EMPIRICAL CORRECTION OF RHESSI SPECTRA FOR PHOTOSPHERIC ALBEDO
AND ITS EFFECT ON INFERRED ELECTRON SPECTRA

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ABSTRACT

Photospheric Compton backscatter (albedo) makes a significant contribution to observed hard X-Ray (HXR) spectral fluxes over the RHESSI energy range and should be allowed for in spatially integrated HXR spectral interpretation.

The high HXR spectral resolution of RHESSI creates the chance for precise study of source electron spectra provided the observed spectra are well corrected for non-primary effects at the sun including albedo, directivity, source ionisation variations and the like. However, the full correction problem is nonlinear and messy but we offer a simple approximate first order correct procedure for global HXR spectra based upon empirical fits to published albedo simulations. We also illustrate the impact of this correction on inferred electron spectra for the thin and thick target models with the Kramers cross-section.

Key words: albedo; electron; hard x-ray; flare.

1. INTRODUCTION

Some of the photons emitted downward around the delta-keV range in the optically thin solar atmosphere undergo Compton backscatter in the low atmosphere and add to the primary photons, emitted upwards, in the observed signal. These albedo photons come from an extended area and arrive with a spread of delay times, depending on the primary source geometry, especially the height.

Here, and in Alexander & Brown (2002), we have investigated the effect of the albedo contribution on the HXR spectrum as a whole and offer a first order correction procedure for global HXR spectral data.

The albedo correction itself is a convolution and not just a spectral correction factor. That is, the fractional albedo addition $A(\epsilon)$ at photon energy $\epsilon$ to the primary photon spectrum $I_0(\epsilon)$ itself depends on the functional form of $I_0(\epsilon)$, since Compton scattering shifts photons in energy. Thus recovery of $I_0(\epsilon)$ from the total observed spectrum $I(\epsilon)$ involves inversion of a nonlinear convolution of $I_0(\epsilon)$ with the scattering and absorption processes.

2. EFFECT OF ALBEDO CORRECTION ON INFERRED ELECTRON SPECTRA

Given $I_0(\epsilon)$, one can derive the source mean electron spectrum $\bar{F}(E)$ ("thin-target") and the collisional thick target electron injection spectrum $F_0(E_0)$ by inversion of the bremsstrahlung spectral integral. These were shown analytically by Brown and Emstie (1988) for the Kramers cross-section to be:

$$\bar{F}(E) = \frac{1}{n_p V Q_o} E \left[ \frac{d}{d\epsilon} \{\epsilon I_0(\epsilon)\} \right]_{\epsilon=E} \quad (1)$$

and

$$F_0(E_0) = \frac{K}{Q_o} \left[ \frac{d^2}{d\epsilon^2} \{\epsilon I_0(\epsilon)\} \right]_{\epsilon=E_0} \quad (2)$$

Here we use a Kramers cross-section to demonstrate how large the effect of $A(\epsilon)$ can be on inference of source electron spectra.

Specifically we:

1. (a) consider cases where the primary electron spectra are in fact power-law ($E^{-\delta}$ or $E^{-\gamma}$), resulting in power-law $I_0(\epsilon)$ in both cases (with $\gamma = \delta + 1, \delta - 1$ respectively)

2. (b) generate the total $I_{tot}(\epsilon) = I_0(\epsilon)(1 + A(\epsilon))$ that would be observed

3. (c) Use the analytic inversion formula to find out what $\bar{F}(E)$, $F_0(E_0)$ would be derived from that $I_{tot}(\epsilon)$ if albedo were ignored, i.e. if it were assumed that $I_0 = I_{tot}$

Our approach uses a parameterized form of $A(\epsilon)$ with a best fit of the ($\gamma$ dependent) parameters $A_0, a, b$ to the Bai & Ramaty (1978) results for each of the four different $\gamma$ values.
3. THIN-TARGET

In reality we observe $I_{tot} = I_o (1 + A(\epsilon))$ rather than $I_o$ and if we ignore the albedo correction by misidentifying $I_{tot}$ with $I_o$ then for (1) we would infer

$$\bar{F}(E) = C' E^{-\gamma + 1} \left[ 1 - A(\epsilon) \frac{(1 + a - (\gamma + b \epsilon))}{\gamma - 1} \right]$$

(3)

where $A(\epsilon) = A_o e^{a \epsilon}$ and $C' = \frac{(\gamma - 1) C}{n_o V Q_o}$

This results in a mean electron spectrum wrong by a fractional error

$$f_{thin}(\gamma) = \frac{\Delta \bar{F}(E)}{\bar{F}_o(E)} = \frac{A_o e^{a \epsilon} e^{-b \epsilon} \left[ (\gamma + b \epsilon) - (a + 1) \right]}{\gamma - 1}$$

(4)

where $\Delta \bar{F}(E) = \bar{F}(E) - \bar{F}_o(E)$. This is shown in Figure 1.

