

Uncertainties in (E)UV model atmosphere fluxes (Research Note)

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ABSTRACT

Context. During the comparison of synthetic spectra calculated with two NLTE model atmosphere codes, namely *TMAP* and *TLUSTY*, we encounter systematic differences in the EUV fluxes due to the treatment of level dissolution by pressure ionization.

Aims. In the case of Sirius B, we demonstrate an uncertainty in modeling the EUV flux reliably in order to challenge theoreticians to improve the theory of level dissolution.

Methods. We calculated synthetic spectra for hot, compact stars using state-of-the-art NLTE model-atmosphere techniques.

Results. Systematic differences may occur due to a code-specific cutoff frequency of the H I Lyman bound-free opacity. This is the case for *TMAP* and *TLUSTY*. Both codes predict the same flux level at wavelengths lower than about 1500 Å for stars with effective temperatures (T_{eff}) below about 30 000 K only, if the same cutoff frequency is chosen.

Conclusions. The theory of level dissolution in high-density plasmas, which is available for hydrogen only should be generalized to all species. Especially, the cutoff frequencies for the bound-free opacities should be defined in order to make predictions of UV fluxes more reliable.

Key words. atomic data – stars: atmospheres – stars: individual: HZ 43 – stars: individual: Sirius B – stars: white dwarfs – ultraviolet: stars – X-rays: stars

1. Introduction

NLTE model atmosphere codes for hot, compact stars have arrived at a high level of sophistication and are successfully employed for spectral analyses, e.g. the Tübingen NLTE Model-Atmosphere Package *TMAP*¹ (Werner et al. 2003; Rauch & Deetjen 2003) in the case of LS V +46°21, the central star of Sh 2–216 (Rauch et al. 2007).

In the case of high-gravity stars like LS V +46°21 ($\log g = 6.9$ [cm/s²], $T_{\text{eff}} = 95\,000$ K) or neutron stars (e.g. Suleimanov & Werner 2007), the consideration of the dissolution of atomic levels by plasma perturbation (for details see, e.g., Hummer & Mihalas 1988) is crucial for a reliable model atmosphere calculation (Hubeny et al. 1994).

Beuermann et al. (2006, 2008) established the DA-type white dwarfs HZ 43 ($\log g = 7.9$, $T_{\text{eff}} = 51\,111$ K) and Sirius B ($\log g = 8.6$, $T_{\text{eff}} = 24\,897$ K) as soft X-ray standards. For a cross-calibration between the Chandra LETG+HRC-S, the EUVE spectrometer and the ROSAT PSPC, pure hydrogen *TMAP* model atmospheres and synthetic spectra were used. In the case of Sirius B with a higher surface gravity g ($\log g = 8.6$), the level dissolution due to pressure ionization is even more efficient (Fig. 1) and thus, it is more important to consider it properly.

2. Level dissolution

Recently, Jelle Kaastra (priv. comm.) has drawn our attention to a deviation between *TMAP* and *TLUSTY*² fluxes for Sirius B

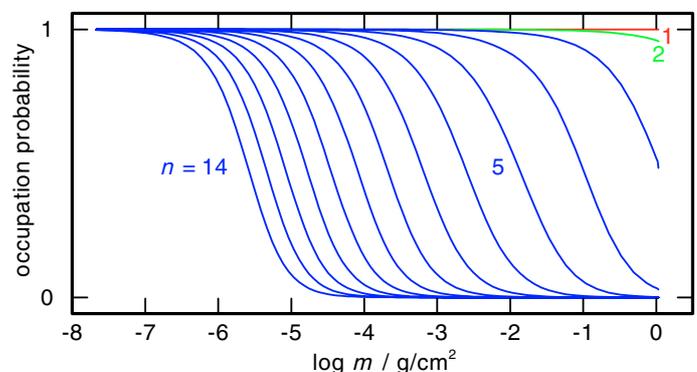


Fig. 1. Occupation probabilities of the lowest 14 H I levels considered in our *TMAP* model atmosphere calculation for Sirius B. Note that the line formation takes place at $\log m \approx -5.5$ – -3.0 .

(Fig. 2) at wavelengths lower than about 1500 Å, while in the case of HZ 43, the model fluxes are in agreement.

