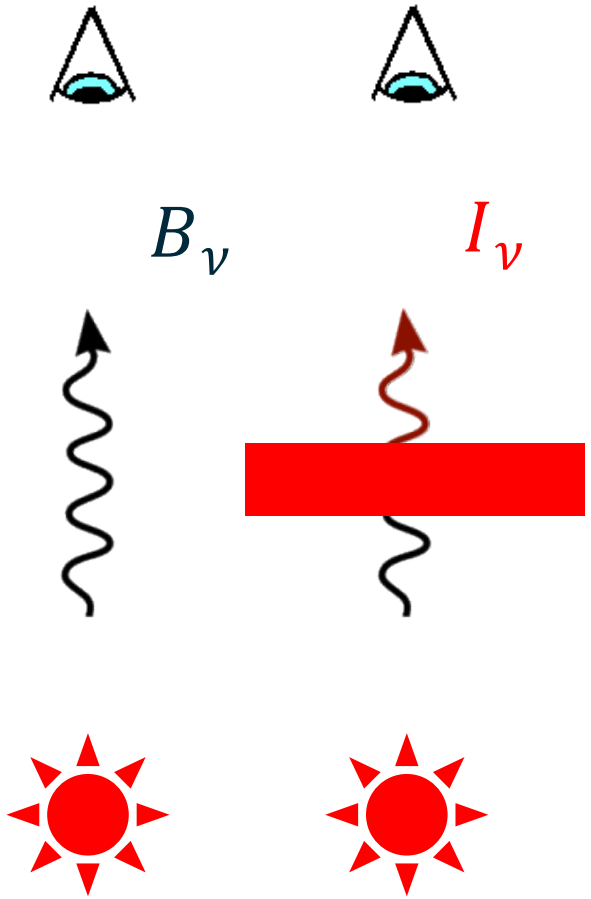
Anchor 2 ~ solar temperature

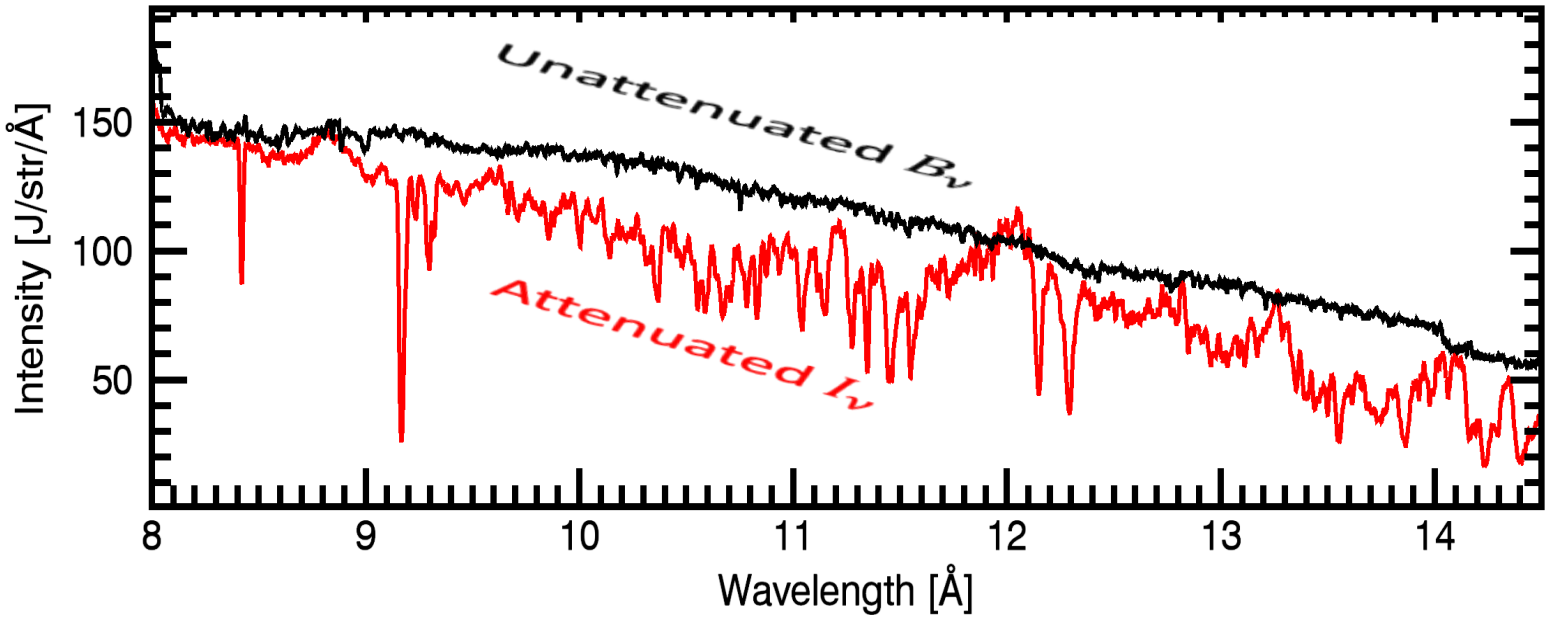
T_e = 182 eV, n_e = 3.1×10^{22} cm^{-3}



Key question: is the analysis accurate?

