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# On the centre-to-limb variation of some visible and infrared atomic hydrogen lines in three facular models

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**Abstract.** The centre-to-limb behaviour of the residual intensities in the line wings of the Balmer, Paschen, and Brackett series lines (alpha to delta) in three facular models at four wing points has been investigated with a view to distinguishing amongst the models.

*Key words*: facular models—centre-to-limb behaviour—line profiles

It has earlier been shown that strong atomic lines of hydrogen, namely Balmer, Paschen, and Brackett series lines (alpha to delta) are useful for distinguishing amongst different models of the quiet photospheric as well as of the various facular models (Bondal and Gaur 1986, Bondal *et al.* 1986).

Further properties of faculae can be determined by studying (i) centre-to-limb (C–L) variation of the continuum contrast, and (ii) C–L variation of the wavelength dependence of the contrast. The study of facular contrast is important for determining their structure as a heating source, and also for measuring the energy loss in an active region. The C–L behaviour of the contrast reveals a great deal about the depth dependence of the source function within the facula.

Much observational data on the C–L variation of the continuum contrast exist in the literature (*e.g.* Hirayama, Hamana & Mizugaki, 1985). Photoelectric observations of facular-to-photospheric line contrast have been given by Mitropol'skaya (1963, 1967) for Balmer H$\alpha$, H$\beta$, Paschen $\beta$ and for Brackett $\gamma$ lines at two points in the line wing and at two C–L positions. However, her investigations do not reveal much about the C–L behaviour of the line contrast.

Spruit (1976) found the strong size dependence of facular contrast in Mg $b_1$ line. He suggested that in determining the size distribution of faculae, the ratio of the contrast in the line to that in the continuum can be used as an indicater of the size of the facular elements. If a well calibrated ratio is available it would provide a powerful tool for studying the properties and distribution of flux tubes on the solar surface. That is, facular line contrast would be able to distinguish between the average and the spatially limited facular models. Here we have investigated theoretically the C–L behaviour of atomic hydrogen lines in terms of residual intensity. The main objective is to show that certain lines can well distinguish the facular models from one another, whereas others may not be good indicators for this purpose.

The facular models chosen here are of Schmahl (1967), Stenflo (1975), and of Caccin & Severino (1979). We took the first four lines of the Balmer, Paschen, and Brackett series and calculated the residual intensities at the wing points $\Delta\lambda = 2, 3,$

