The Effect of Photospheric Albedo on Low Energy Cutoffs in Solar Flares

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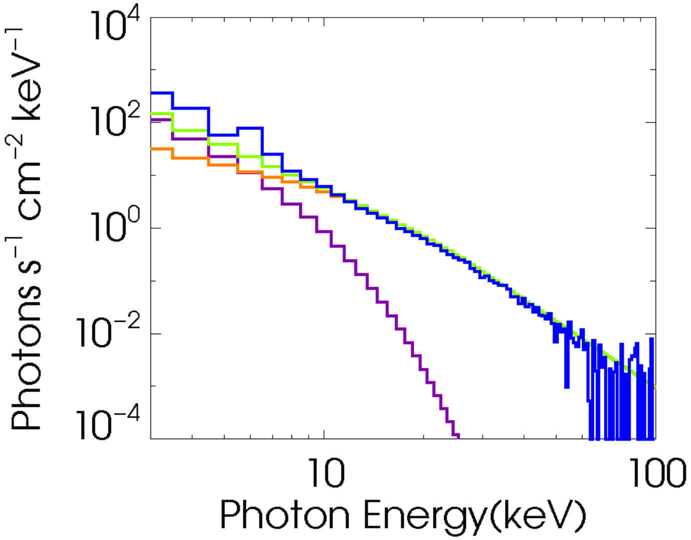
Electron Spectrum

- Observed X-ray spectrum must be converted into electron spectrum
- Common method of performing this inversion is forward fitting

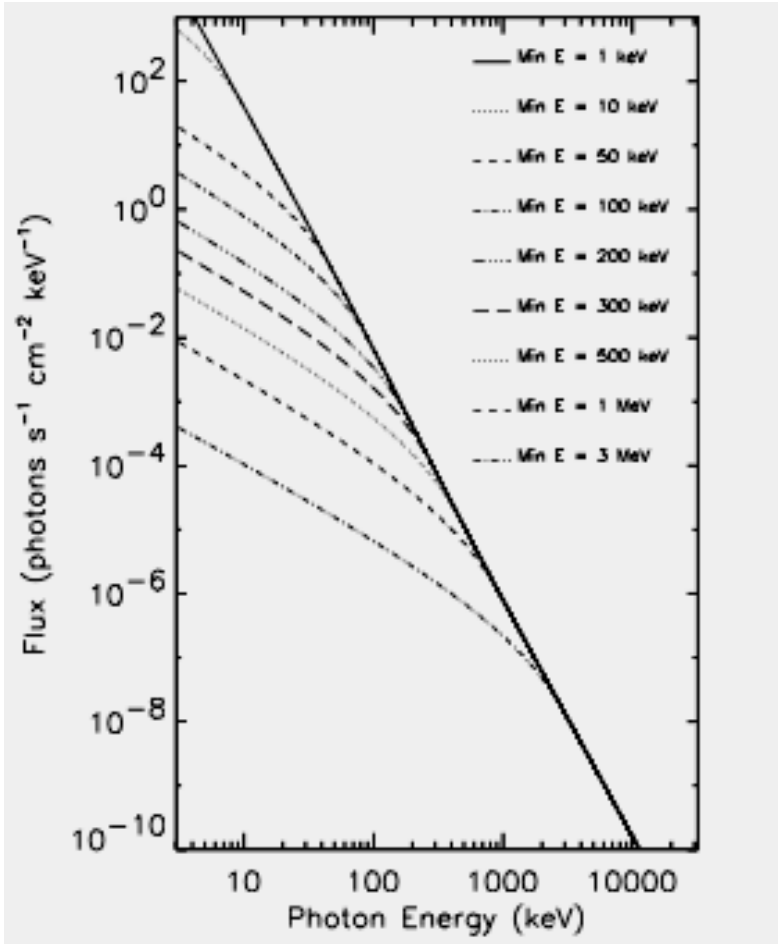
$$I(\varepsilon) = \frac{\bar{n}V}{4\pi R^2} \int_{\varepsilon}^{\infty} \overline{F}(E)Q(\varepsilon,E)\,dE$$



Low Energy Cutoff

- Low energy cutoff can alter photon spectrum
- Majority of energy concentrated at low energy end

