The Ionizing Fluxes of Early-Type Stars and Their Impact on H II Regions and the 'Diffuse Ionized Gas'

Daniel Schaerer

Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

Abstract. We discuss recent results on the ionizing fluxes of O stars obtained from our 'combined stellar-structure and atmosphere' (CoStar) models, accounting for stellar winds, non-LTE effects, and line blanketing. The implications on the ionization structure of H II regions are summarized, and observational constraints on the ionizing spectra and the total ionizing photon fluxes are presented. Using our CoStar models we derive new, consistent predictions for the H and He I ionizing fluxes of steady-state massive-star populations. Implications for the interpretation of observations of 'Diffuse Ionized Gas' in galaxies are discussed. Finally, we present preliminary model calculations aimed at improving our current predictions further, and compare our results to recent results from the Munich group.

1. Introduction

The 'combined stellar-structure and atmosphere' (CoStar) models have been applied in detail to the main-sequence phase (Schaerer et al. 1996ab, hereinafter Papers I & II). Here we concentrate on some important predictions regarding the spectral evolution on the main sequence, namely, recent results on the ionizing fluxes of OB stars for which considerable progress has been achieved in the recent years. Predictions of ionizing fluxes are of special interest for analysis of massive stars, H II regions, young starburst galaxies, and related objects.

We first present current models for O stars (Section 2). In Section 3 we summarize some of the implications of recent calculations of ionizing fluxes on H II regions, and how observations of H II regions might be used to constrain model atmospheres. New predictions of ionizing fluxes of steady-state massive-star populations, and some of their implications on the diffuse ionized gas in galaxies, are given in Section 4. In Section 5, we finally present preliminary results from new calculations aiming to improve our current predictions further.

2. Ionizing Fluxes of O Stars

The input physics of the CoStar models is described in detail in Paper I. The most important ingredients regarding the prediction of ionizing fluxes are the treatment of non-LTE, the stellar wind, and line blanketing (see Schaerer & de Koter 1997, hereinafter Paper III). The current sets of models (Paper III) covers the entire main-sequence evolution for stars with initial masses between 20 and $120 M_{\odot}$, and includes sets for solar metallicity ($Z = 0.02$) and low metallicity ($Z = 0.004$ and appropriately scaled wind parameters). The coverage approximately corresponds to spectral types from O3 to B0 and all luminosity classes. As discussed in Paper III, reliable predictions for later types are currently not available for physical and technical reasons. Spectral-energy distributions, H II-region models (see below), and additional information are available on the Web[1] and on CD-ROM (see Leitherer et al. 1996).

Extensive comparisons of our predictions with previous calculations (Kurucz models, plane-parallel line-blanketed models) are given in Paper III. A detailed discussion of the physical processes affecting the ionizing spectrum is also given there. The main results can be summarized as follows: (*i*) The flux in the He II continuum is increased by 2 to 3 (3 to 6) orders of magnitudes compared to predictions from plane-parallel non-LTE (LTE) model atmospheres (cf. Gabler et al. 1989). (*ii*) The flux in the He I continuum is known to be increased due to non-LTE effects. In addition, the combined effect of a mass outflow and line blanketing leads to a flatter energy distribution in the He I continuum. This has profound implications on the structure of H II regions (Section 3). (*iii*) To a lesser extent than at high energies, the flux in the Lyman continuum is also modified due to line blanketing and the presence of stellar winds. Generally one obtains a reduction of the Lyman continuum flux compared to plane-parallel model atmospheres.

Based on our CoStar models we have also derived integrated photon fluxes for stellar parameters corresponding to the new spectral-type and luminosity-class calibrations of Vacca et al. (1996). Our results are compared with former calibrations of Panagia (1973) and Vacca et al. (1996), both based on plane-parallel model atmospheres. It must, however, be remembered that such a calibration is quite strongly dependent on the assignment between spectral types and stellar parameters, for which considerable uncertainties remain for O stars (cf. Vacca et al. 1996; Crowther 1997; Lamers et al. 1997; Schmutz 1998).

