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Using Albedo to Determine Changing Anisotropy in a Flare

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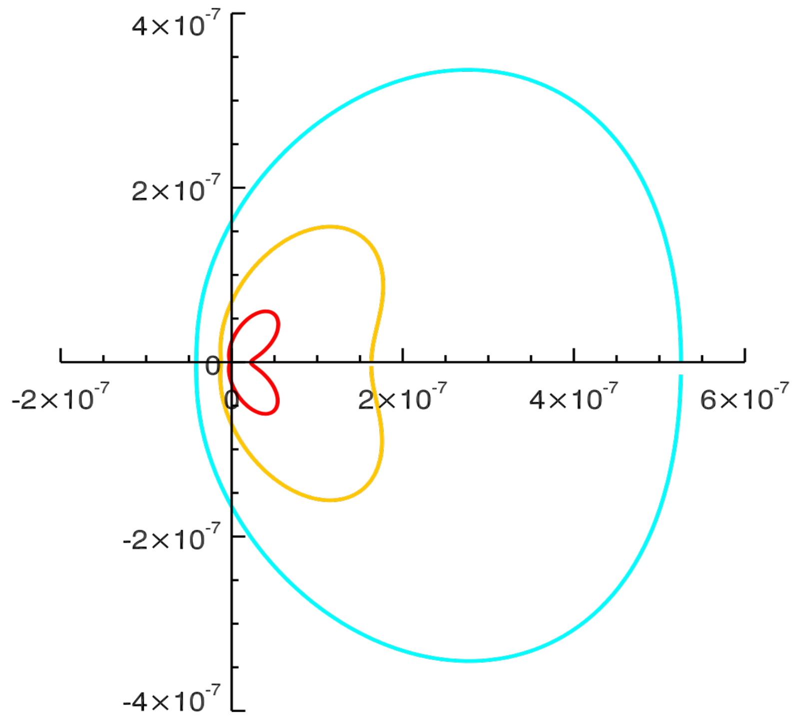
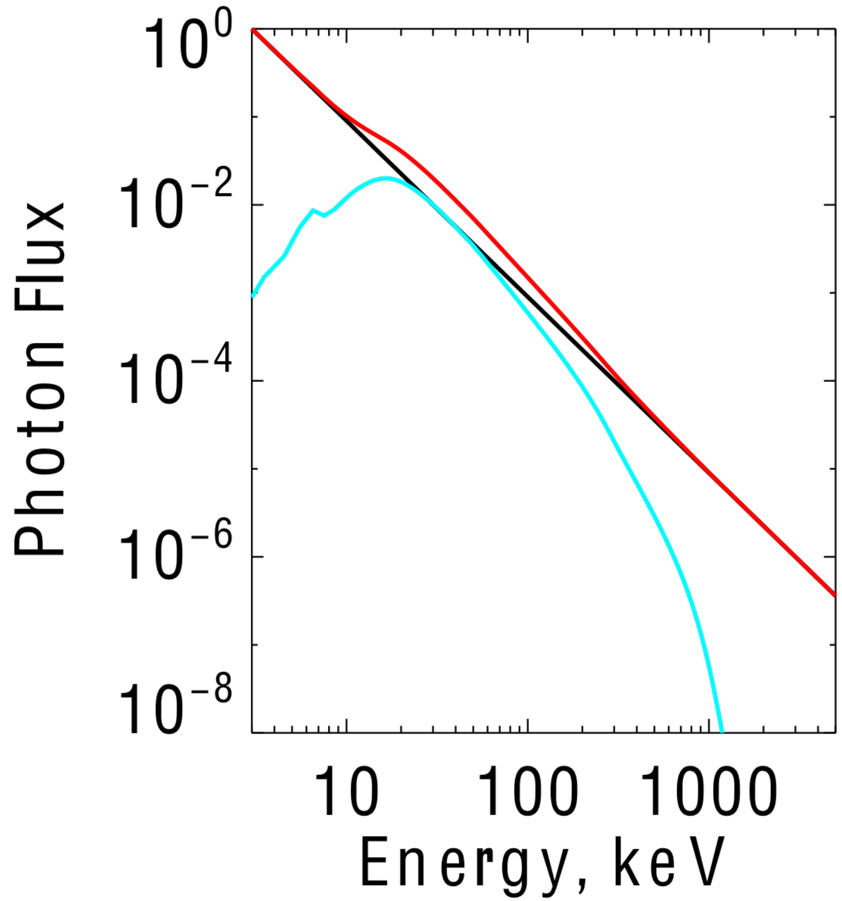
- Observed X-ray spectrum must be related to emitting electron spectrum
- In general electron distribution will varies with angle.
- Many models assume strong downward beaming.
- However in when determining the electron distribution from observations an isotropic emission is assumed.