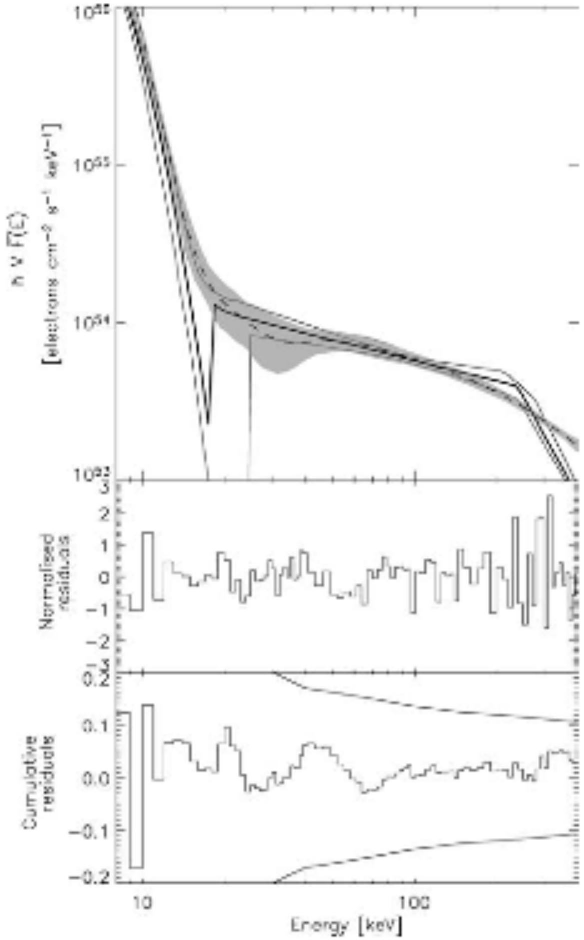
$$W \sim \int_{E_{Min}}^{\infty} F(E) E\, dE$$



Holman (2003)

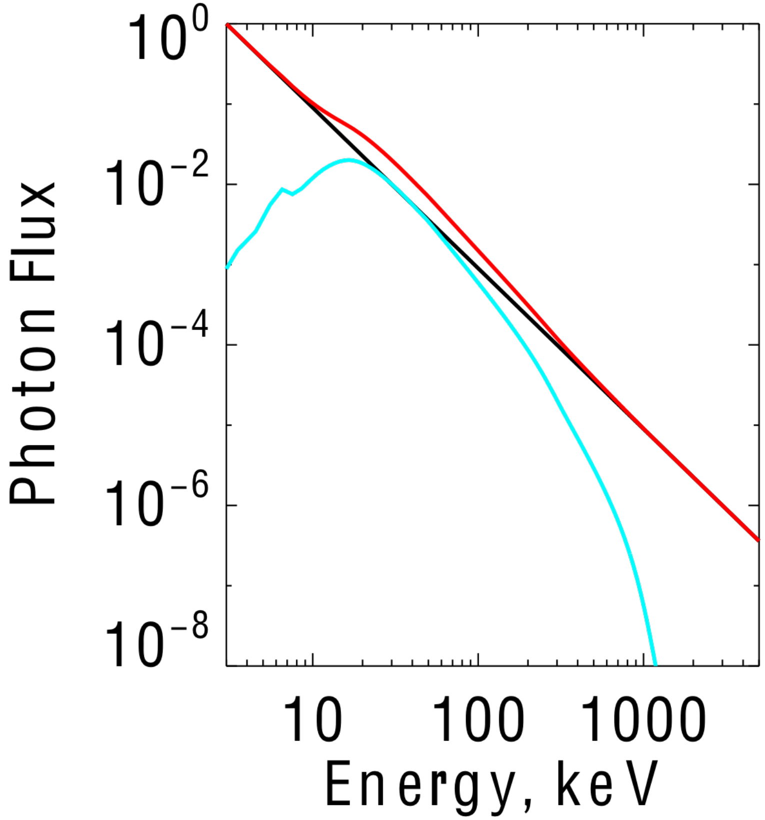
Evidence for Low Energy Cutoff

- Early evidence proposed by Nitta et al. in 1990 using data from the Solar Maximum Mission
- Further evidence given by Farnik et al. in 1997 using Yohkoh
- More produced since then by RHESSI spacecraft (Kašparová et al. 2005)



Albedo

- X-rays emitted towards sun can be Compton scattered back to observer
- Results in a broad hump in reflectivity
- Flattens photon spectrum at low energies and steepens it at high energies