3. The Impact of CoStar Ionizing Fluxes on H II Regions, and Possible Tests of Atmosphere Models

Using the photoionization code PHOTO we have computed a large grid of single-star H II-region models based on the new CoStar ionizing fluxes (Stasińska & Schaerer 1997, hereinafter Paper IV). For comparison, a similar grid has been calculated using fluxes from plane-parallel LTE model atmospheres by Kurucz (1991). The main additional parameter determining the structure of the H II region, the ionization parameter U, is varied over a wide range, corresponding to conditions expected between the most compact H II regions and the most diluted interstellar medium. Detailed results are available on our Web page and on CD-ROM (see above).

The flatter spectral-energy distribution in the He I continuum (cf. Fig. 1, left panel) generally leads to higher ionic ratios in the nebula if CoStar models

[1] `http://www.stsci.edu/ftp/science/starburst`

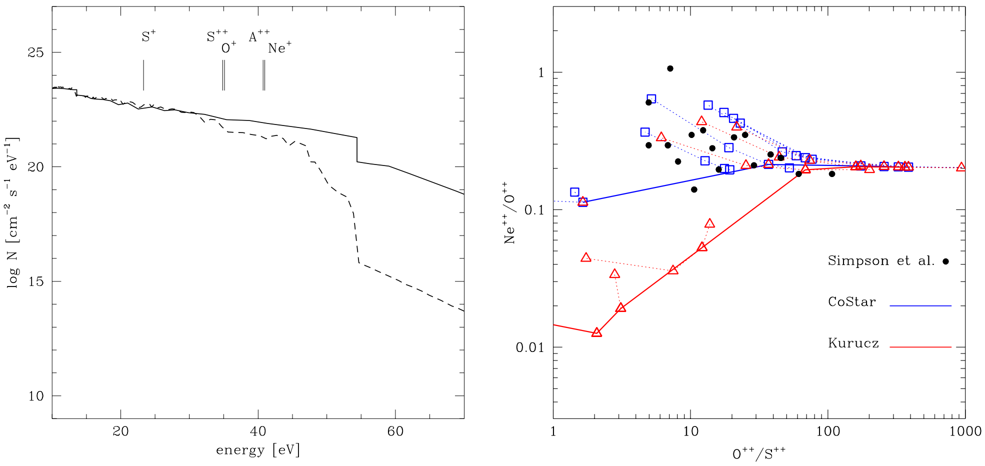

Figure 1. *Left panel:* Comparison of the EUV continuous spectral-energy distribution from a CoStar model (solid line) and a Kurucz model (dashed) for $T_{\rm eff} \simeq 45\,000$ K (from Paper IV). *Right panel:* Predicted ionic Ne^{++}/O^{++} abundance ratio as a function of the O^{++}/S^{++} ionic abundance ratio for the solar metallicity models (squares: CoStar models, triangles: Kurucz models). The solid lines connects photoionization models for a 'standard' ionization parameter (cf. Paper IV) and varying stellar temperatures. Dotted lines show variations of the ionization parameter. Observations from the IR-line measurement of Simpson et al. (1995) are shown by filled circles.

are compared to plane-parallel atmospheres at the same stellar temperatures. In particular, with ionizing fluxes from CoStar models one obtains ionic fractions of $x(N^+)/x(O^+)$ and $x(Ne^{++})/x(O^{++})$ which are close to unity for ionization parameters typical of H II regions, over a large range of stellar temperatures. Therefore N^+/O^+ and Ne^{++}/O^{++} should provide safe indicators to derive N/O and Ne/O abundance ratios over a wide range of astrophysical conditions.