$$I(\epsilon) = \frac{\bar{n}V}{4\pi R^2}\int_0^{\pi}\int_{\epsilon}^{\infty}\overline{F}(E,\theta)Q(\epsilon,E,\theta)\,dE\,d\theta$$

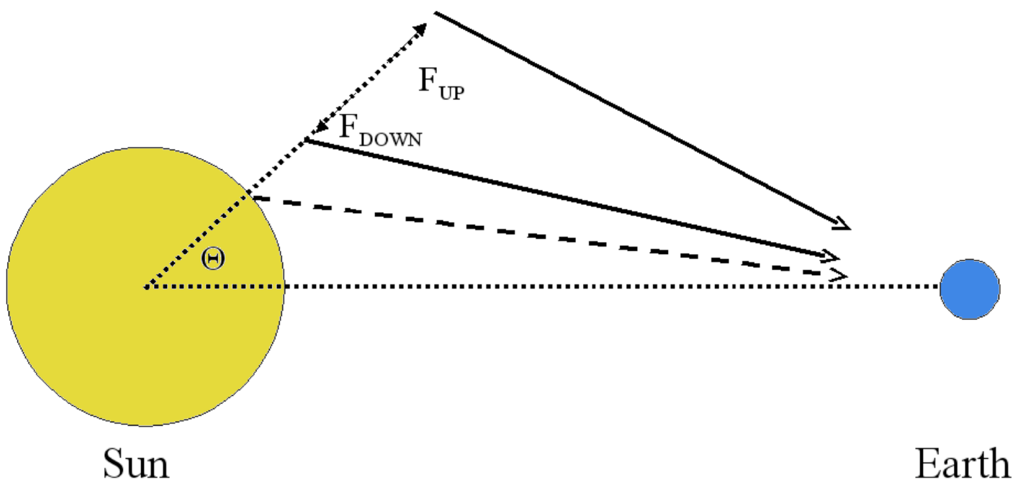


- One technique is to look at the centre to limb variation.
- Disadvantage is that variation can only be seen as an average over a large number of flares.
- More direct approach is the stereoscopic method. The disadvantage of this is the difficulty in cross calibrating, leading to large errors.
- Previous research on this problem suggests that the electron angular distribution is fairly isotropic with some studies showing directivity at higher energies

- Downward travelling X-rays can Compton backscatter low in the solar atmosphere and be observed at Earth.
- Albedo distorts primary X-ray spectrum.
- This effect will vary depending on the fraction of downward to upward going electrons.
- Direct estimate of downward going electrons



Bi-Directional Approximation



$$\overline{Q}(\epsilon, E, \theta_0, \alpha) = \frac{1}{2\pi(1-\cos(\alpha))}\int_{\phi=0}^{2\pi}\int_{\beta=0}^{2\pi} Q(\epsilon, E, \theta')\sin\beta \, d\beta \, d\phi$$

$$\mathbf{I} = \begin{pmatrix} \mathbf{Q^F + AQ^B} & \mathbf{Q^B + AQ^F} \end{pmatrix} \begin{pmatrix} \mathbf{F_U} \\ \mathbf{F_D} \end{pmatrix}$$