Inversion

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

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

$$\mathbf{A} = \mathbf{R}\mathbf{Q}$$

$$Q_{ij} = \frac{\overline{n}V}{4\pi R^2} Q\left(\left(\varepsilon_{i+1} + \varepsilon_i \right)/2, \left(E_{j+1} + E_j \right)/2 \right)$$

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

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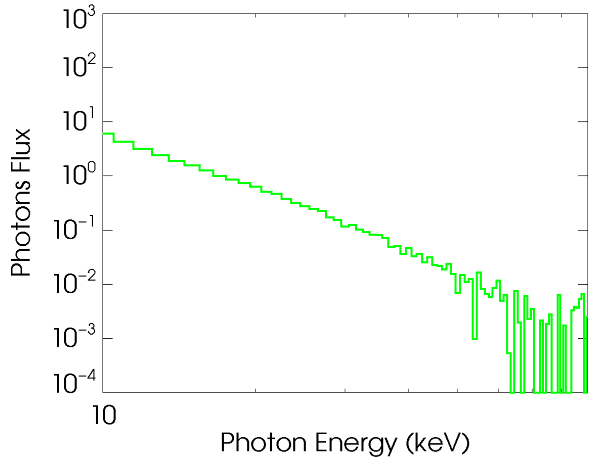
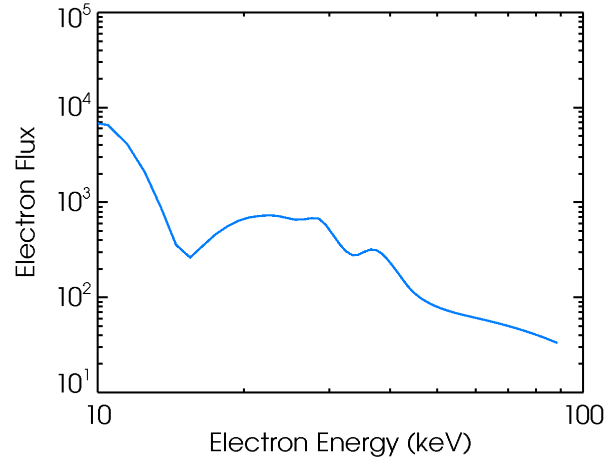
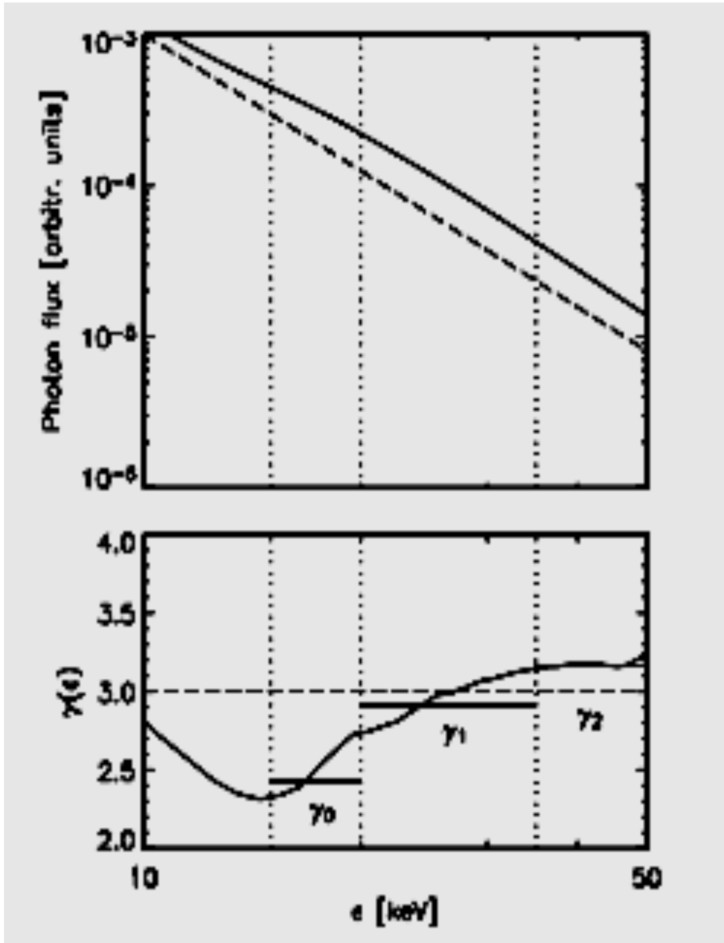