As shown by the exploratory calculations by Sellmaier et al. (1996), the use of ionizing fluxes from non-LTE wind models including line blocking seems to resolve the so-called [Ne III] problem, which was made particularly clear when Simpson et al. (1995) plotted the values of Ne^{++}/O^{++} as a function of O^{++}/S^{++} (all derived from far-IR line measurements). The problem is illustrated in Fig. 1 (right panel), where the observations indicate an essentially flat Ne^{++}/O^{++} ratio while the predictions of photoionization models using the Kurucz atmospheres fail to reproduce the observations. Indeed, the higher ionic ratios obtained from photoionization models using the CoStar fluxes are in much better agreement with the observations than models based on Kurucz atmospheres (see Fig. 1). As shown in Paper IV, a similar 'observational test' can be performed by using optical lines. Both comparisons support our ionizing fluxes from non-LTE atmospheres including stellar winds and line blanketing.

Although such comparisons may represent extremely useful tests of predicted EUV fluxes, good constraints on the ionization parameter and a precise knowledge of the ionizing sources (stellar type, number of stars) must be obtained for accurate comparisons. This should be possible with future observations of, in the ideal case, integrated single-star H II regions. Careful studies of the metallicity dependence (and hence also the dependence on the wind properties) of the predicted fluxes will be both necessary and extremely useful for many astrophysical applications. For example, the great sensitivity of the Ne (and several other IR) lines on the shape of the ionizing spectrum in the He I continuum has important consequences for the interpretation of emission-line spectra of H II regions and young starbursts in the wavelength range observed by ISO. Derived stellar temperatures, IMF slopes, and upper mass cut-offs depend strongly on the adopted ionizing fluxes, as illustrated by Kunze et al. (1996).

3.1. Constraints on the Lyman-Continuum Production of OB Stars

Another fundamental test to which atmosphere models have to be subjected is, of course, whether the integrated ionizing photon flux (e.g., in the Lyman continuum) is correctly predicted. The best example of such a test is certainly the B2 II star ϵ CMa, for which direct EUVE observations below the Lyman limit could be obtained (Cassinelli et al. 1995). For this case a large excess (by a factor of $\sim$30) of the Lyman continuum flux was found compared to plane-parallel atmosphere models! Although this excess can be explained by a temperature excess in the continuum-forming layers (see Cassinelli et al. 1995; Paper IV; and Aufdenberg et al. 1997), the physical cause for this temperature increase remains to be explained. Obviously, in a larger context the fundamental question is, however, if the Lyman continuum excess is a general phenomenon, and, if so, for what type of stars?

In principle this question can easily be answered by observations measuring the integrated recombination rate (e.g., Hα luminosity) of nebulae around single stars of known spectral type. Detection of excess radiation compared to predictions for the determined spectral type could indicate an intrinsic excess of the Lyman continuum flux from the central star (or an undetected additional source). A lack of radiation can be interpreted as leakage of photons out of the region or important internal absorption by dust. To our knowledge, no such systematic comparison has been done so far, especially for B stars. Few statements can nevertheless already be made at this stage.

For ultracompact H II regions which, according to the $T_{\rm eff}$ derived from FIR line ratios, contain stars of spectral types B0–O7, a slight excess might be found for some cases (Afflerbach et al. 1997). However, their stellar content is not known directly, and multiple sources therefore cannot be excluded. The first ultracompact H II region where the spectral type of the central star has been directly identified (Watson & Hanson 1997) indicates leakage or dust absorption. Oey & Kennicutt (1997, 1998) have recently compared observed H II-region luminosities with the Lyman-continuum luminosities predicted for their well-determined stellar content. The vast majority are found to be leaking photons (up to $\sim$50%). From their samples, mostly dominated by several O stars, an excess of Lyman-continuum flux can *on average* be excluded for O stars. Similar observations of less populated regions and of nebulae dominated by later spectral types would be highly rewarding.

