On the relevance of Compton scattering for the interpretation of spectra of the LETGS DA white dwarf standard candles HZ43 and Sirius B

Jeremy Drake

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Summary

An abstract submitted to the *6 Years of Science with Chandra* symposium by Kaastra, Lanz & Hubeny implies that pure hydrogen white dwarf model atmospheres for the standard candles HZ43 and Sirius B computed using Compton redistribution of scattered photon energies lead to significantly different spectra in the LETGS bandpass than models that employ the commonly adopted Thomson scattering approximation. Since the LETGS calibration employs non-LTE model atmospheres computed with classical Thomson scattering, the Kaastra et al. abstract implies that this simplifying assumption is inappropriate and might have lead to an erroneous calibration for $\lambda > 50$ Å where HZ43 and Sirius B are used. This *memo* reports two independent calculations employing rigorous treatments of Compton scattering that show differences between predicted spectra of DA white dwarfs using Compton and Thomson scattering are completely negligible for the interpretation of X-ray observations.

1 Background

The scattering of radiation by free electrons is one of the dominant sources of continuous opacity in the atmospheres of hot white dwarfs. Most model atmosphere calculations adopt the classical Thomson isotropic scattering approach, whereby only the direction of photon propagation changes as the result of a scattering event. More rigorously, finite electron mass instead implies that both momentum and energy exchange should actually occur.

The effects of Compton scattering on white dwarf model atmospheres was first investigated in detail by Madej (1994,A&A,286,515), who found that pure hydrogen models with temperatures of 10^5 K show a significant depression of the X-ray continuum for wavelengths < 50 Å. Effects for models containing significant amounts of helium, or helium and heavier elements, were found to be much smaller or negligible, in keeping with expectations based on the relative importance of electron scattering as an opacity source as opposed to photoelectric absorption.

In a later paper (1998,A&A,340,617), Madej computed the effects of Compton scattering for a model corresponding to the parameters of the DA white dwarf HZ43. Representative results are reproduced in Figure 1. Differences between Compton and Thomson scattering model spectra are apparent for $\lambda < 55$ Å, and grow to orders of magnitude by 40 Å.

The LETG+HRC-S effective area calibration is based on observed spectra of HZ43 and Sirius B (Pease et al., 2003, Proc. SPIE,4851,157). Of the components entering into the effective area, the HRC-S quantum efficiency is by far the least well understood. It is treated essentially as a free parameter in comparison of predicted and observed spectra and adjusted to achieve agreement. Being a nearby well-studies binary, the fundamental parameters of Sirius B are known with particularly accuracy and model spectra of this object are used to provide the effective area normalisation in the range within which significant flux is detected—approximately 80-170 Å. Models for the soft X-ray flux of HZ43 are then used to extend the HRC-S QE calibration down to ~ 60 Å. At shorter wavelengths neither HZ43 or Sirius B have detectable flux and blazar continua are used instead.

Since The LETGS calibration does not depend on the absolute flux of HZ43 for $\lambda < 60$ Å, and Compton scattering effects are expected to be smaller in Sirius B than in HZ43, the Madej (1998) calculations suggested that Compton scattering is not relevant to the use of DA white dwarfs as LETGS standard candles. This is the assumption that has underlain the LETG+HRC-S effective area calibration to date.

Recently, an abstract was submitted to the *6 Years of Science with Chandra* symposium by Kaastra, Lanz & Hubeny that challenges this conclusion. These authors state

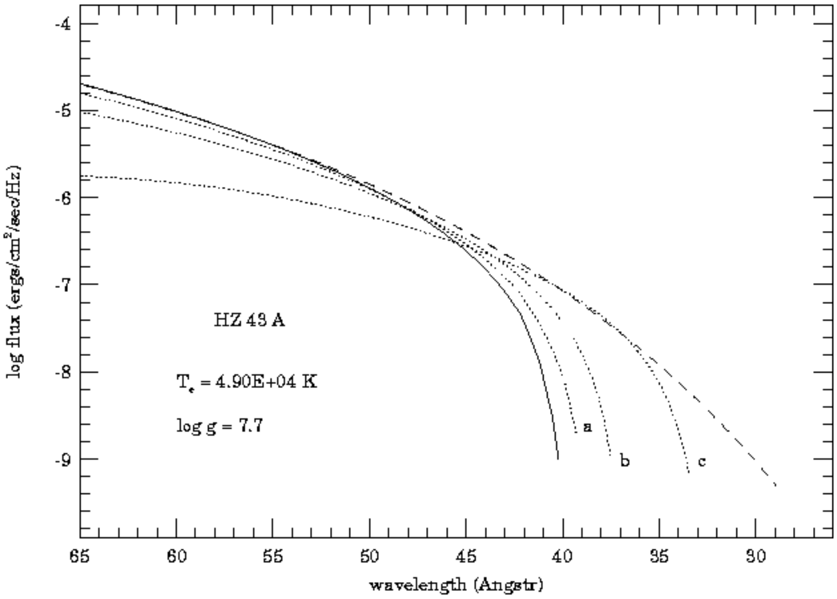

Figure 1: Reproduced from Madej (1998) Figure 3: "X-ray spectra of various model atmospheres of the DA white dwarf HZ 43 A. The solid line is the Comptonized spectrum of a pure H model, whereas the dashed line is the Thomson scattering spectrum. Note the X-ray flux deficiency of the spectrum computed with Compton scattering. Dotted lines present Comptonized spectra of H-dominated atmospheres with He number abundance (line a), (line b), and (line c), and with zero abundance of heavier elements."