Sample opacity is inferred by measuring backlight with and without the sample





1. Determine transmission T_ν

$$T_\nu = \frac{I_\nu - \epsilon_\nu}{B_\nu - \epsilon_\nu}$$

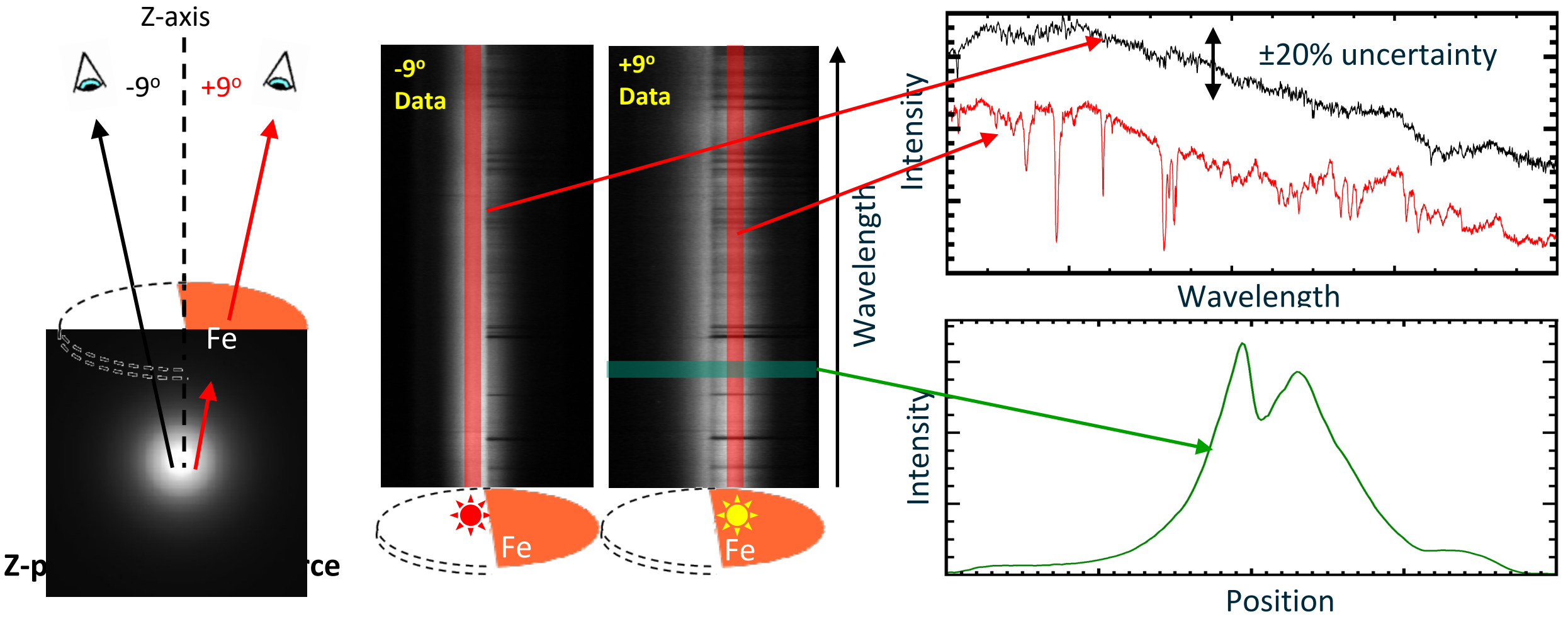
2. Convert T_ν to opacity κ_ν

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

Sources of uncertainty

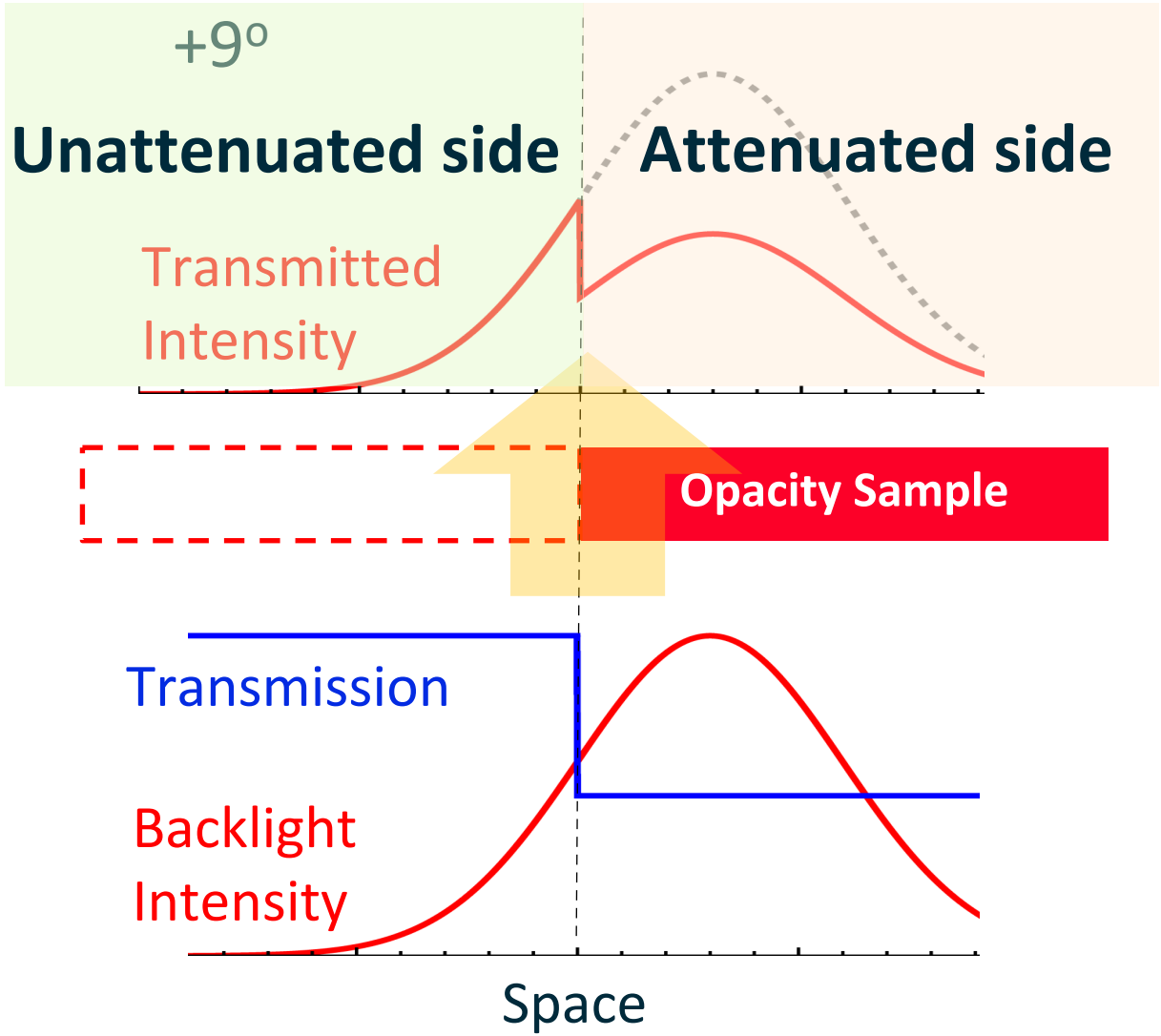
- **Unattenuated B_ν**
- **Background ϵ_ν**
- **Sample thickness ρL**