4. Photoionization of the Diffuse Ionized Gas by Massive Stars

The multi-phase interstellar medium (ISM) contains a diffuse ionized component representing a significant fraction of its total mass and volume. This gas is often referred to as the 'Reynolds Layer' in the Milky Way, or the 'Diffuse Ionized Medium' (DIM), 'Warm Ionized Medium' (WIM), 'Diffuse Ionized Gas' (DIG), etc. in external galaxies. We shall adopt the acronym 'DIG'. It is usually found that OB stars provide enough power to ionize the DIG (e.g., Reynolds 1984; Hunter & Gallagher 1990; Ferguson et al. 1996; Martin & Kennicutt 1997). The picture of photoionization by massive stars has, however, been challenged by recent measurements of a low helium ionization fraction in the Galactic DIG (Heiles et al. 1996). On the other hand, the observations by Martin & Kennicutt (1997) show that important variations in the physical state of the DIG exist among galaxies.

To provide a quantitative base to address some of the questions raised by these studies it is highly desirable to use results from the most appropriate atmosphere and evolutionary models. For example, the expected helium ionization of the DIG is dependent on the hardness of the ionizing fluxes of OB stars, which, as discussed above, has been revised considerably in recent years. Following the lines of Heiles et al. (1996), we will therefore derive new, consistent calibrations of the H and He I ionizing fluxes for massive-star populations based on our CoStar models. Some implications for the DIG of various galaxies will be discussed in Section 4.2.

4.1. Ionizing Fluxes of Massive-Star Populations

For studies of the DIG one usually considers a stellar population at a steady-state equilibrium ('constant star formation'). The basic quantities of interest are then (cf. Heiles et al. 1996): the lifetime $\tau(M)$ of a star of initial mass M; its time-averaged Lyman continuum luminosity $s_{\rm H}(M)$; and its time-averaged He I continuum luminosity $s_{\rm He\,I}(M)$. These quantities can then be integrated over an initial mass function (IMF) to derive the total output of a stellar population.

For the derivation of these quantities we use the CoStar models (Papers I–III). We also extend the calculations to include the post-main-sequence (MS) phases, which have been neglected in all previous calculations. The adopted input physics (tracks, atmospheres) is the same as in the synthesis models of Schaerer (1996) and Schaerer & Vacca (1997); we use the most recent Geneva tracks, Schmutz et al. (1992) atmospheres for Wolf-Rayet (WR) stars, and Kurucz (1991) atmospheres for the remaining phases.

Fitting the results for solar-metallicity models we obtain the following descriptions:

$$\log \tau_{\rm MS}(M) = 9.818 - 3.286 \log M + 0.8074 (\log M)^2, \quad (1)$$

$$\log \tau_{\rm total}(M) = 9.986 - 3.496 \log M + 0.8942 (\log M)^2. \quad (2)$$

Here $\tau_{\rm MS}$ and $\tau_{\rm total}$ (in years) are the main-sequence and total lifetimes, respectively. Equations 1 and 2 are valid for $7 \leq M/M_\odot \leq 120$. Note that the most massive stars ($M \geq 85 M_\odot$) enter the WR phase during core hydrogen burning. In this case we have restricted the definition of the 'MS phase' to the non-WR