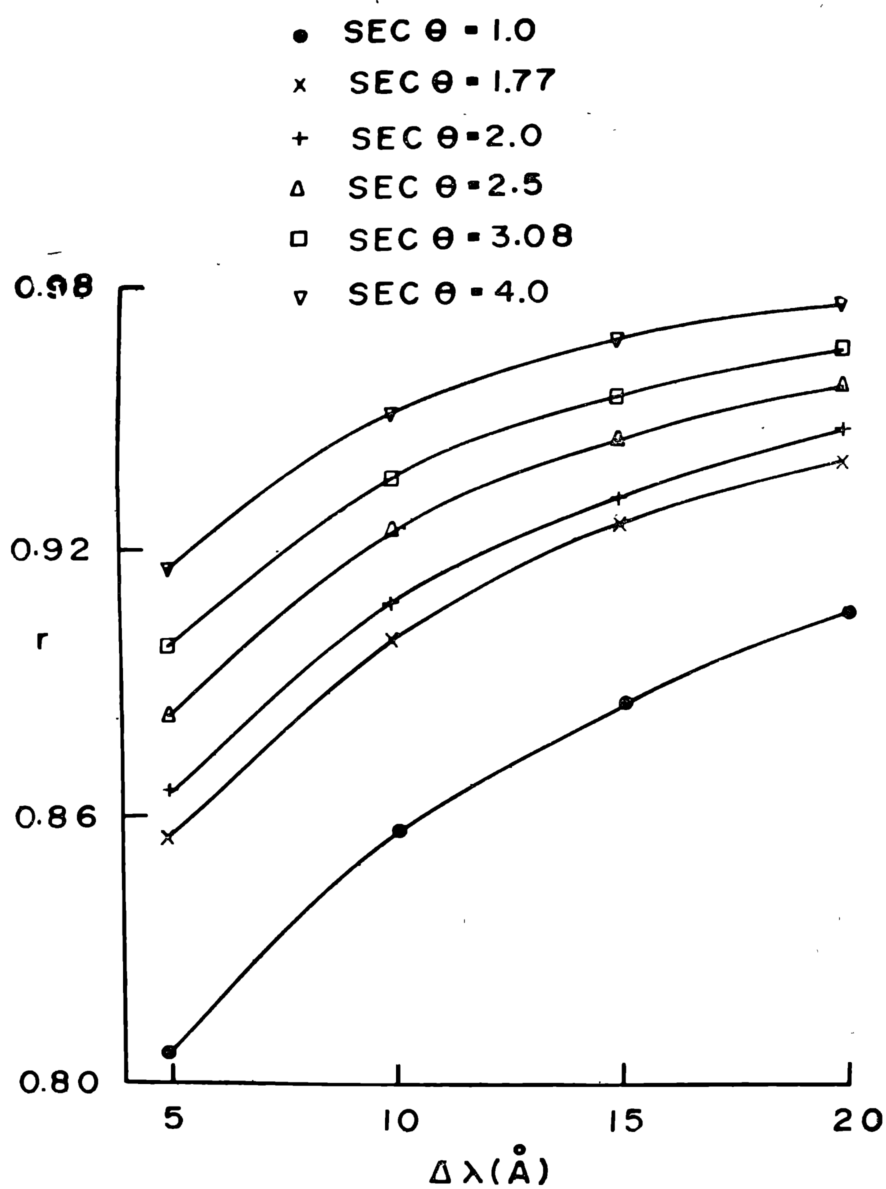


**Figure 1.** Variation of residual intensity ($r$) with sec θ at four wing points $\Delta\lambda$ = 5, 10, 15 and 20 Å for a given line in a typical facular model (see text).

5, 10, 15, 20, 25, 30, 40 and 50 Å for all the lines. The chosen C–L positions correspond to sec θ = 1.0, 1.77, 2.0, 2.5, 3.08 and 4.0. The computational procedure for calculating the residual intensities has been given earlier (Bondal and Gaur,