Transmission spectra is determined by dividing attenuated by unattenuated spectra → ±20% uncertain

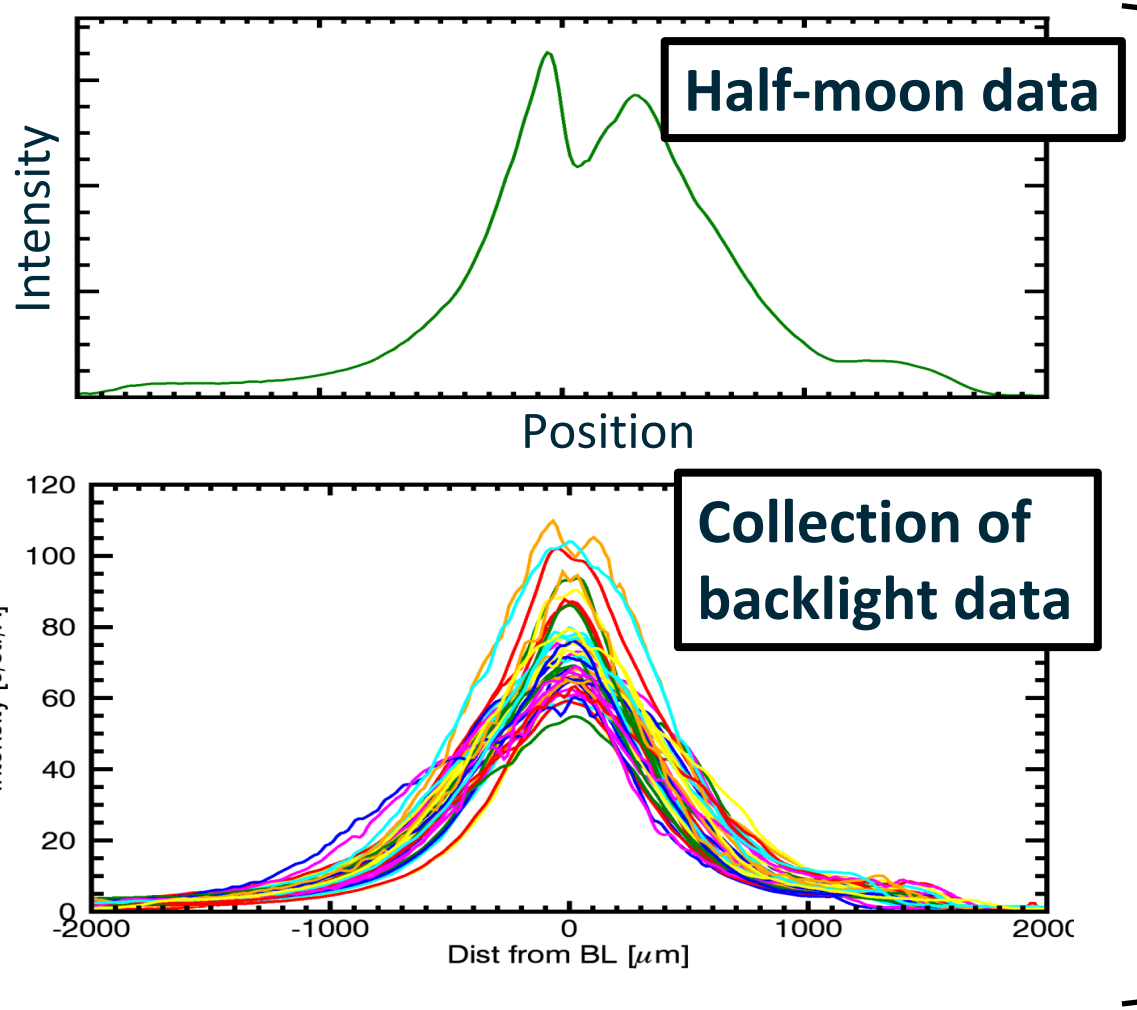


We use spatial shape to improve our accuracy of our transmission analysis

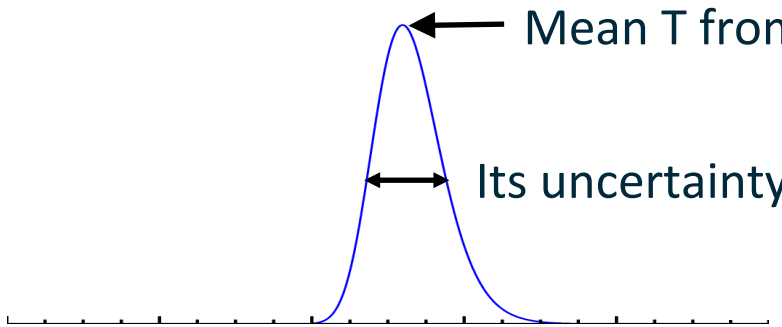
Spatial shape has unattenuated and attenuated side and provide essential clue on transmission



We analyze measured half-moon sample aided by backlight statistics to improve transmission accuracy



Transmission Probability Distribution (TPD)