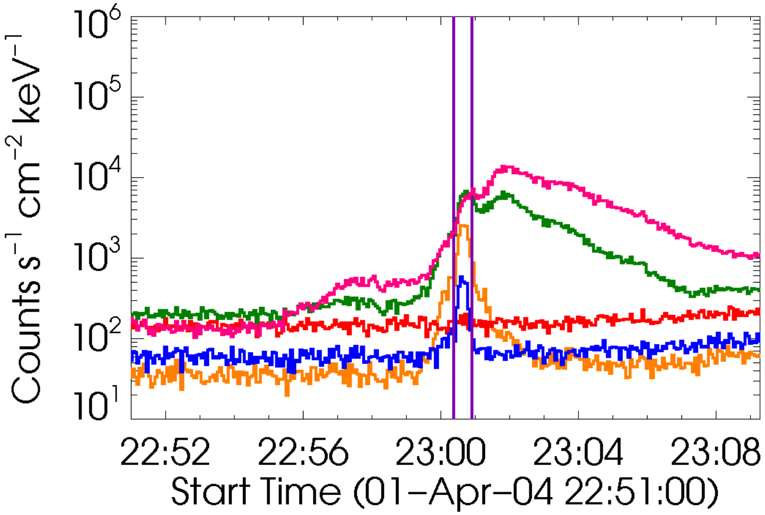
Flare List

- List of 398 flares compiled by Kašparová et al. (2007)
- Weak thermal component
- Pulse pileup and particle contamination avoided
- List further reduced by taking only flares with $\gamma_0 < 4$



Kašparová, Kontar and Brown (2007)