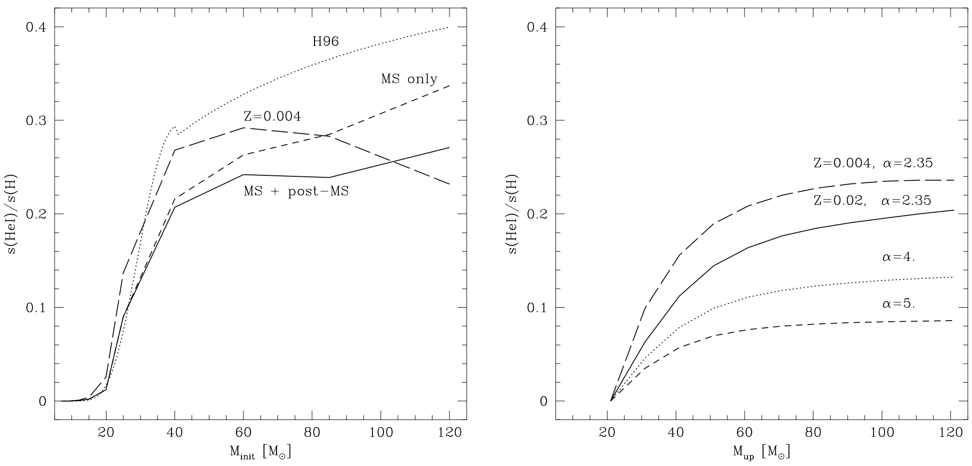

Figure 2. *Left panel:* He I/H hardness of the ionizing flux as a function of initial mass. Time-averaged value over the entire lifetime (solid for solar metallicity; long-dashed for $1/5Z_\odot$) and over the MS lifetime only (short-dashed for $Z_\odot$) derived from our models. Dotted: Eqn. 8 of Heiles et al. (1996). *Right panel:* He I/H hardness of the ionizing flux of an integrated steady-state stellar population as a function of the upper mass cut-off. Solar-metallicity models: Salpeter IMF (solid), $\alpha = 4$ (dotted), $\alpha = 5$ (short-dashed). Model at $1/5Z_\odot$ and Salpeter IMF: long-dashed.

phase. We note that the MS lifetimes differ by less than ~15% from the values of Güsten & Mezger (1982) used by Heiles et al. The mean Lyman-continuum luminosity can be fitted by

$$\log s_{\rm H}(M) = 32.47 + 17.35 \log M - 4.362 (\log M)^2, \tag{3}$$

for the same mass range as above. It turns out that this expression represents well both the average over the MS and the total average. Our values agree well with those of Cox et al. (1986) for $M \simeq 20$–$40 M_\odot$. Otherwise our values for s_H are lower, with differences up to a factor of ~5 at the border of the fit interval.

To describe the He I ionizing flux $s_{\rm He\,I}$ we use $\zeta(M) \equiv s_{\rm He\,I}/s_{\rm H}$ (see Fig. 2), which can be approximated by

$$\begin{aligned} \zeta(M) &= -0.1729 + 0.0096\, M \quad \text{for } 20 \le M/M_\odot \le 40 & (4)\\ \zeta(M)_{\rm MS} &= 0.1656 + 0.0014\, M \quad \text{for } 40 \le M/M_\odot \le 120 & (5)\\ \zeta(M)_{\rm total} &= 0.1861 + 0.0007\, M \quad \text{for } 40 \le M/M_\odot \le 120. & (6) \end{aligned}$$

For $M < 20 M_\odot$ the fraction of He I ionizing photons is negligible ($\zeta(M) < 0.005$).

The 'time-averaged hardness' ζ as a function of the initial mass M is shown in Fig. 2 (left panel). Also shown is $\zeta(M)$ given by Heiles et al. (1996), which was obtained from the plane-parallel non-LTE atmospheres of Kudritzki et al. (1991). Note that these atmosphere models predict a similar hardness of the ionizing flux (in terms of $Q_{\rm He\,I}/Q_{\rm H}$) as the CoStar models including also wind effects and line blanketing. The data of Heiles et al., however, only correspond to values typical for characteristic parameters of main-sequence stars; any temporal evolution has been neglected. The evolutionary tracks in the considered mass range extend to temperatures below 40 000 K on the MS. Given the rapid decrease of the He I ionizing luminosity below this temperature (e.g., Paper III), the MS average of ζ is systematically lower than the value given by Heiles et al. for $M \gtrsim 30 M_\odot$. For lower masses our results are in good agreement with the values of Heiles et al. Incidentally, this is also the mass range which is critical for the interpretation of the observations of the DIG in the Milky Way (see Section 4). It must, however, also be noted that this is likely the domain where current models are the most uncertain, for the reasons discussed in Paper III. Fig. 2 also illustrates the difference between averaging over the MS only and the more correct average over the MS and post-MS phases: For the most massive stars ζ averaged over their entire lifetime can be up to ~25% lower than the MS value. This is due to their evolution in the WR phase, which leads to lower average luminosities. For comparison we have also plotted ζ (average over total lifetime) at 1/5 solar metallicity. As expected, the average spectrum is slightly harder, mostly due to the temperature shift of the MS. In short, we conclude that *the time-averaged spectrum predicted from consistent modelling using, in particular, the ionizing fluxes from our CoStar models yields a lower He I/H hardness than the results of Heiles et al. (1996).*[2]