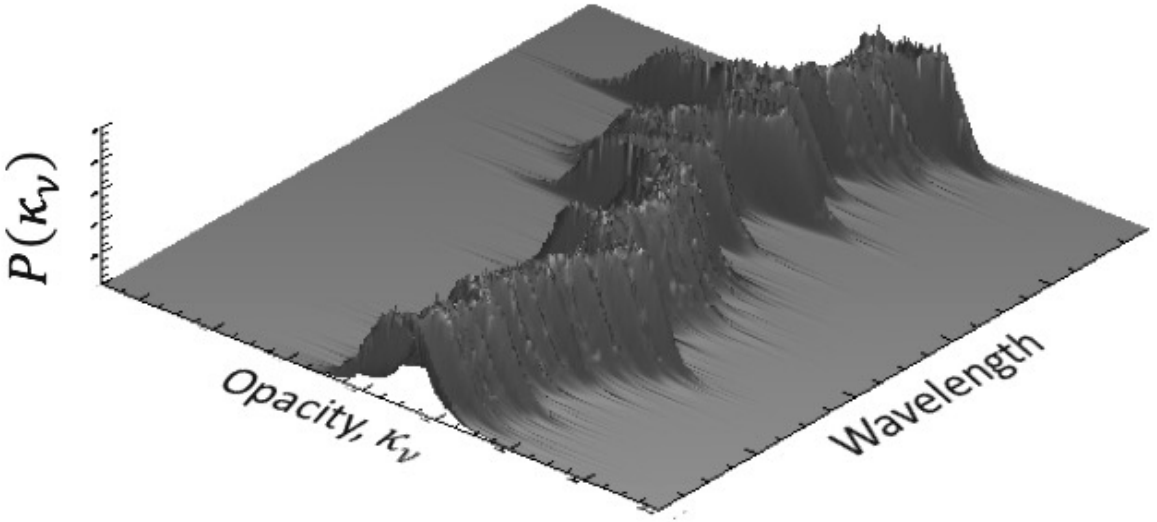


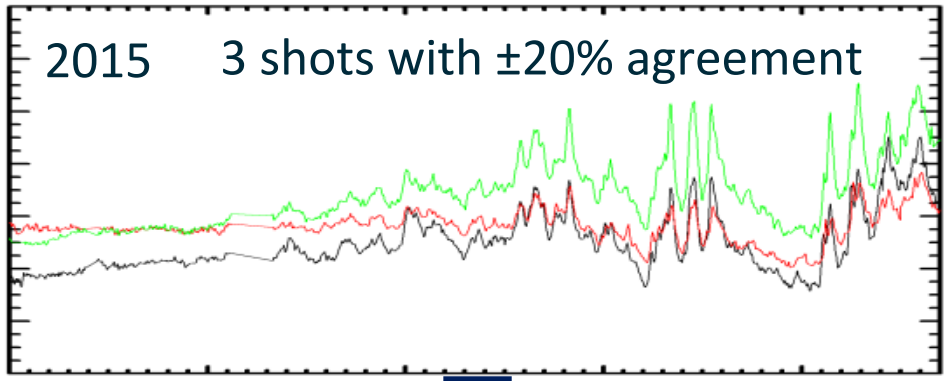
We developed multiple TPD methods that rely on different backlight statistics.

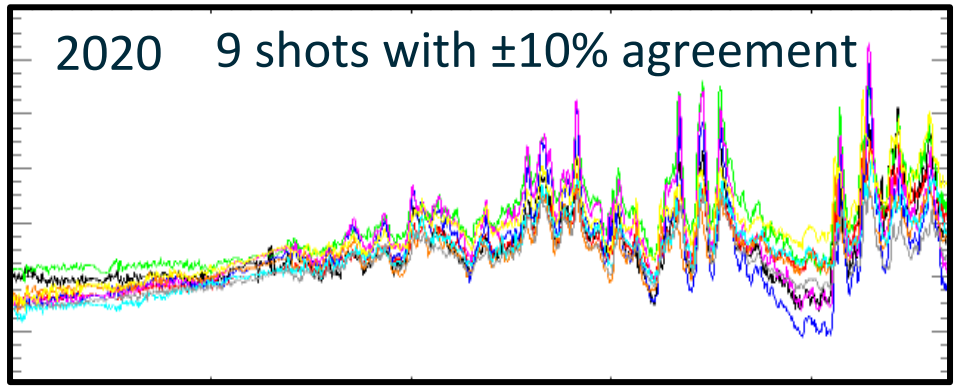
[1] Nagayama et al PRL (2019)

TPDs* are converted to opacity probability distribution; This method significantly improved analysis accuracy

Asymmetric non-Gaussian opacity PDF*





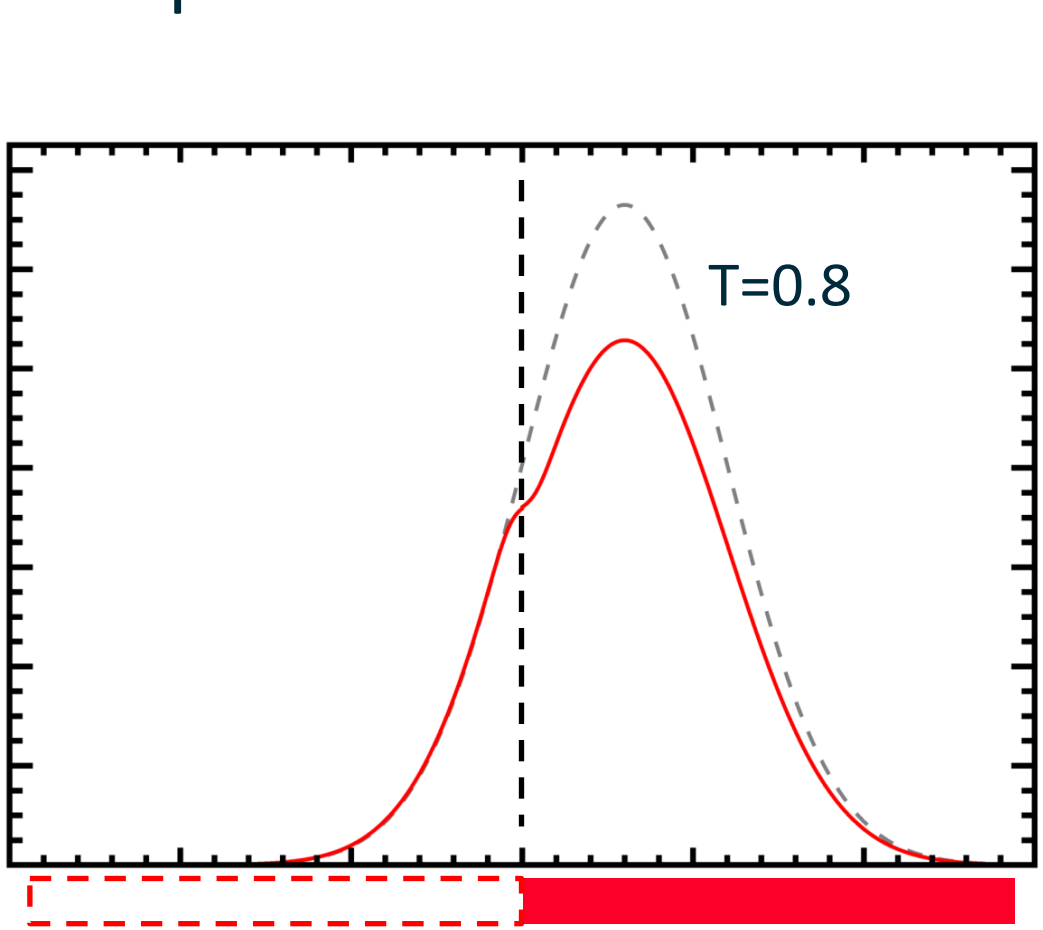


- Large volume of backlight-only data statistics
- Monte Carlo for robust errors propagations
  - Backlight intensity, B_ν
  - Background, ϵ_ν
  - Sample areal density, ρL