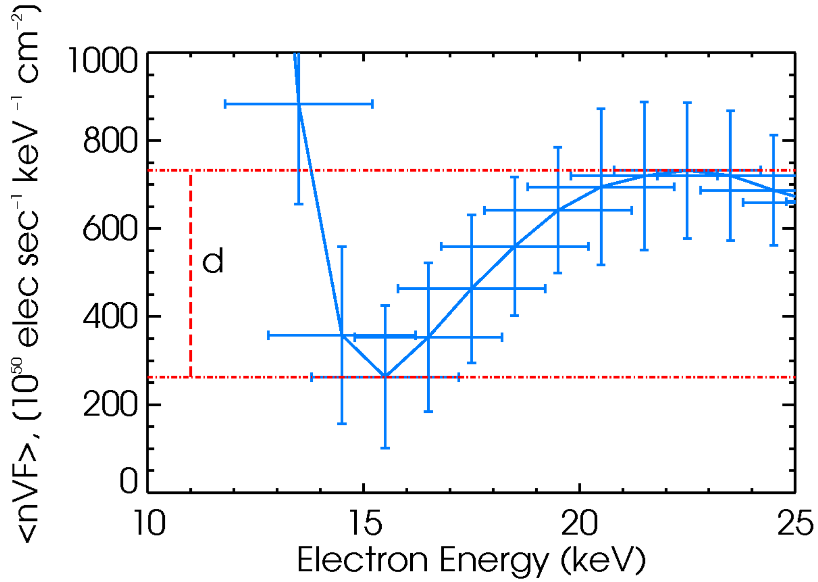
Method



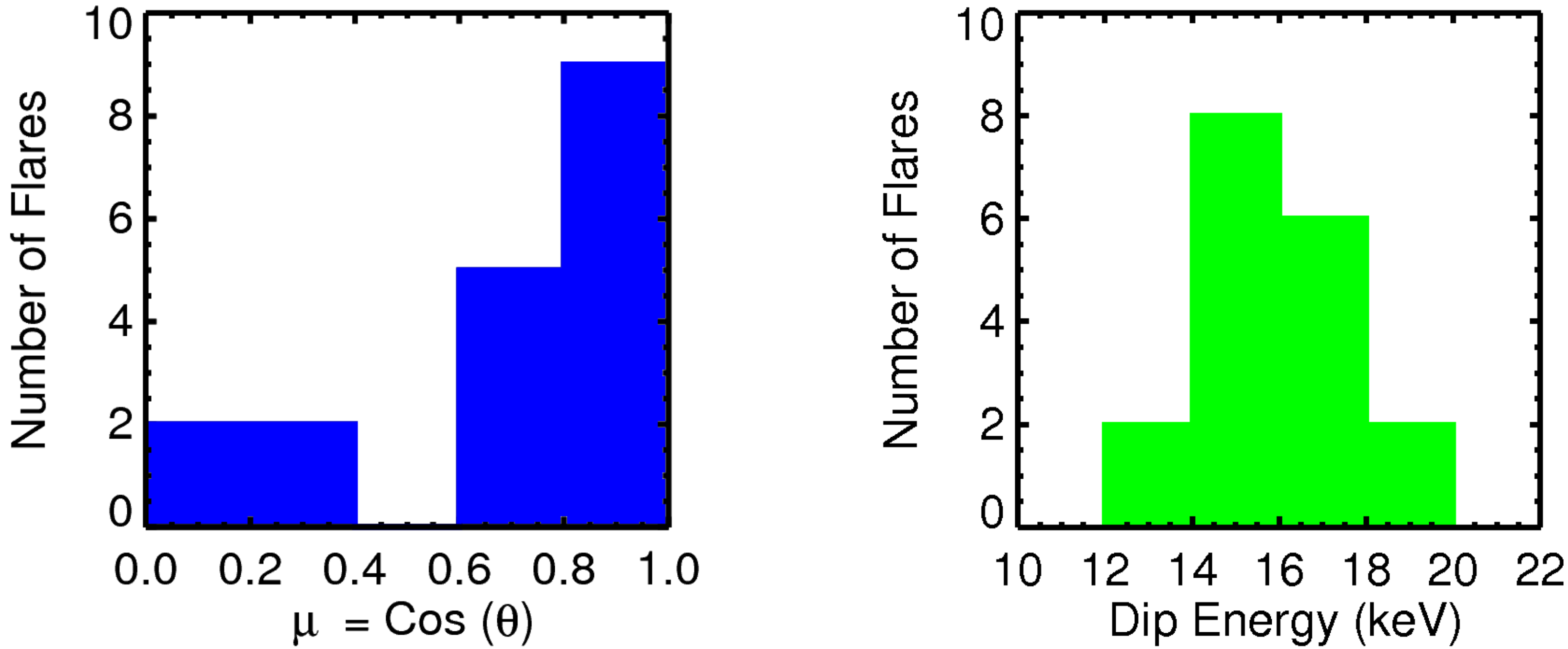
- Photon counts accumulated over the impulsive phase
- 1 keV energy bins
- Range 3 – 100 keV
- Inversion performed on count spectra of each of the flares
- Electron spectra examined for dips