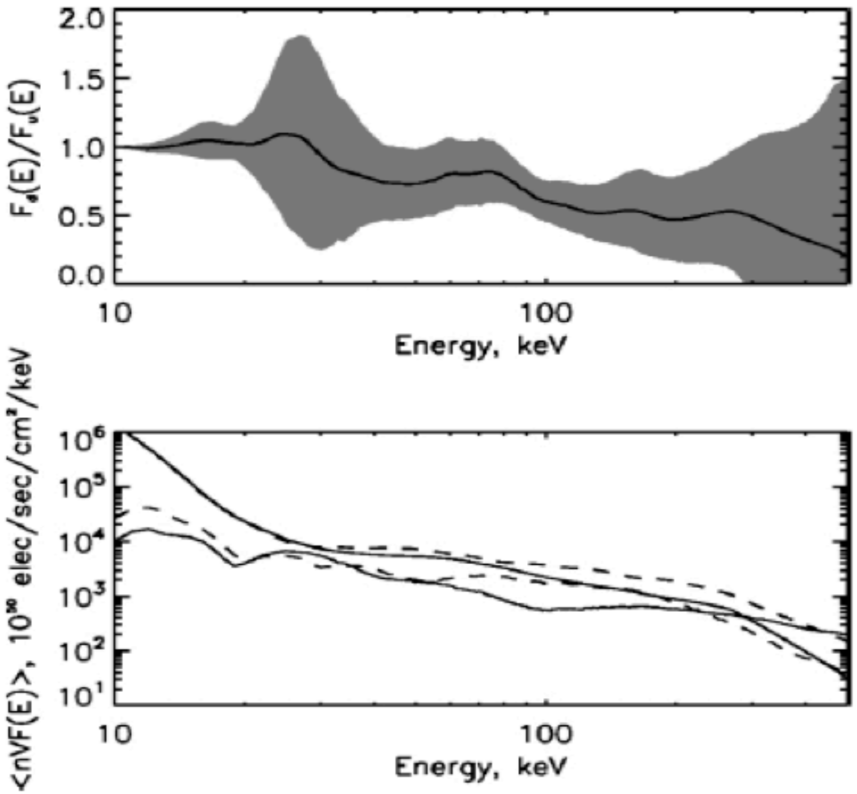
- Divide the electron flux into two components one going up away from the solar centre and one going down towards it.
- Angular dependant cross-section is averaged over two hemispheres
- Can be used to distinguish between highly beamed and isotropic cases.

- Model independent method
- Direct inversion too contaminated by noise
- Use Tikhonov Regularisation
- Constraint is that electron spectrum is differentiable

$$\mathbf{I} = \mathbf{MF}$$

$$\left\|\mathbf{M}\overline{\mathbf{F}} - \mathbf{I}\right\|^2 = \min$$

$$\left\|\mathbf{M}\overline{\mathbf{F}} - \mathbf{I}\right\|^2 + \lambda\left\|\mathbf{LF}\right\|^2 = \min$$



Top : Plot of Anisotropy (Fdown/Fup) against electron energy for flares full impulsive phase of the flare occurring on 20 Aug 2002
Bottom: Confidence bands for the two component electron flux (Kontar and Brown 2006)

- This method was previously employed by Kontar et. Al on 2 fares detected by RHESSI
- Results suggested a distribution consistent with isotropic