In the last two decades, we have thoroughly compared *TMAP* and *TLUSTY* from time to time and found only negligible differences due to different numerical approaches and slightly different constants. In an investigation of the flux discrepancy, we are now able to identify its reason. Both codes, *TMAP* as well as *TLUSTY*, follow a generalized form to consider the level dissolution by Hubeny et al. (1994). A hitherto unsolved problem, however, is a precise, generalized formulation of the extrapolation of the hydrogen Lyman bound-free opacity into a pseudo-continuum below the unperturbed position of the

¹ <http://astro.uni-tuebingen.de/~rauch/TMAP/TMAP.html>

² <http://nova.astro.umd.edu>

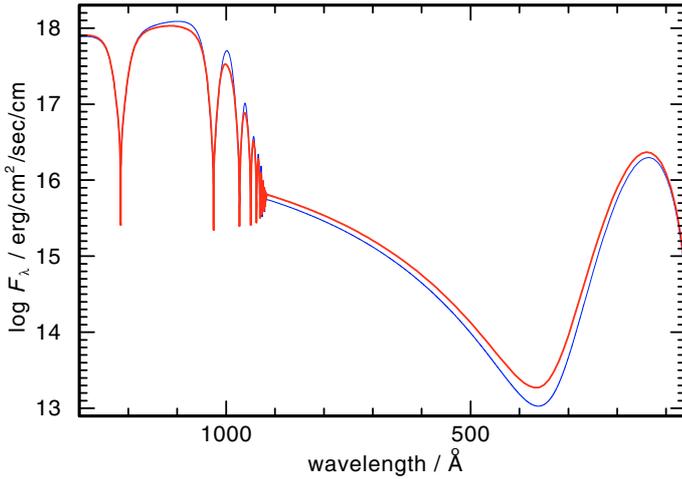


Fig. 2. Discrepancy between synthetic spectra for Sirius B calculated by *TMAP* (thick, long cutoff, see text) and *TLUSTY* (thin, short cutoff, Lanz priv. comm.) with the same parameters.

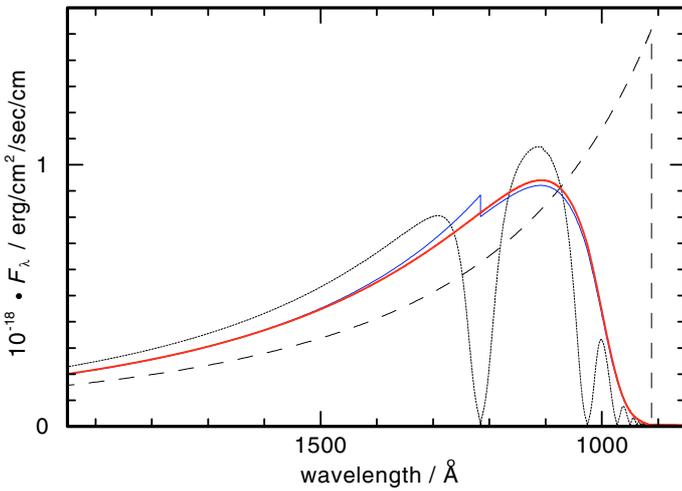


Fig. 3. Synthetic fluxes for Sirius B calculated from continuum models (no line transitions considered for test reasons) with a short (thin line) and a long cutoff (thick). The dashed line shows a synthetic spectrum with neglect of the level dissolution. Note that the artificial absorption edge at the short cutoff is hidden in the strong $L\alpha$ absorption when those lines are considered (dotted).

absorption threshold (cf. Däppen et al. 1987). *TMAP* uses a heuristic approach with

$$\nu_i^{\text{th}} = f \cdot \left[\frac{1}{n_i^2} - \frac{1}{(n_i + 1)^2} \right] \cdot \nu_i^{\text{th},0} \quad (1)$$

where ν_i^{th} and $\nu_i^{\text{th},0}$ are the extrapolated and unperturbed threshold frequencies, respectively, of level i and n_i is its principal quantum number, i.e., $n_i^2 = 1$ for the Lyman continuum. Since this approach results in artificial absorption edges at $f = 1$ (corresponding to $\lambda_1^{\text{th}} = 1215.67 \text{ \AA}$, “short” cutoff), *TMAP* introduced $f = 0.5$ (corresponding to $\lambda_1^{\text{th}} = 2431.34 \text{ \AA}$, “long” cutoff) in order to achieve a smooth transition into the continuum (Fig. 3).