Let us now consider the hardness ζ of the spectrum produced by an integrated stellar population at a steady-state equilibrium. Figure 2 illustrates the dependence of ζ on the upper mass cut-off, $M_{\rm up}$, for various slopes α of the IMF. In our notation the Salpeter IMF is $\alpha = 2.35$. Obviously the results are not sensitive to the lower mass cut-off $M_{\rm low}$ as long as $M_{\rm low} \lesssim 20 M_\odot$. Despite differences in all the ingredients (see above), our results agree well with those of Heiles et al. (their Table 6) for $M_{\rm up} \lesssim 30 M_\odot$, whereas we obtain a softer spectrum for larger values of $M_{\rm up}$. For illustration, we also plot the run of ζ for a low-metallicity population. We shall now briefly discuss some implications from these results.

4.2. Implications for the Diffuse Ionized Gas

As shown by Heiles et al. (1996), the observations of the DIG in the Milky Way pose serious difficulties for the massive-star photoionization picture: while the high fraction of neutral helium requires that very massive stars are excluded, the observed Galactic ionization requirement would imply a total star-formation rate much larger than derived from other observations. Indeed, the ratio of the He I

[2]This contradicts several statements made by Martin & Kennicutt (1997). Some comments must be made on the mass scales shown in their Fig. 3: (*i*) All scales are representative for dwarf stars and do not include the time average, whose importance was shown above. (*ii*) Martin & Kennicutt's scale 'd' was drawn from the preprint version of Heiles et al., which used LTE model atmospheres, while their final results are based on non-LTE models yielding a similar hardness to the CoStar models. Similarly, for other results ($M_{\rm up}$, Galactic star formation rate) the statements by Martin & Kennicutt refer to the preprint of Heiles et al., before important revisions were made.

ionizing-photon production rate $Q(\mathrm{He\,I})$ to $Q(\mathrm{H})$ derived from the observations is $\lesssim 0.013$–0.027 (Heiles et al.).

Our results confirm entirely the interpretation of their Milky Way data. In contrast with some statements by Martin & Kennicutt, the use of our atmosphere models does not change the conclusions of Heiles et al. for the reasons discussed above (see footnote). Indeed, a comparison with the right-hand panel of Fig. 2 shows that the observed $Q(\mathrm{He\,I})/Q(\mathrm{H})$ implies an upper mass cut-off of $M_{\mathrm{up}} \simeq 25 M_{\odot}$. This result is robust even to large variations of the IMF slope (e.g., the very steep slopes found by Massey et al. (1995) for field stars) as also show by Fig. 2. For $\alpha = 2.35$ we also obtain the same Lyman-continuum production as Heiles et al., which confirms the requirement of a large Galactic star-formation rate to reproduce the observed Galactic ionizing-photon production rate.

As an unconventional explanation for these problems, Heiles et al. consider the possible excess of Lyman-continuum flux from B stars, motivated by the observed excess in the B2 II star ϵ CMa. If common among B stars, this could potentially solve the above-mentioned difficulties. As discussed in Section 3.1, it should be possible to constrain the ionizing fluxes of B stars observationally in the future.

The observations of the DIG of three Magellanic irregular galaxies by Martin & Kennicutt (1997) reveal a different picture. There the helium ionization fraction is approximately equal to the hydrogen fraction, which translates to a lower limit of $Q(\mathrm{He\,I})/Q(\mathrm{H}) \gtrsim 0.1$ (Martin & Kennicutt). From the right-hand panel in Fig. 2 this translates to a lower limit for the upper mass cut-off of $M_{\mathrm{up}} \gtrsim 30$–$40 M_{\odot}$ for a Salpeter IMF. We also note that the high helium ionization in these objects could, in principle, even be explained by a population with an IMF slope as steep as those derived by Massey et al. (1995) for field stars. For this case the required upper mass cut-off is $M_{\mathrm{up}} \gtrsim 40$–$60 M_{\odot}$, in good agreement with numerous independent observational constraints (cf. Leitherer 1998, Massey 1998). The ionization by radiation leaking out from H II regions (with a 'normal' IMF slope) is, however, a more likely explanation, as shown by recent observations (Ferguson et al. 1996, Martin & Kennicutt 1997, Oey & Kennicutt 1997, Wang et al. 1997).