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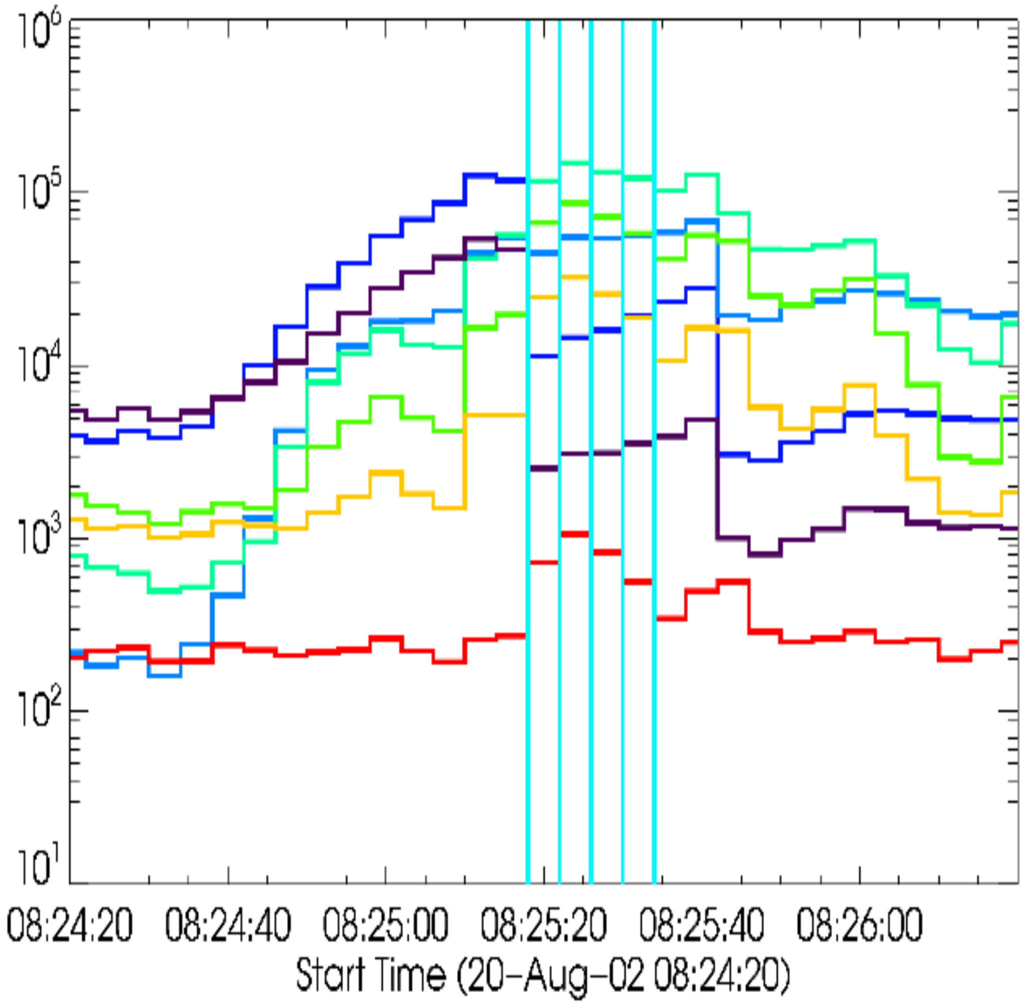
Flare Studied



- Is there any variation in anisotropy over the impulsive phase?
- Suitable flares need good statistics at high energies and be close to disk centre
- Four second time intervals over the impulsive peaks were studied