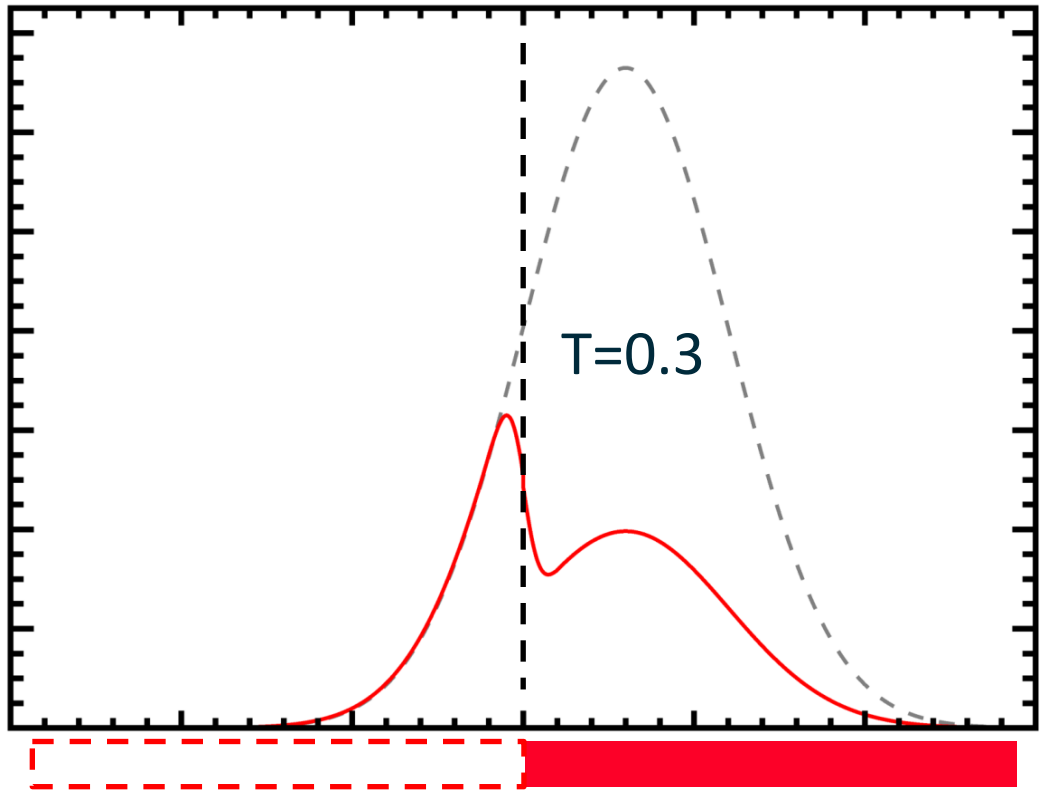
Concern: Backlight-only data were collected over more than a decade
➔ Can we assess opacity independently of the backlight data?

TPD = Transmission Probability Distributions

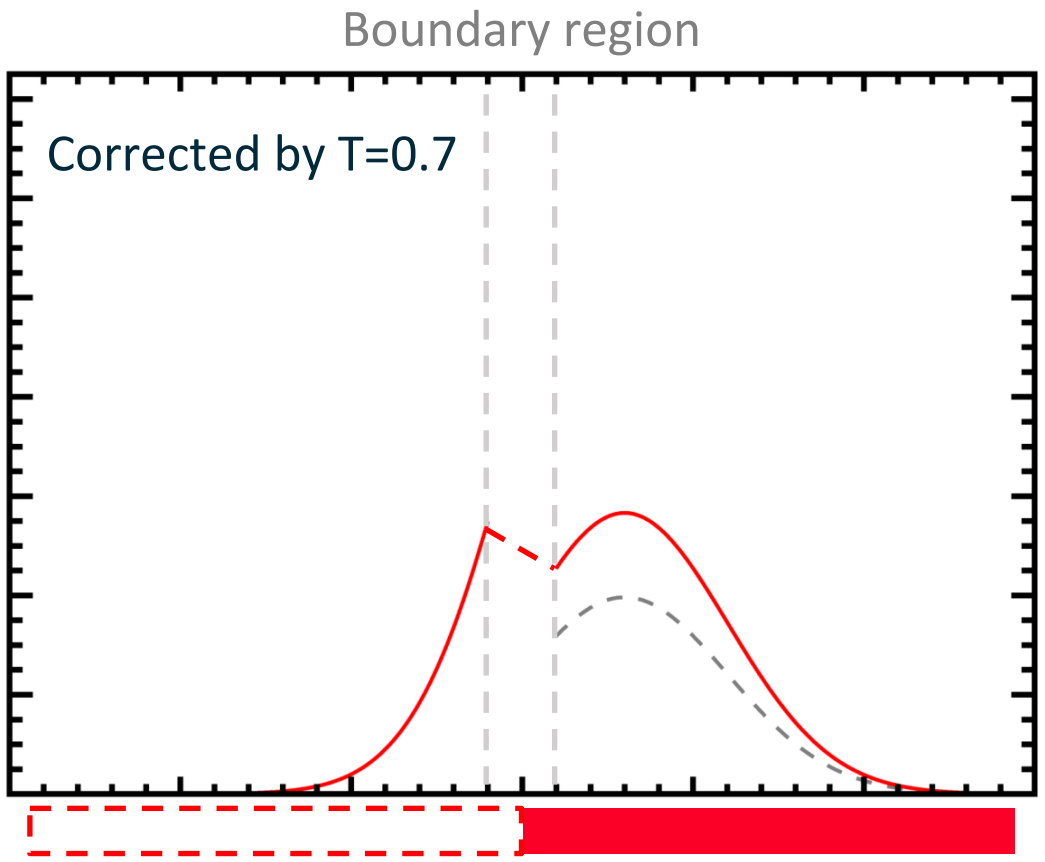
Which half-moon spatial profile corresponds to lower sample transmission?