Results – dips

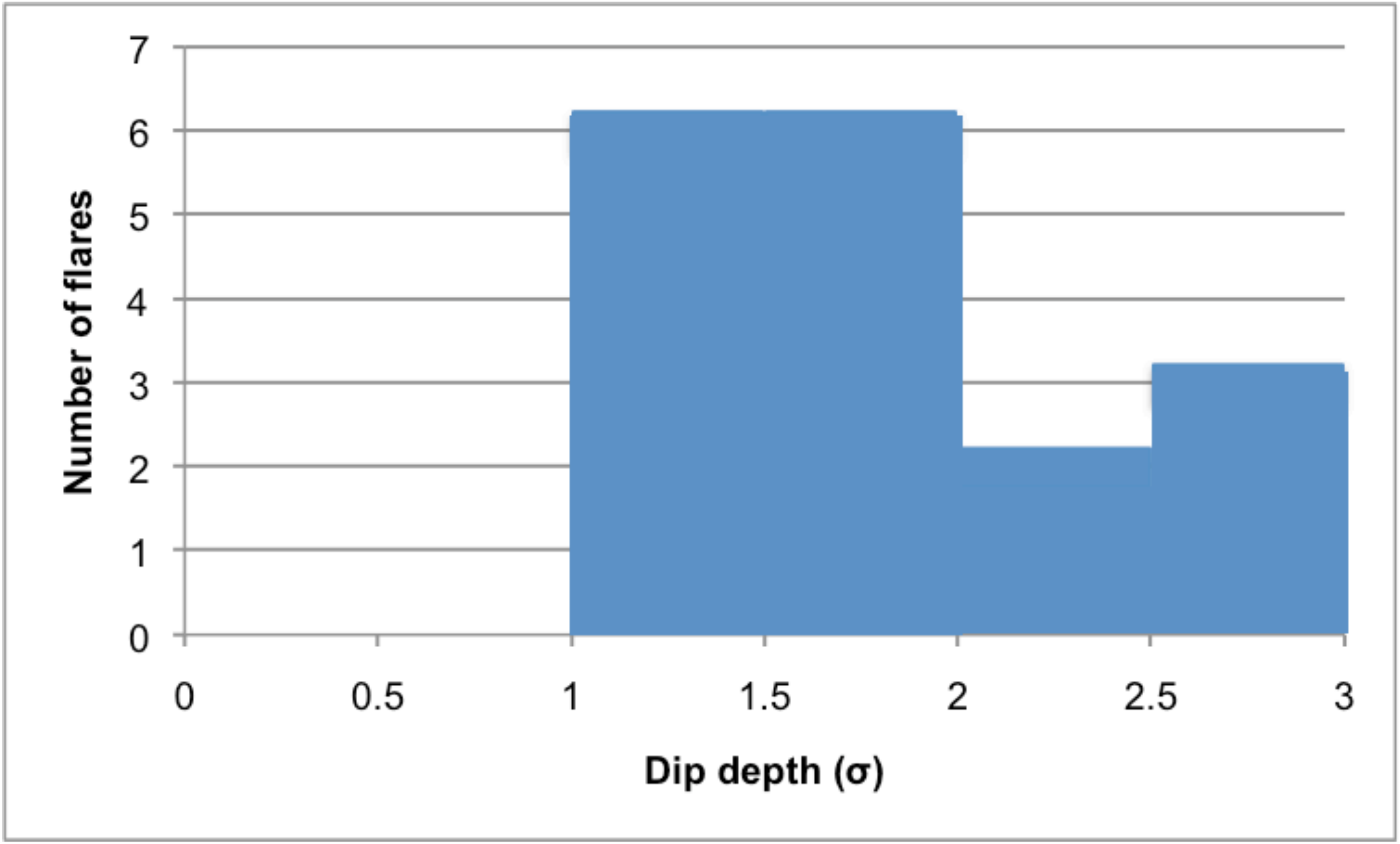
- Out of 177 flares 18 were found with statistically significant dips
- The depths of each dip and the energy at which the minimum occurs were determined for each flare