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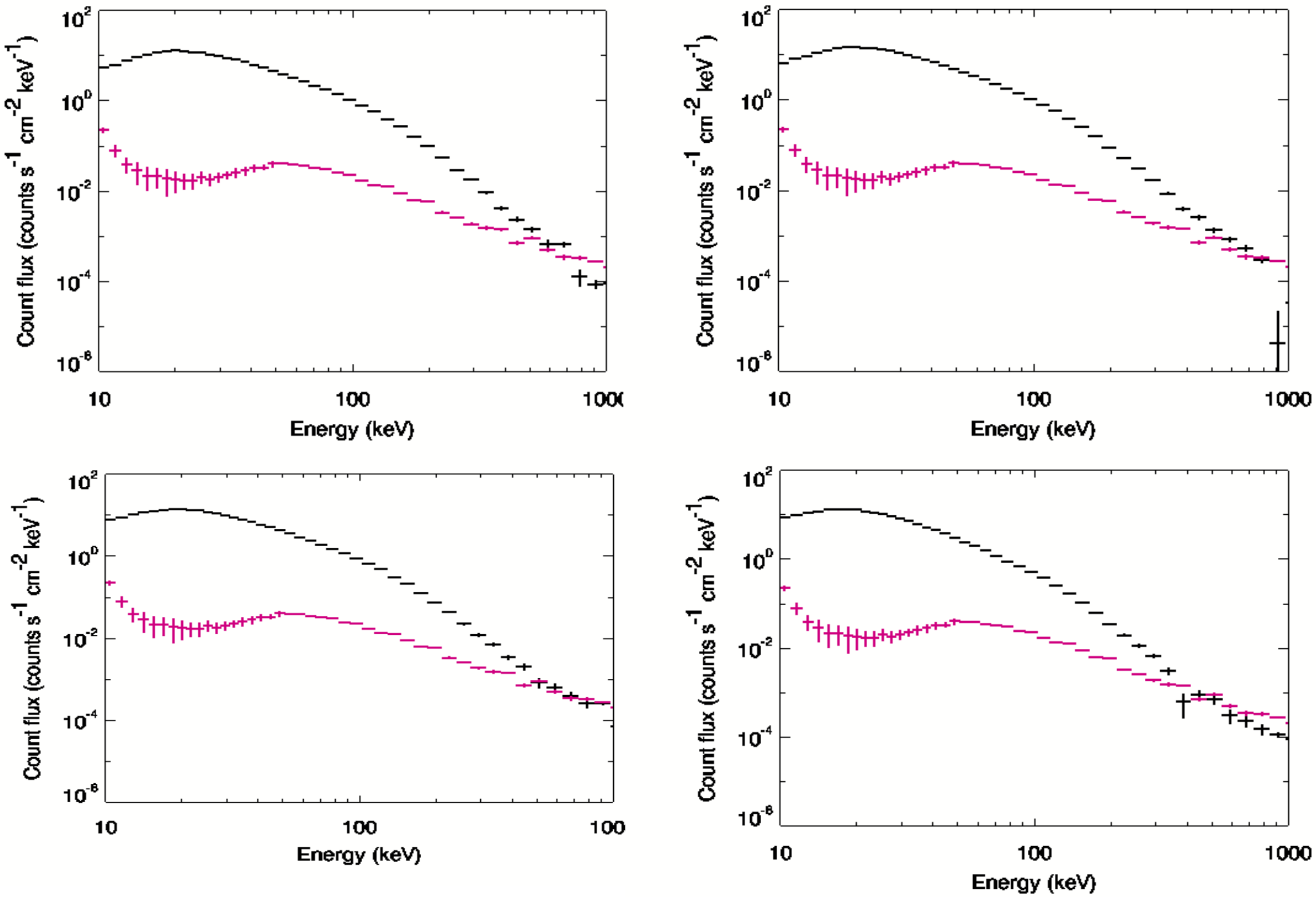
Count Spectra - 20 Aug 02 Flare - 4s Intervals



Plots of Count Flux against energy for each 4 second interval (black) with associated background (magenta)

- Photon counts accumulated over the impulsive phase.
- Pseudo logarithmic energy bins used.
- Energy range used – from 10 keV to maximum where counts are 3 sigma above background