More drastic drop over the boundary



We can search for the transmission that makes the T-corrected profile nice and smooth



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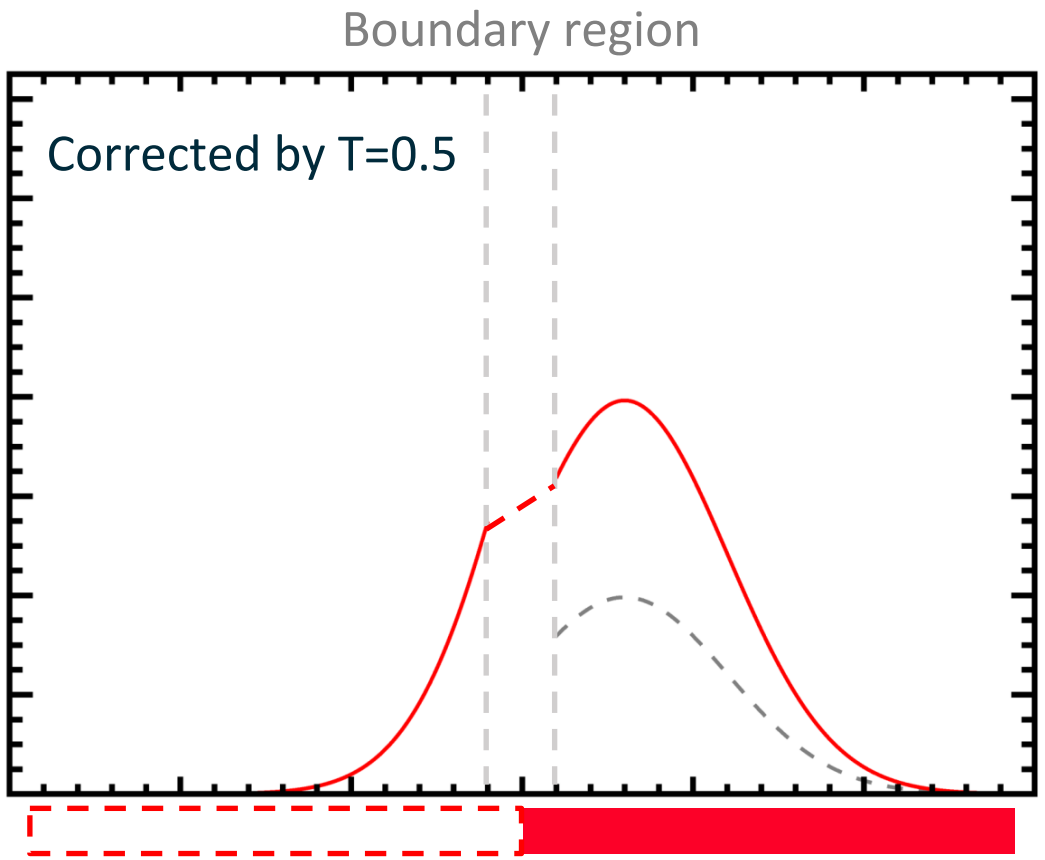

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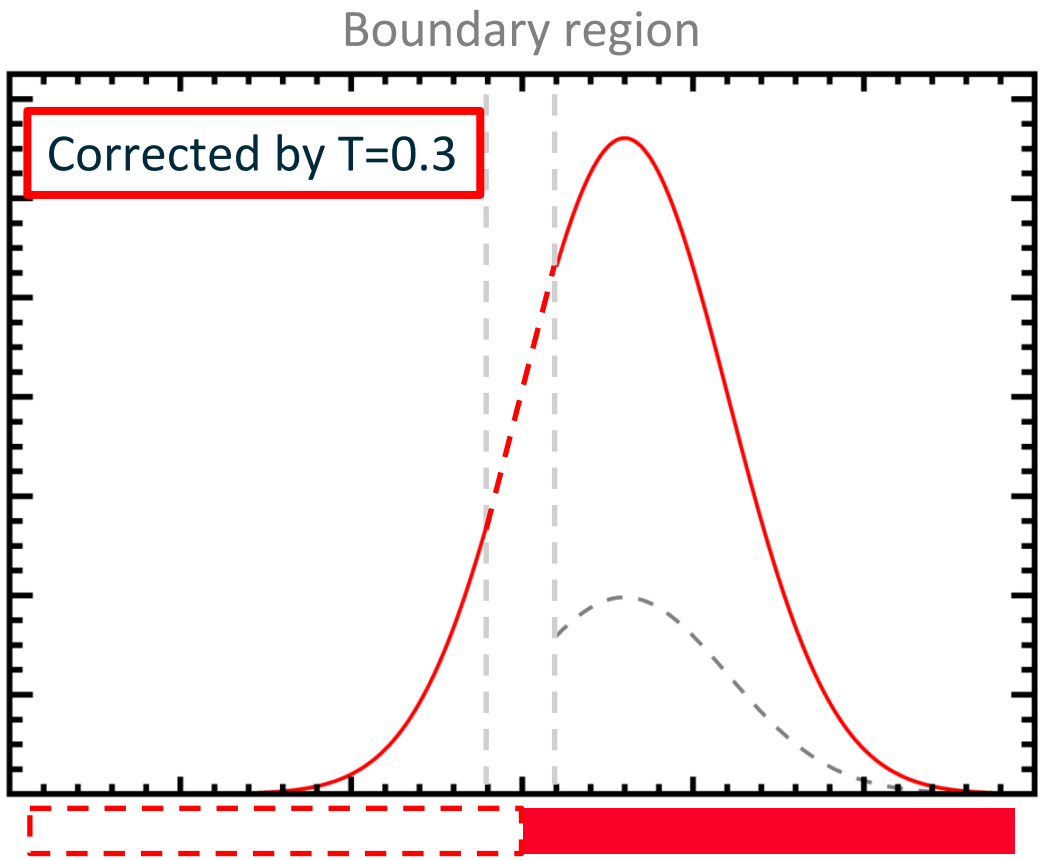