> ...The new models take Compton scattering into account, a process that is unimportant for the global UV/optical spectrum but which diminishes the flux at the hardest X-rays significantly. Using these models together with the observed LETGS spectra of both stars allows us to refine the basic parameters of these stars as well as to re-calibrate the effective area of the LETGS. In particular at the longer wavelengths we find significant ($> 20\%$) differences with the previously used effective area. ...

At the time of writing, no quantitative information on the influence of Compton scattering on the analysis, as opposed to other possible factors such as information regarding fundamental parameters, has been provided by these authors.

2 Independent calculations of the effects of Compton scattering

In order to attempt to verify the 1998 Madej results, Valery Suleymanov (Tuebingen) has performed independent calculations of HZ43-like models with Compton and Thomson scattering. While his approach employs the local thermodynamic equilibrium (LTE) approximation, instead of the more general non-LTE approach known to be required for accurate modelling of hot DA white dwarf atmospheres, this does not affect in any significant fashion the predicted *differences* between Compton and Thomson scattering approaches. The results of these calculations are illustrated in Figure 2.

Examination of Figure 2 indicates that spectra computed with Compton and Thomson scattering only begin to diverge for wavelengths < 40 Å or so. Since no flux from HZ43 is detected in LETGS spectra at such wavelengths, the effects of Compton scattering can be considered completely negligible.

Comparison of Figures 1 and 2, however, reveal very large discrepancies for the predicted Compton scattering flux deficit toward shorter wavelengths. The former suggests a precipitous decline in emergent flux at ~ 40 Å, whereas the latter predicts effects orders of magnitude smaller, amounting to differences of less than a factor of 2 as short as 20 Å. While not so important for the LETGS, these differences could be relevant for observations with other instrumentation, such as *XMM-Newton* or future X-ray observatories with larger effective area in the $\sim$ 40-30 Å range.

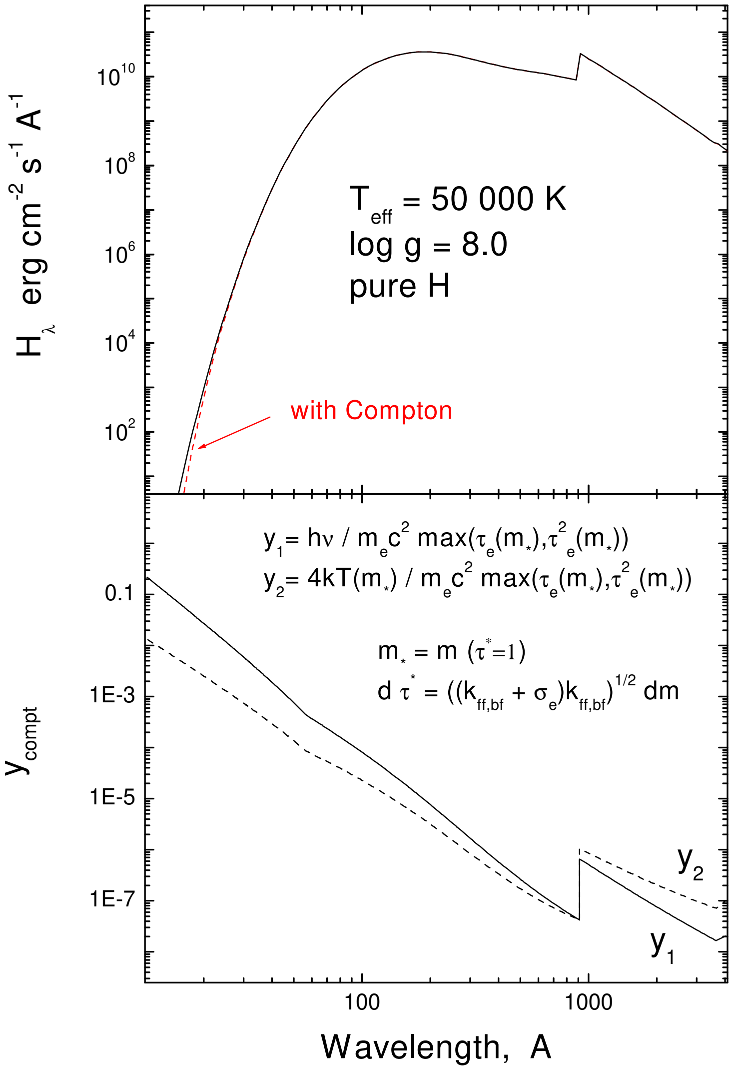

Figure 2: Upper panel: spectra in the LETGS range computed by Suleymanov (private communication) for Compton and Thomson scattering using a model atmosphere with parameters appropriate for HZ43 ($T_eff = 50000$ K and $\log g = 8.0$). Lower panel: the two Comptonisation parameters from the same calculations. These parameters are significantly less than 1 throughout the relevant LETGS range and demonstrate that Compton scattering cannot change the spectrum to any large extent.