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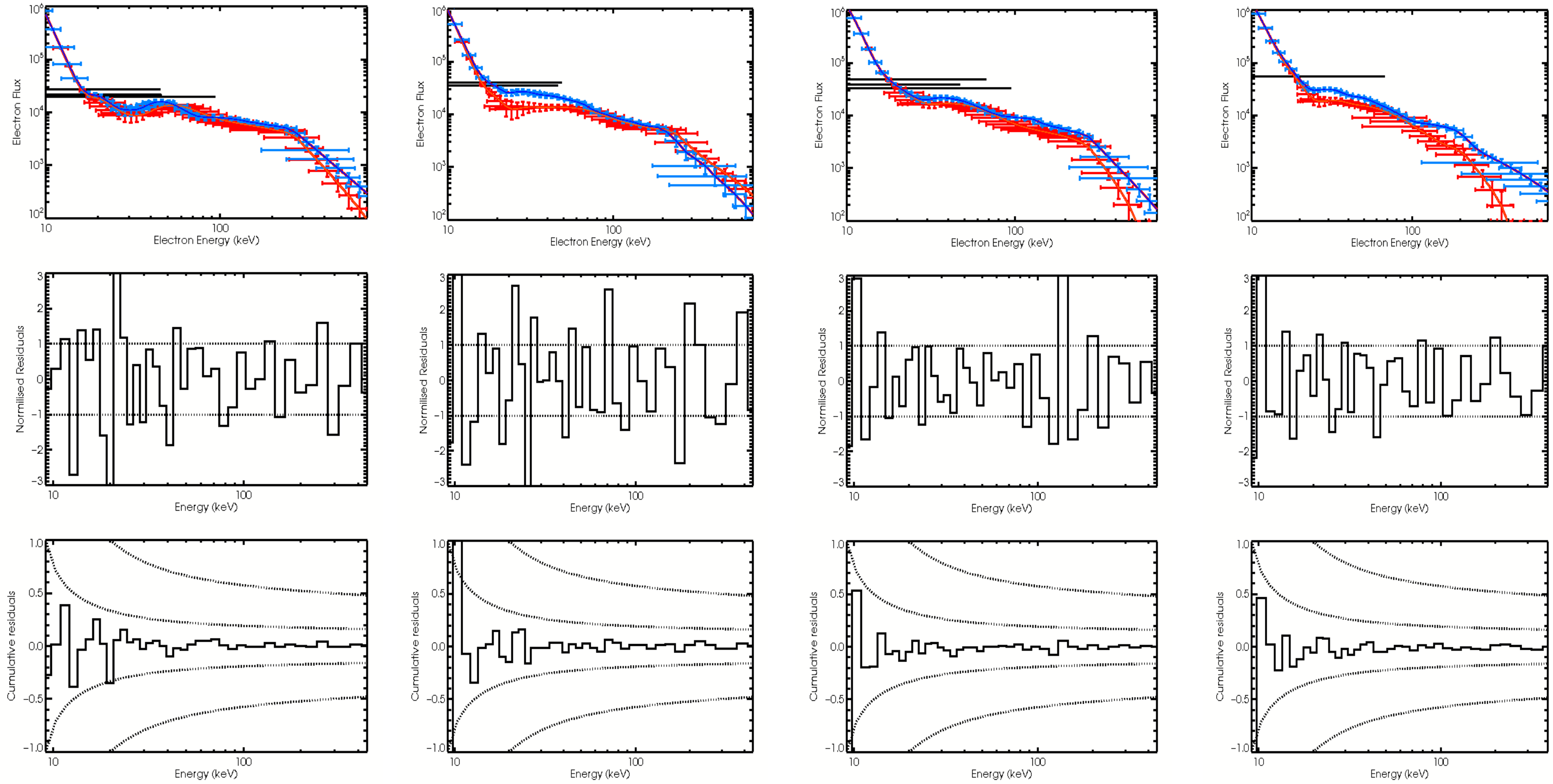
Electron Fluxes - 20 Aug 02 Flare - 4s Intervals

Regularized Inversion performed on count spectra for each time interval to determine 2D Electron spectra