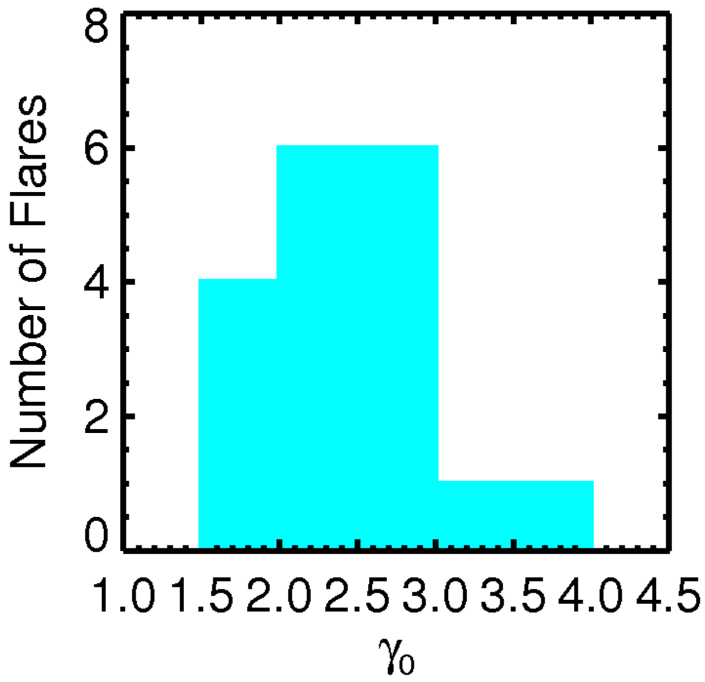
Graphs of μ and dip minimum energy

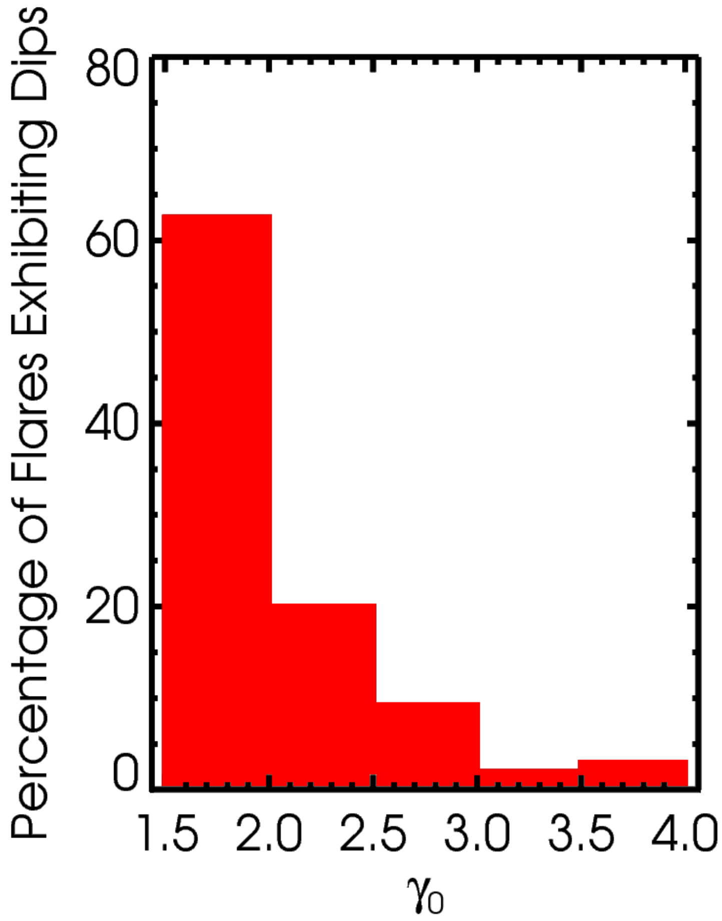


Graph of dip depth



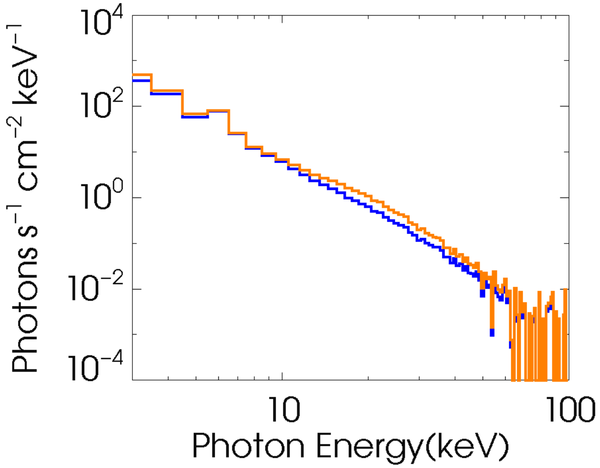
Spectral Index plots

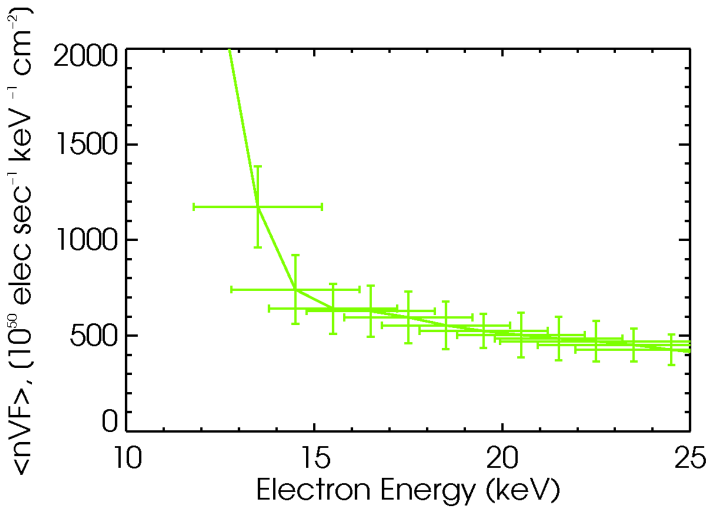




Albedo Correction

- In order to assess the effect of albedo a correction must be applied to estimate the primary spectrum
- This is then inverted in the same manner as the observed spectrum





Conclusions

- All dips were consistent with the albedo model
- Correction removes dips from electron spectrum in all flares studied
- Value of dip energy consistent with albedo
- If low energy cutoff exists it must be deeper into thermal component $\lesssim 12$ keV