Further insights into this problem have recently been obtained by private communication from J. Madej, who has also repeated Compton and Thomson scattering calculations for a model with HZ43 parameters using computational methods outlined by Madej et al. (2004,ApJ,602,904). Emergent spectra in the 20-60 Å range from these new calculations are illustrated in Figure 3. These calculations are in good agreement with those of Suleymanov (Figure 2), indicating that Compton flux suppression amounts to a factor of 2 or less at 20 Å. Such differences are in fact much smaller than the predicted uncertainties resulting from uncertainties in the current knowledge of the fundamental parameters of HZ43. The spectrum in this Wien tail region is especially sensitive to uncertainties in the effective temperature.

Madej attributes the large differences between his earlier and present calculations to the different numerical approaches adopted, and to inadequacies in the approach used in the earlier work. He was able to confirm that the method adopted for the 1998 paper did indeed lead to overestimation of the flux suppression at shorter wavelengths.

3 Conclusions

New calculations by two independent workers using rigorous numerical methods confirm the effects of Compton energy redistribution in photon-electron scattering events are completely negligible for the interpretation of X-ray spectra of DA white dwarfs such as Sirius B and HZ43. The large flux suppression at $\lambda < 40$ Å predicted for HZ43-like models by Madej (1998) appear to be spurious and are convincingly explained by impropriety of computational expedients employed in those calculations.

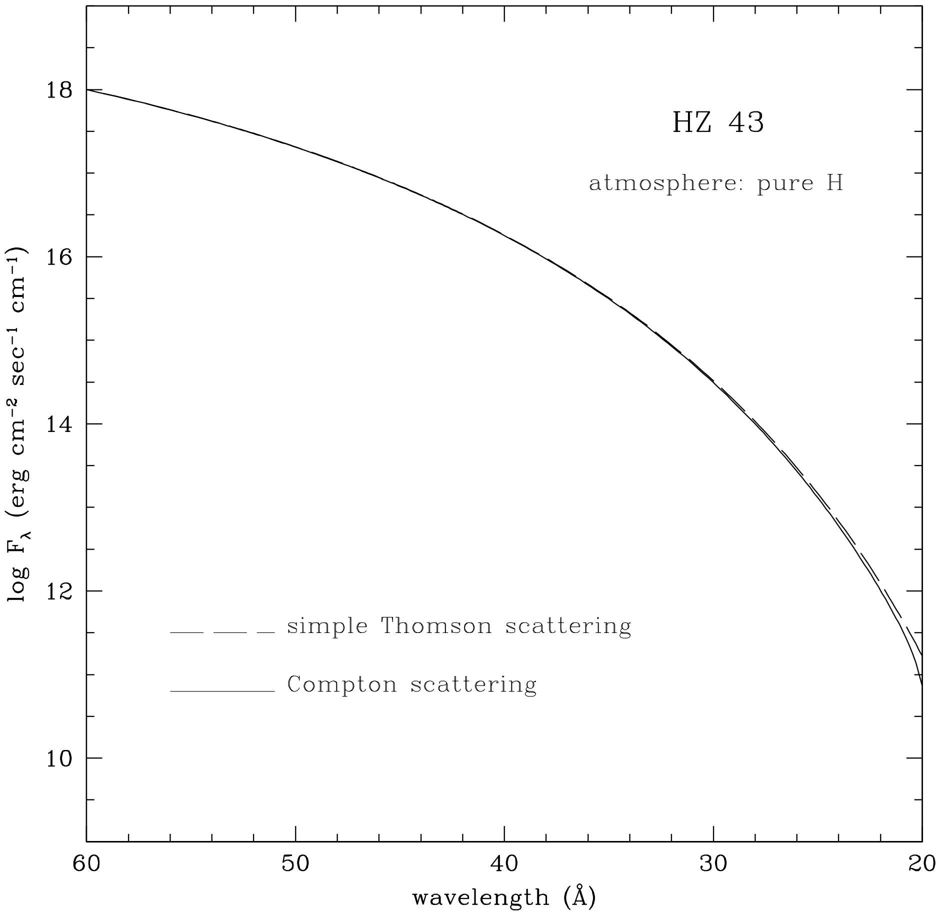

Figure 3: Emergent spectra for a pure hydrogen model atmosphere appropriate for the parameters of HZ43 computed for classical Thomson scattering (dashed) and Compton scattering (solid) by Jerzy Madej (private communication) using the method of Madej et al. (2004,ApJ,602,904).