THE ULTRAVIOLET SOLAR OPACITY

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Abstract. Ultraviolet solar observations are compared with predictions from a new solar model. From 3600 to 1700 Å there is heavy line blanketing; probably one or more major sources of opacity are missing from the theoretical calculation in this region.

The Sun provides a particularly well-observed example of the ultraviolet spectrum of a typical G2 V star with a chromosphere. Because of the large increase in opacity toward shorter wavelengths, the ultraviolet continuum radiation arises at progressively higher levels. Hence, the construction of an empirical model becomes possible using continuum intensities alone. Because the opacity also rises with longer wavelengths, such a model can be checked from observations in the infrared.

Ultraviolet intensities predicted from a model newly constructed along these principles are shown in Figure 1. This model, which will be described in more detail in *Solar Physics*, differs from the Bilderberg Continuum Atmosphere (Gingerich and De Jager, 1968) in having a somewhat deeper temperature minimum and an earlier chromospheric temperature rise.

The solar spectrum beyond the Balmer continuum (911 to 3643 Å) can be divided into three general regions. From the Balmer limit down to 1683 Å (the edge produced by the first excited state of silicon), the spectrum is characterized by heavy absorption line blanketing and limb darkening. Between 1683 and 1525 Å (the emission edge from the ground state of silicon), the spectrum is at first glance deceptively similar to that at the longer wavelengths, but a closer inspection shows a dense pattern of *emission* lines. No atomic absorption lines have been identified in this interval, although certain strong CO lines have been found (Porter *et al.*, 1967). The center-to-limb variation is almost flat (Tousey, 1963). Radiation in this interval must arise from near the solar temperature minimum (Gingerich and Rich, 1968). Finally, between 1525 Å and the Lyman limit, the spectrum arises from the low chromosphere; it is presumably limb brightened, the bound-free opacity edges appear in emission, and the strong emission lines become sufficiently separated so that the continuum is readily isolated.

These characteristics of the spectral regions are important for understanding the mixed success of the model predictions shown in the figure. Toward the shorter wavelengths, where the continuum is well defined, the model represents the observations quite well – in fact, better than the observational accuracy warrants. Above 1683 Å, the heavily line-blanketed spectrum falls well below the predicted continuum level.

Nevertheless, the difficulty of finding the continuum cannot mask the fact that one or more opacity sources must still be missing from the theoretical calculations, especially in the 1700 to 1900 Å region. Through this part of the spectrum, the model assumes an opacity we formerly identified with the distant resonance broadening wing

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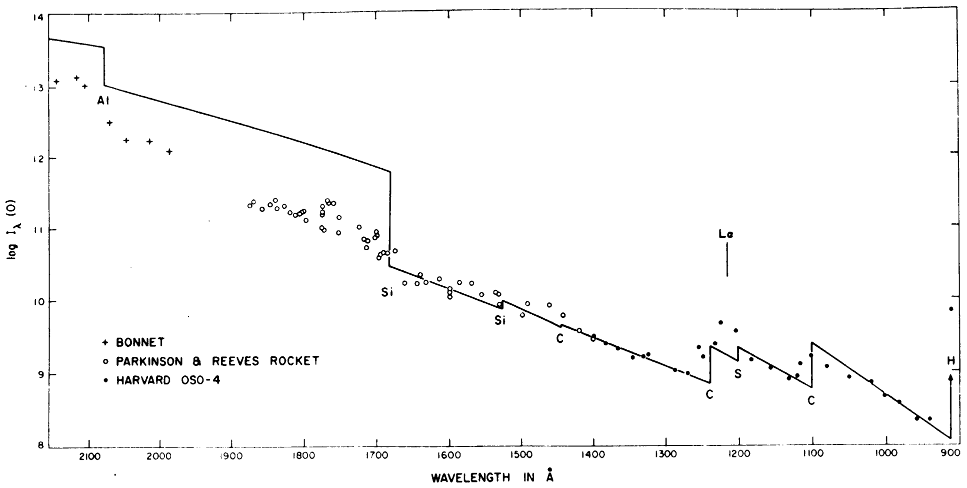

Fig. 1. The predicted solar ultraviolet continuum compared with observations by Bonnet (1968) and Parkinson and Reeves. (The observations at 1460 and 1490 Å are still provisional.)

of Lyman α; but this is incorrect, so the situation is actually worse than graphed here. Carbon monoxide, the quasi-H_2 molecule, and the proper (molecular) form of the Lyman α wing all absorb in the 1700 to 1800 Å region, but not very strongly. One good possibility for the missing opacity would be the several lower levels of bound-free iron, especially if the solar iron abundance is higher than that recently accepted.

Perhaps I should point out explicitly that the discrepancies between the predictions and the observations at 1700 to 2000 Å cannot be reconciled by adjusting the temperature structure of the new model. This would wreak havoc with the agreement at longer wavelengths. Therefore, the search for additional absorbers must continue.

Acknowledgements

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Discussion

Morton: Does your new solar UV flux distribution change the effective temperature of 5180 K derived by Labs and Neckel?

Gingerich: No. There is so little flux in the solar UV that a change of this size will have no appreciable effect.

Müller: I am referring to the discrepancy between the observed and predicted opacity near 1700 Å. You mentioned to me yesterday that a higher photospheric iron abundance might account for the strong increase in the observed opacity near 1700 Å. Since, apparently, there are some evidences for a higher photospheric iron abundance (i.e. a factor of 10 to 20 higher than the GMA value), I wonder whether the 1700 Å region is the only one in which a large photospheric iron abundance would affect the opacity distribution and whether the increase of the photospheric iron abundance by a factor 10 to 20 would be sufficient to produce the observed opacity.

Gingerich: Unfortunately there are no laboratory or quantum mechanical values for the iron cross sections, but if the hydrogenic approximation has any validity, then with a 10 × GMA iron abundance, about five bound-free levels will be important around 1700–1800 Å, where we find now a severe discrepancy between the models and observations. I hope that laboratory cross sections will be determined soon in the Harvard Shock Tube Laboratory. At how much longer wavelengths the iron might contribute noticeably, I can't guess, but we do have definite evidence for a comparatively smooth unidentified absorber diminishing at longer wavelengths up into the visual spectrum. An increased iron abundance should also give a desirable increase in electron density in the solar chromosphere.

Conti: From the reports by Davis and by Hallam, we understand there is an ultraviolet deficiency for A, F, and G stars. This is also true for the Sun. Would Gingerich care to comment on the possible explanations for the discrepancy?

Gingerich: With the possible exception of iron, I believe we have the major bound-free opacity sources. I have looked for neutral and ionized atoms without finding other candidates for these temperatures. Most molecules are out – carbon monoxide, for example, is overwhelmed by silicon in the Sun. At 1700 Å the resonance wing of Lyman α, which acts like a molecule here, may be significant, and there is always the possibility of something strange like HHe. Consequently it appears that line blocking may be the most likely cause of the ultraviolet deficiency both in the Sun and in earlier stars. However, in the Sun the major discrepancy is $\sim$2500 Å, whereas in Sirius the disagreement also includes the resonance line region down to 1200 Å.