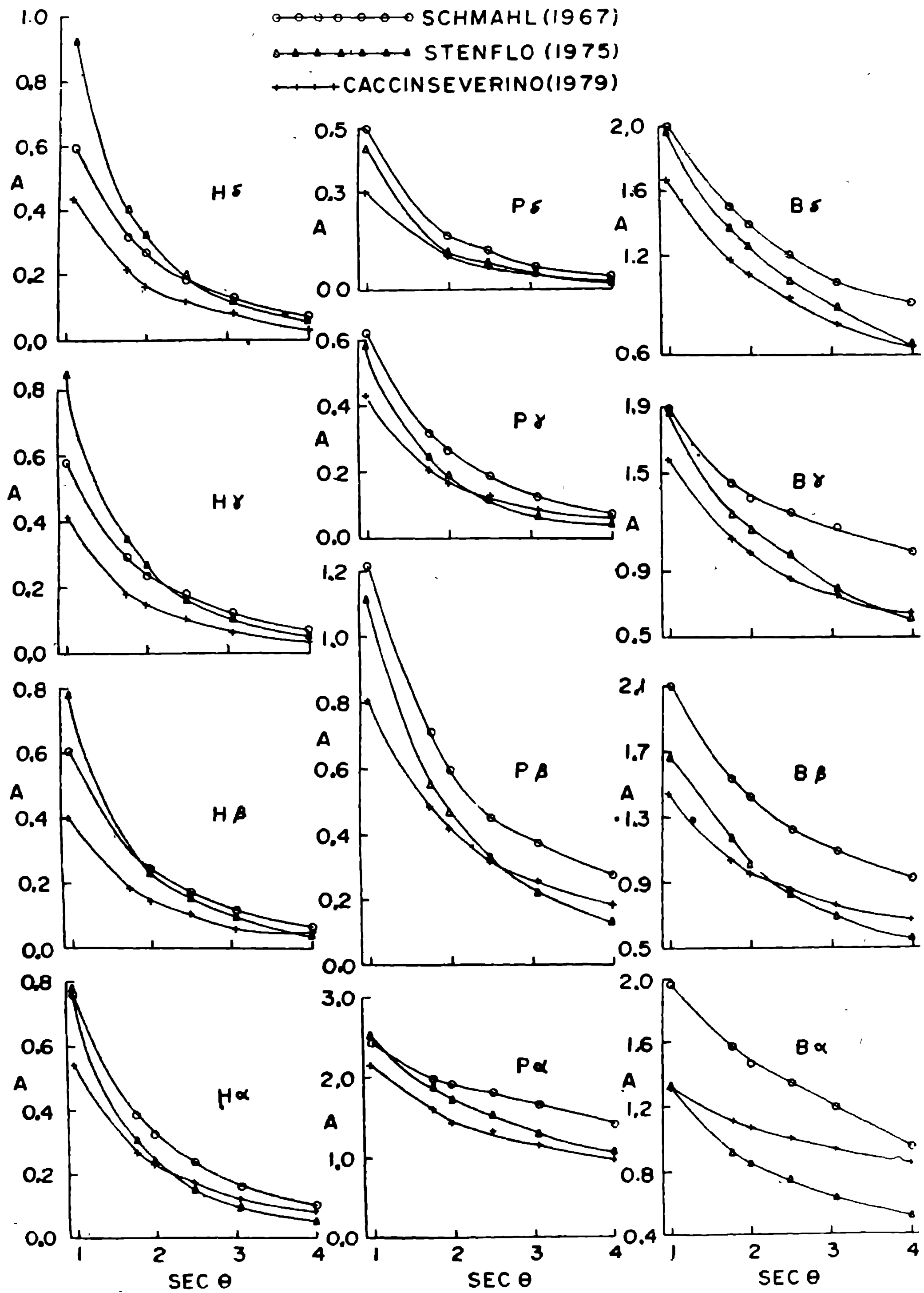


**Figure 2.** Variation of area ($A$) of computed profiles of lines from Hα to Hδ, Pα to Pδ and Bα to Bδ in three facular models as a function of sec θ

1986). For our purpose here, however, we have selected four wing points, at $\Delta\lambda = 5$, 10, 15, and 20 Å, because their being near the shoulders of the line profiles makes them sensitive to intensity variations. Taking each sec θ value, we have plotted the residual intensities at each of these $\Delta\lambda$ values, so that for a given wavelength, we have a set of six curves. These curves are in fact line profiles in the sense that they resemble the residual intensity versus $\Delta\lambda$ plots. An example of a typical curve is shown in figure 1. The area of each of these curves was determined and then plotted against sec θ values. These areas represent fractional equivalent widths which decrease from centre to limb. This is shown in figure 2.

From figure 2, we see that in the visible region, the models are well separated out at the disc centre, the separation increasing from Hα to Hδ and the variation in each model from the centre towards the limb. Hδ seems to be the best line to distinguish amongst the three models. We find that Schmahl's (1967) model is most sensitive to the Hα line and stands well separated from the remaining two models, whereas Caccin & Severino's (1979) model is separated from the other two in the Hβ, Hγ, and Hδ lines. However, the maximum change in going from C–L is shown by Stenflo's (1975) model since its curve has the largest slope which is maximum in Hδ. This could be due to rapid change in the stratification of the layers in going from centre to limb. The intersection of the curves at some point is probably due to model effect.

In the case of Paschen series, Schmahl's (1967) model again stands out as being the most sensitive to the Pβ line. The curves for all the three models in Pα line have smaller slopes than in the remaining lines of this series. Also, unlike in the Balmer series, even towards the limb the Paschen series lines separate out the three models. Here also, Stenflo's model has the largest slope, followed by that of Schmahl (1967) and then by Caccin & Severino (1979). The sensitivity of the model however, appears to decrease for the Pγ and Pδ lines.

Coming to the Brackett series, Bγ and Bβ distinctly separate out Schmahl's (1967) model from the rest. Stenflo's (1975) model again shows the highest slope in all the lines of the series. As in the Paschen series lines, the models stand well separated even towards the limb.

Mitropol'skaya (1967) has pointed out that the infrared lines have the advantage that they are formed in higher layers than the visible (Balmer series) on account of the high coefficient of continuous absorption in this region. Therefore the infrared lines can provide a diagnostic tool to understand and improve the upper layers of the faculae, i.e. towards the limb. In as much as the Balmer lines prove useful for the deeper layers, i.e. towards the disc centre.

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