A comparison of (3) with its equivalent primary (power law) electron spectrum highlights that there is a spurious bump in the inferred electron spectrum (Figures 2–5). This bump decreases with increasing spectral index.
4. THICK TARGET

Using (2), the total electron injection rate \( \mathcal{F}(E_0) \) electrons per s\(^{-1}\) per unit \( E_0 \) (Brown & Emslie 1988) for a primary power law \( I_0(\varepsilon) \) with the albedo correction ignored \( (I_{\text{albd}} \text{ is misinterpreted as } I_0) \) leads to

\[
\mathcal{F}(E_0) = \frac{K}{Q_0} CE_0^{-\gamma} \left[ \frac{\gamma}{E_0} (\gamma - 1) + A_0 e^{e^{\gamma}} \right] \times \\
\left( (\gamma - 1) (\frac{E_0}{E_0} - 2(\frac{\varepsilon}{E_0} - b)) + E_0 \left( (\frac{\varepsilon}{E_0} - b)^2 - \frac{1}{E_0^2} \right) \right)
\]

which is incorrect by a fractional amount

\[
I_{\text{thick}}(\gamma) = \frac{\mathcal{F}(E_0) - \mathcal{F}(E_0)}{\mathcal{F}(E_0)} = \frac{A_0 e^{e^{\gamma}} E_0}{\gamma (\gamma - 1)} \times \\
\left[ (\gamma - 1) (\frac{E_0}{E_0} - 2(\frac{\varepsilon}{E_0} - b)) + E_0 \left( (\frac{\varepsilon}{E_0} - b)^2 - \frac{1}{E_0^2} \right) \right]
\]

and is shown in 6.

Figures 7–10 show the log plots of the recovered thick target Kramer electron spectrum \( \mathcal{F}(E_0) \) (full lines) along with their respective primary electron spectrum \( \mathcal{F}_0(E_0) \) (broken lines) for the four values of \( \gamma \) studied.

The fractional error in the thick target spectra was found to be significantly larger than the thin target case (note and compare scales with the thin target case!). This is evident in the spectral bumps present in the inferred thick target spectrum. This error decreased with increasing spectral index \( \gamma \).
5. DISCUSSION

RHESSI spectra have not been reported as exhibiting evident spectral bulges like those shown above. In order to redress this apparent discrepancy the following explanations might be offered:

1. The primary spectrum \( I_e(e) \) has a dip where \( A(e) \) has a bulge, the two offsetting one another. This seems too much of a coincidence to be plausible!

2. The bulges are present but have not been specifically noticed or reported as such. In fact, the lower energy end of the bulge is down around 10keV which may be lost in the thermal emission component. The middle and upper end energy range of the bulge looks somewhat like a downward knee in the deka-keV range. Such features are regularly seen in data - cf. discussion in Kontar, Brown and McArthur (2002). Albedo may be a partial explanation of these.

3. There are other corrections - especially that for non-uniform target ionisation in the case of thick target primary sources discussed by Kontar, Brown and McArthur (2002) which have been ignored in this paper. Depending on the depth ('energy') of the transition region, this correction might tend to either augment or hide the effect of albedo on the spectrum.

4. The assumption of an isotropic, point source Ramaty (1978) which provided our source data for \( A(e) \) may require modification.

6. CONCLUSIONS

We have demonstrated, for the Kramers cross-section, the consequences of ignoring the albedo correction in using observed spectra to infer flare source electron spectra for thin and thick target interpretations. These are very significant in terms of inferred spectral shape, especially for hard spectra. We have not extended the analysis to other cross sections but we note that the effects of albedo on deriving electron spectra will be even larger for more realistic smoother cross-section approximations, such as the Bethe Heitler, than for Kramers because they filter the electron spectral features even more. It should be noted, however, that the effects of albedo should be considered alongside other corrections such as that of nonuniform target ionisation in the case of the thick target beam model as discussed by Kontar, Brown and McArthur (2002).

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REFERENCES