TLUSTY uses a different treatment of the continuum. Based on the physical picture used to derive the pseudo-continuum formulation (cf. Däppen et al. 1987), which is valid only near the ionization limit, an artificial “short” cutoff of the bound-free opacity of the hydrogen Lyman-continuum at $\lambda_1^{\text{th}} = 925 \text{ \AA}$

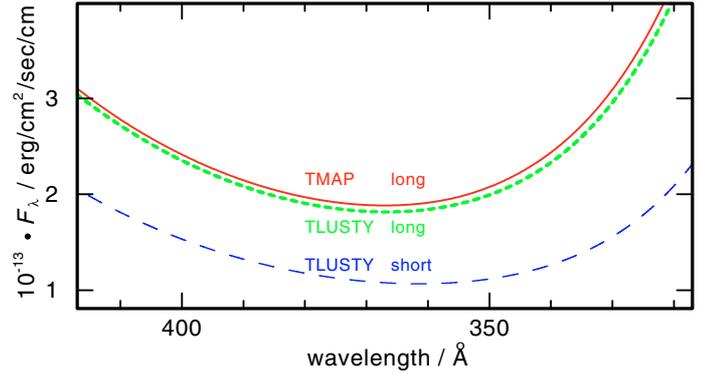


Fig. 4. Comparison of *TMAP* and *TLUSTY* (dotted: long cutoff, dashed: short cutoff) fluxes in the vicinity of the largest deviation (Fig. 2).

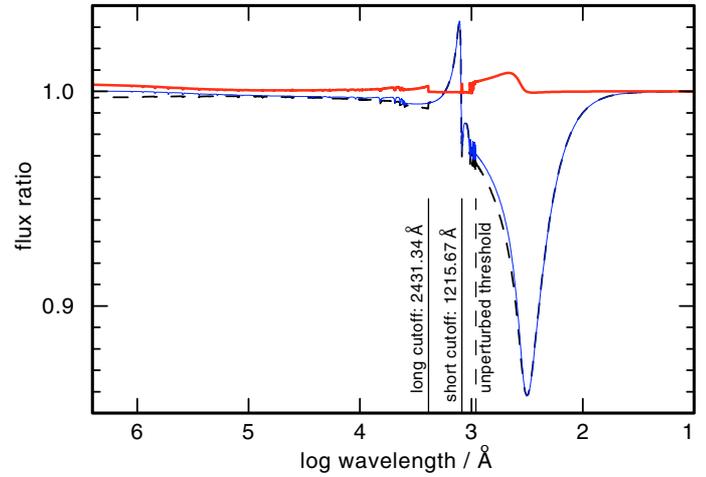


Fig. 5. Ratios of synthetic fluxes calculated by *TMAP*. Shown are short/long cutoff (dashed), short/extralong cutoff (thin, the extralong cutoff frequency is 10^{12} Hz), and long/extralong cutoff (thick). Note that in the case of the extralong cutoff, the flux ratio slightly increases above $100\,000 \text{ \AA}$ due to an artificial bound-free opacity in the infrared.

(Lanz priv. comm.) may be chosen (*TMAP*: $\lambda_1^{\text{th}} = 2431.34 \text{ \AA}$). A test calculation has shown that the model atmosphere fluxes of *TMAP* and *TLUSTY* agree within 5% if a long cutoff is used by *TLUSTY*, too (Lanz priv. comm., Fig. 4).

Test calculations of pure hydrogen models with *TMAP* via the WWW interface *TMAW*³ at $\log g = 8.6$ and T_{eff} between 10 000 and 50 000 K have shown that deviations between short-cutoff and long-cutoff model fluxes are negligible at $T_{\text{eff}} \gtrsim 30\,000 \text{ K}$ due to the increasing degree of ionization. This explains the good agreement of *TMAP* and *TLUSTY* fluxes in case of HZ 43.

3. Conclusions

Since no reliable theory is available, the choice of different cutoff frequencies of the H I Lyman bound-free opacity in the NLTE model-atmosphere codes *TMAP* and *TLUSTY* demonstrates that the estimate of the pseudo-continuum at longer wavelengths is presently an uncertainty and definitely deserves further investigation. However, the necessity of a cutoff in order to avoid an unrealistic opacity in the infrared is shown in Fig. 5.

Moreover, a reliable theory for level dissolution by pressure ionization is presently available only for H I. Since this is

³ <http://astro.uni-tuebingen.de/~rauch/TMAW/TMAW.html>

important for all other species as well, a generalized theory is highly desirable. However, this is out of the scope of this work.

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