5. Reliable Ionizing Fluxes for OB Stars: Further Developments

To improve our atmosphere models further, and to compare the predicted spectra with UV observations, we have recently upgraded the non-LTE calculations by including a detailed treatment of CNO and Si in addition to H and He (following de Koter et al. 1997). Improvements are also brought about for the completeness of the line list used in the line-blanketing Monte-Carlo simulations. In this Section we briefly present some preliminary results on the EUV fluxes and compare our latest calculations with new models from the Munich group (Pauldrach et al. 1998).

The main changes with respect to Paper IV are the explicit non-LTE treatment of CNO and Si, whose populations were previously described by our modified nebular approximation (see Paper I and references therein). By the same token this also allows us to derive a finer description of the radiation temperature as a function of the ionization potential, which is used to describe the ioniza-

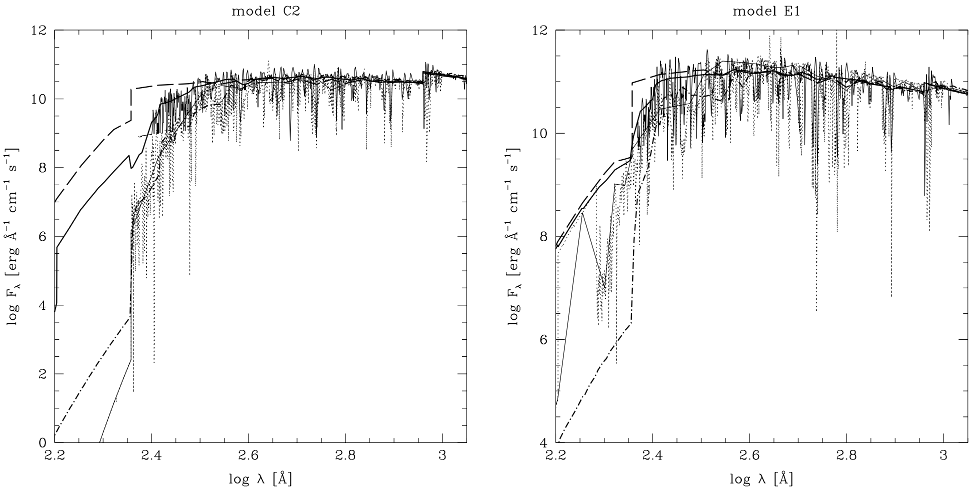

Figure 3. Comparison of the emergent fluxes from different models. Long-dashed, from Paper IV; solid, new model (continuous distribution, thick; detailed line+continuum, thin); dotted, Pauldrach model (smoothed spectrum traced by thin solid line); dashed-dotted, Kurucz model. *Left panel:* model C2 ($T_{\rm eff} \simeq 40\,000$ K), *right panel:* model E1 ($T_{\rm eff} \simeq 5\,0000$ K).

tion structure of the remaining elements. The bound-free opacities of CNO and Si are now also included. In Fig. 3 we plot a comparison for two models from Paper IV. For $\lambda \gtrsim 310$Å the new calculations agree well with the previous ones. Between ~310Å and the He II edge (228Å) our new models predict less flux, mostly due to the inclusion of the bound-free CNO opacity. Predictions for the He II continuum remain subject to other considerable uncertainties (see Paper IV).