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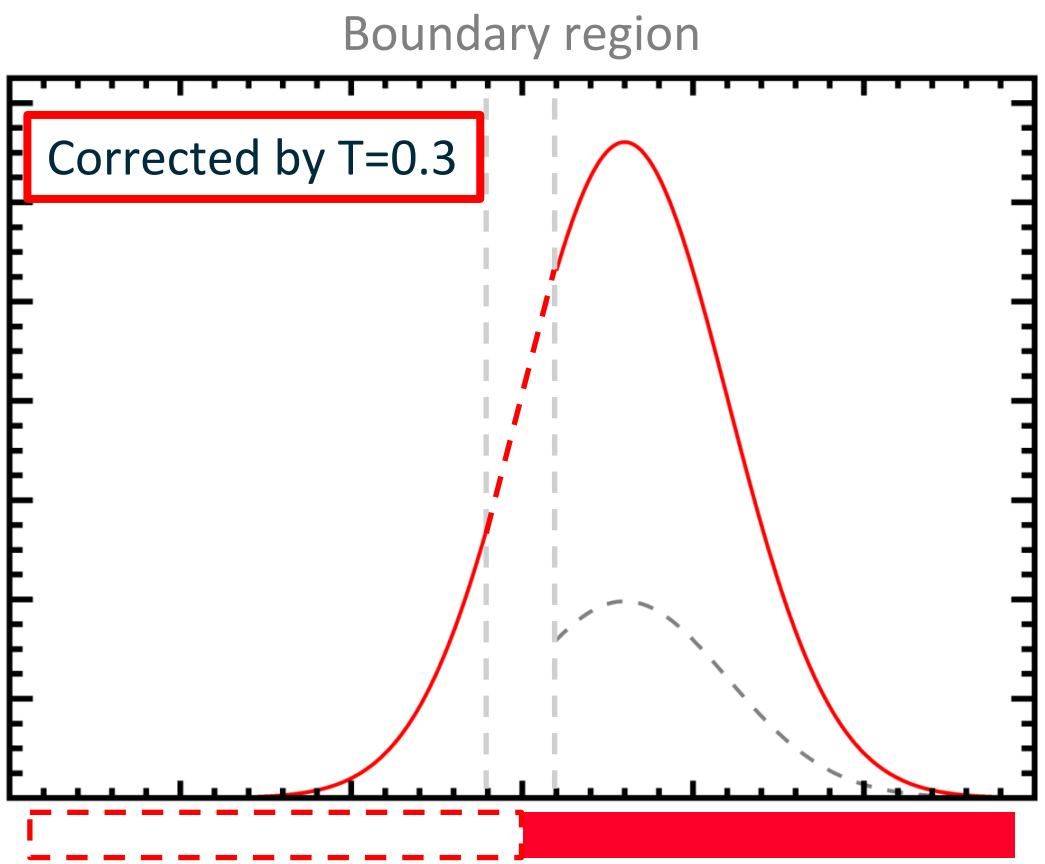
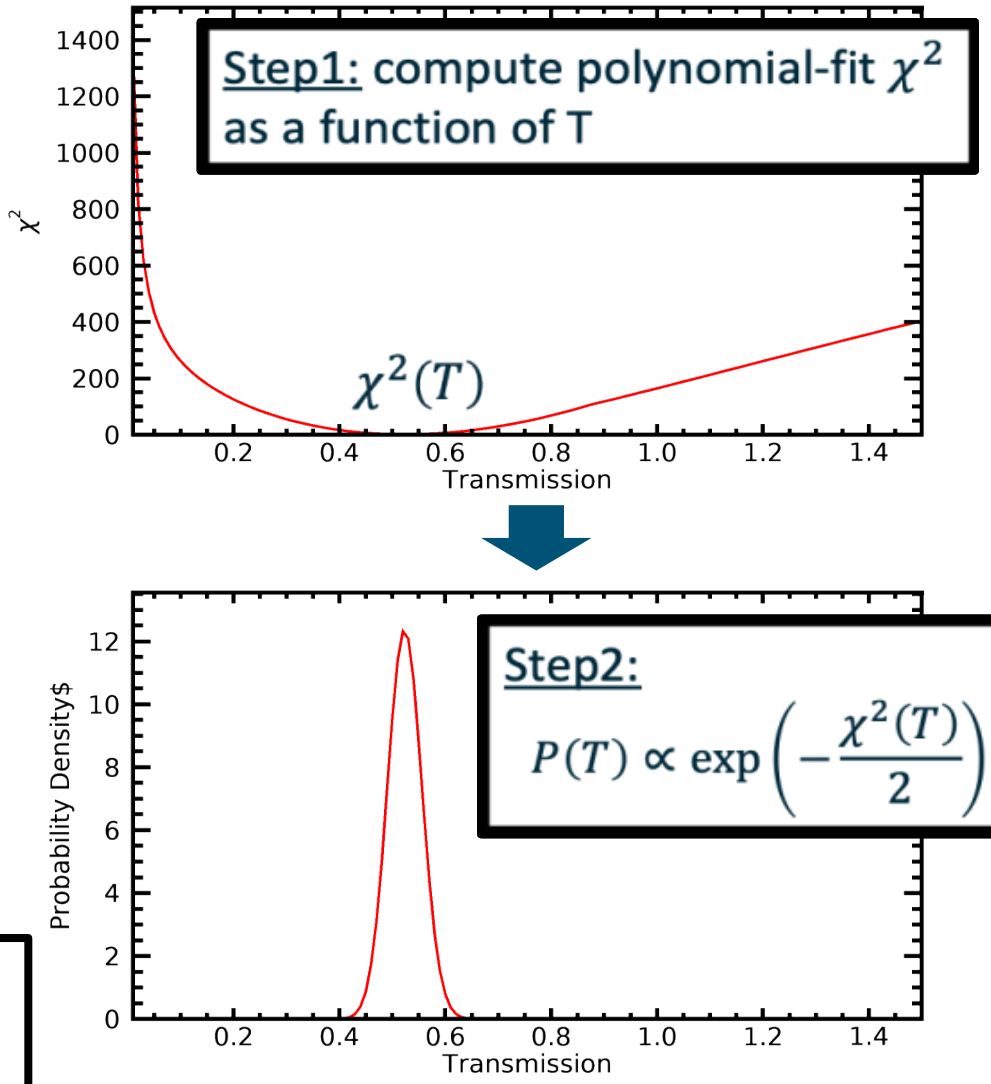
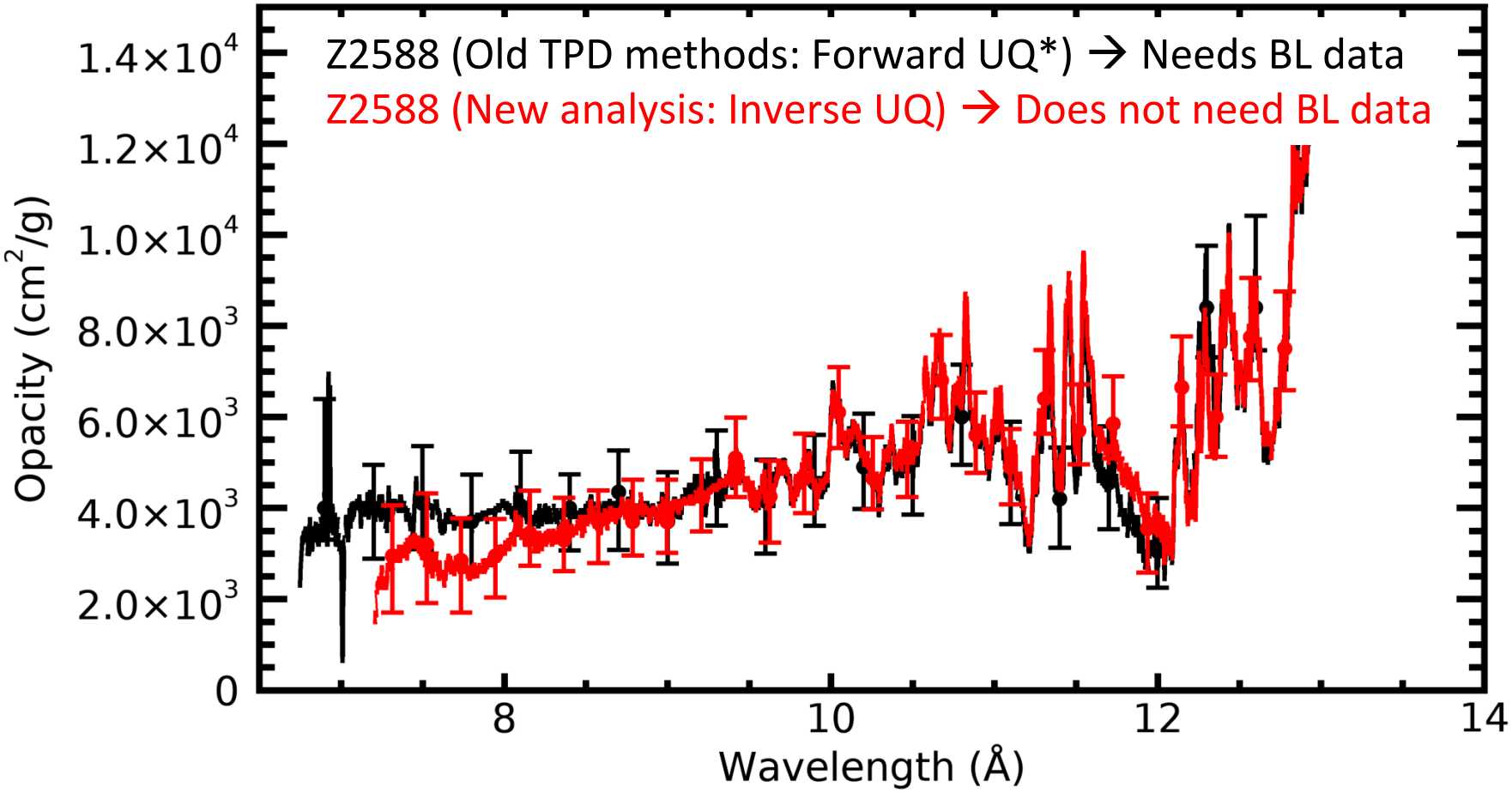