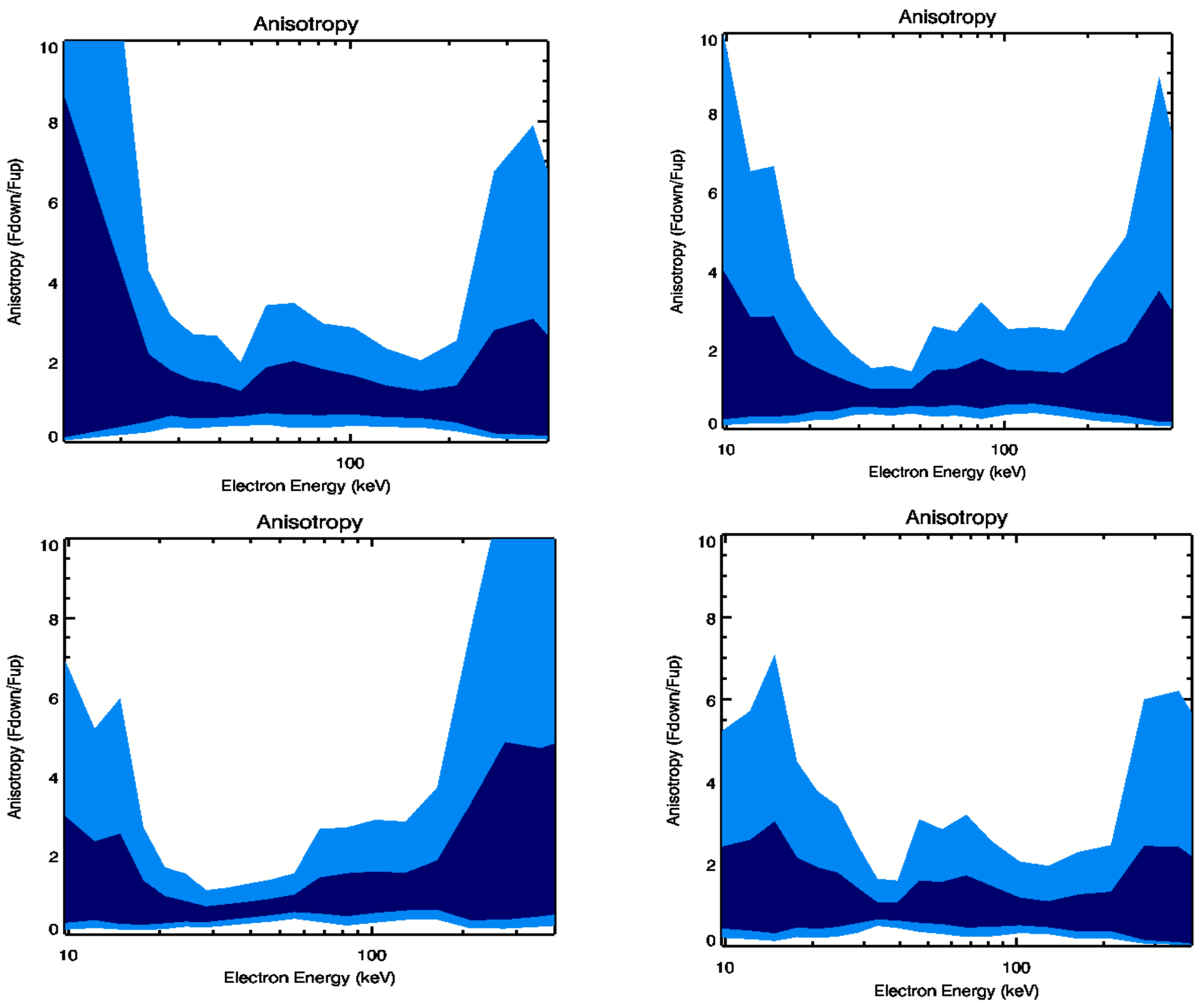
Electron Flux

Normalized Residuals

Cumulative Residuals

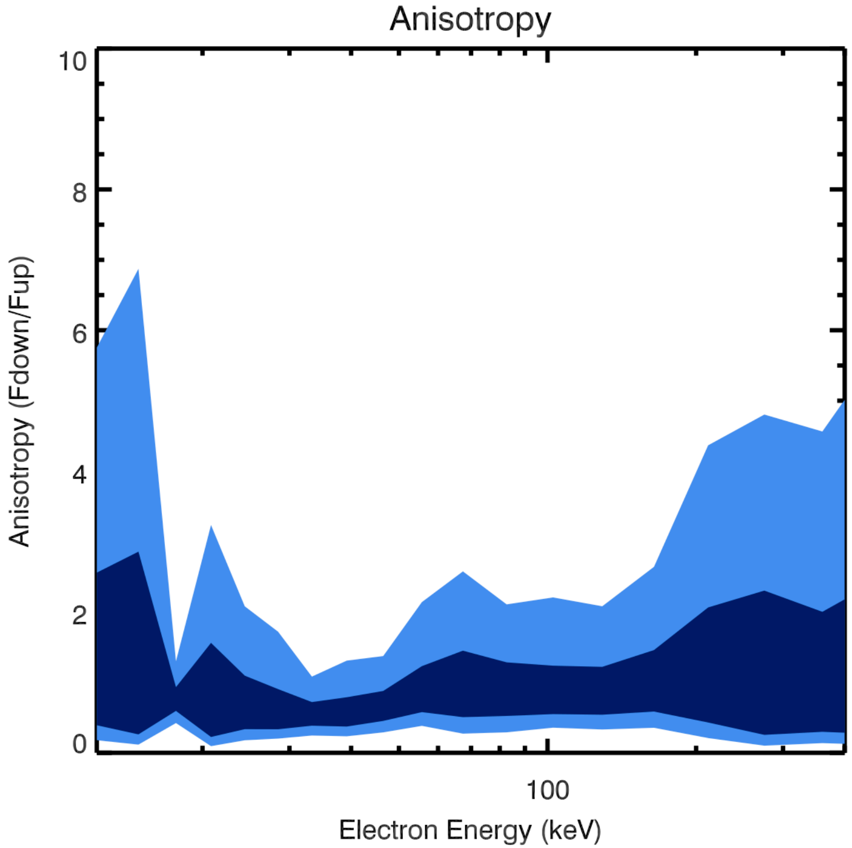


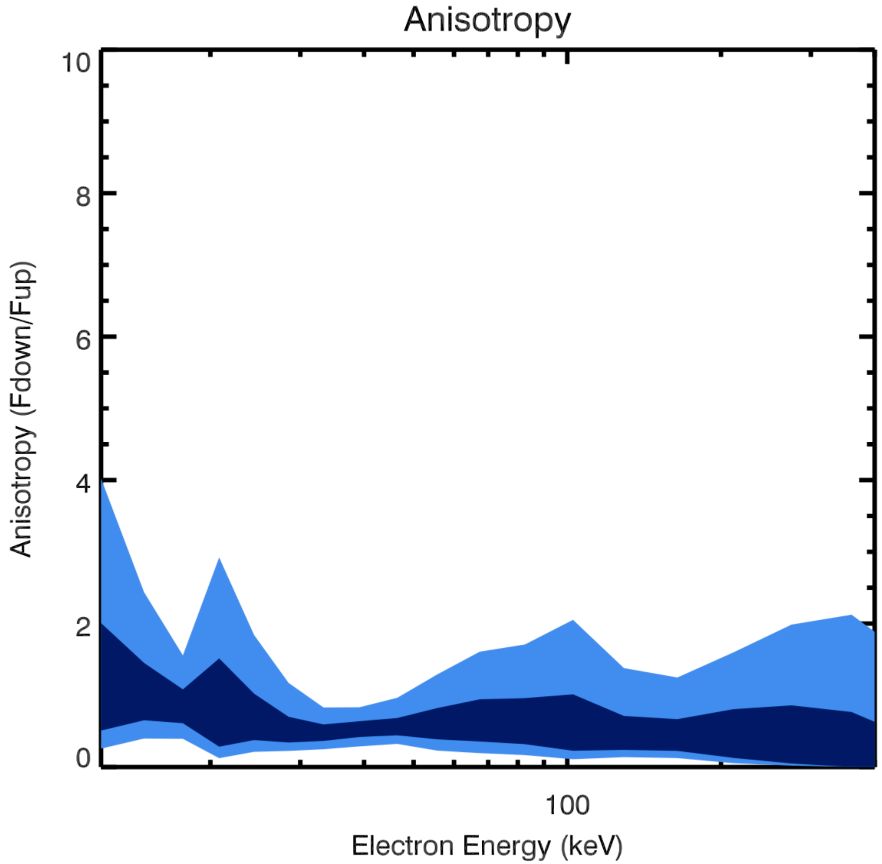
Anisotropy Measurements – 20 Aug 02 Flare - 4s Intervals



Confidence intervals -- Anisotropy (Fdown / Fup) against electron energy calculated using error estimates on electron spectra

Longer Time Intervals





- Longer time intervals give better statistics but changes in anisotropy over shorter timescales wont be apparent.

Conclusions

- This is consistent with studies which suggest that the electron spectrum is isotopic at low energies
- No evidence of variation on 4 second timescales.
- Where counts are strong enough could be possible to measure anisotropy for 2 second time intervals.