In Fig. 3 we have also plotted the flux from two new atmosphere models, including line blocking, calculated with similar parameters (see Pauldrach et al. 1998). The overall agreement between the models is quite good for $\lambda \gtrsim 310$Å, although some distinct features exist. At shorter wavelengths, however, the flux from the Munich model decreases more strongly, remaining fairly close to the Kurucz model for $T_{\rm eff} \simeq 40\,000$ K (left panel). We have done test calculations of photoionization models using both sets of fluxes. Regarding the nebular Ne^{++}/O^{++} abundance ratio (cf. Section 3) we find only minor changes for our models, while the Pauldrach model at 40 000 K yields $Ne^{++}/O^{++} \simeq 0.1$–$0.15$ and $O^{++}/S^{++} \gtrsim 25$, more similar to Kurucz models.

Given important differences between the model techniques and the some of the input physics (e.g., line lists) it is difficult to explain the reason(s) for the differences in the predicted spectra. More detailed work remains to be done to explore further the dependence on various model assumptions and to improve the treatment of line blanketing and non-LTE effects in spherically expanding atmospheres. Concomitantly, it appears very useful to pursue further studies of 'simple' H II regions to constrain the atmosphere models as much as possible. In view of the difficulties hot-star models have faced so far in reproducing correctly the observable UV from consistent calculations (see, e.g., Groenewegen & Lamers 1991; Pauldrach et al. 1994) such new tests could be crucial to reaching the goal of obtaining accurate predictions of the spectral evolution of early-type stars.

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Discussion

Najarro: Daniel, have you tested for any difference if you treat CNO with Sobolev or in the comoving frame? It could be very important just close to the edges.

Schaerer: Not specifically; the code has been extensively tested for differences between Sobolev and comoving frame, but only for hydrogen and helium.

Pauldrach: You found a difference with respect to your old models by including CNO elements in the analysis; would you expect that including iron would make further changes?

Schaerer: It is difficult to say; we have to understand the physical reason why we get the differences in this wavelength range. As I said, I think the important test is to look at the implications of what these model spectra give you, so if we combine the nebular analysis with the classical spectral range we can learn more about the ionizing fluxes.

Kudritzki: I agree that one of the most important tests is to make this sort of comparison with the observations. On the other hand, we have two codes, yours and Adi's, and they give significant differences for exactly the same input parameters. Both codes make a lot of approximations, and it may be that some of them are crucial and simply bad. Maybe one of the codes will give better agreement with observations – but you can always be right for the wrong reason. So I think it's very important to try to understand the physical reasons for the differences in the two codes.

Schaerer: Yes, that's why I'm pleased we now have results so we can really make a comparison.

Conti: Is it premature to say anything about the λ4686 nebular emission that's found in some of these starburst galaxies, and which up to now is unexplained?

Schaerer: Well, you know I like these objects, but I think there's definitely no hope that the O stars are responsible for this ionization. In the best case you can only get to 10^{-3}–10^{-4} of the observed flux with O stars. As you know, with WC stars and hot WN stars, if you believe in the ionizing fluxes in the literature, you can do it reasonably well. Even in the lowest-metallicity objects, like I Zw 18, you find WC stars, and so there's a very good hope that they can produce this ionization.

Kudritzki: You know there is a paper by Gabler et al., in '92, which says for extreme O stars, with high mass-loss rates, very close to the Eddington limit, you might get enough ionization. These were only hydrogen/helium models, so can you confirm their result, or...?

Schaerer: We got agreement with the Gabler results, but just for the regular O stars. I haven't pushed my models as far towards the Eddington limit, but in any case I don't think these rather strange stars will do it, simply because if you want to explain the fluxes you need a huge number of them.

Hanson: I just wanted to point out that the star I discussed on Monday [p. 1], which is the ionizing source for G29.96−0.02, was studied by Simpson's group, and they get an upper limit to $T_{\rm eff}$ of 37 000 K. When you apply your numbers to S II/O II, you get about the same; but when you look at the *star,* the minimum temperature is probably 40 000 K. So I think there are still some problems, even in a case like that where you have a fairly simple ultracompact H II region.

Schaerer: We haven't really starting compiling lists of objects where detailed testing can be done, so it's good to have at least one.