We have tested this method with many synthetic half-moon data created from backlight-only data

The new method is applied on a few experiments
The preliminary results are encouraging



We are working on applying both techniques to all iron data
Reanalysis involves ~40 iron experiments and >1,000 spectral images

*UQ = Uncertainty quantification

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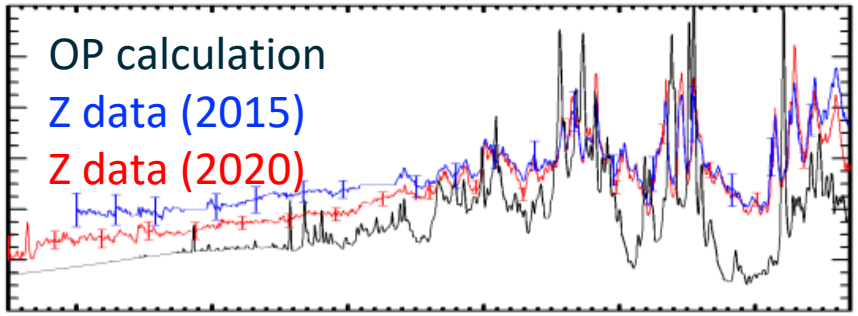

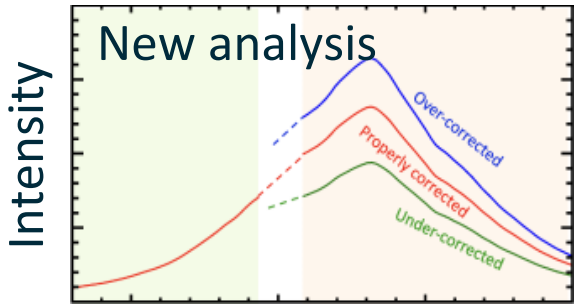

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