

Uses of solar hard X-rays

- Basics of observations
- Hard X-rays at flare onset
- The event of April 18, 2001
- Conclusions

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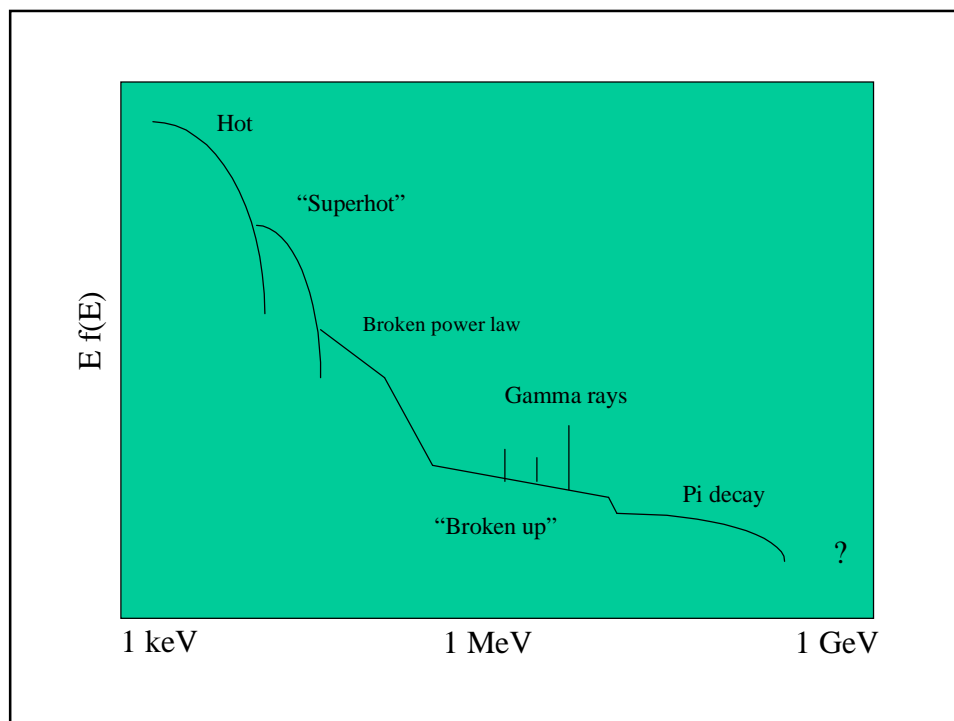
ITP Santa Barbara, Jan. 18, 2002

Hard X-ray basics

- Hard X-rays come from bremsstrahlung
- Bremsstrahlung is inefficient, and electrons >20 keV dominate flare energetics
- Flare hard X-rays normally follow the Neupert effect
- Footpoints (often double) are prominent

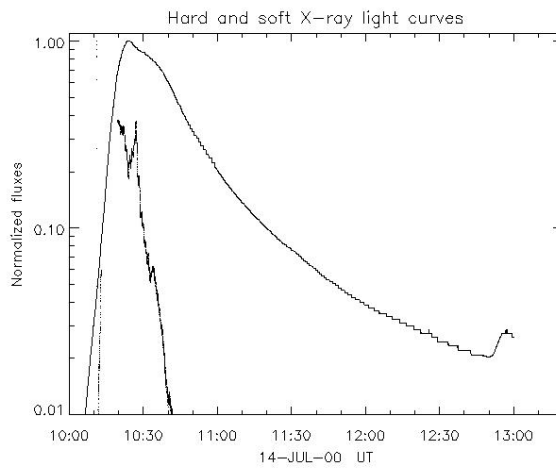
Basics II

- Spectra look like power laws (may be broken)
- Impulsive-phase hard X-rays follow the Soft-hard-soft pattern
- Protons > 10 MeV now appear to resemble electrons > 20 keV energetically
- Also see “superhot” hard X-rays

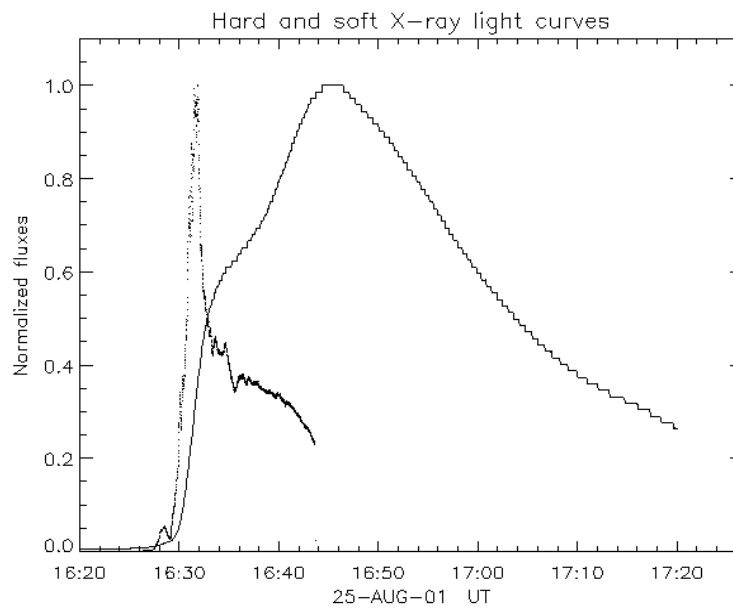


Neupert effect I

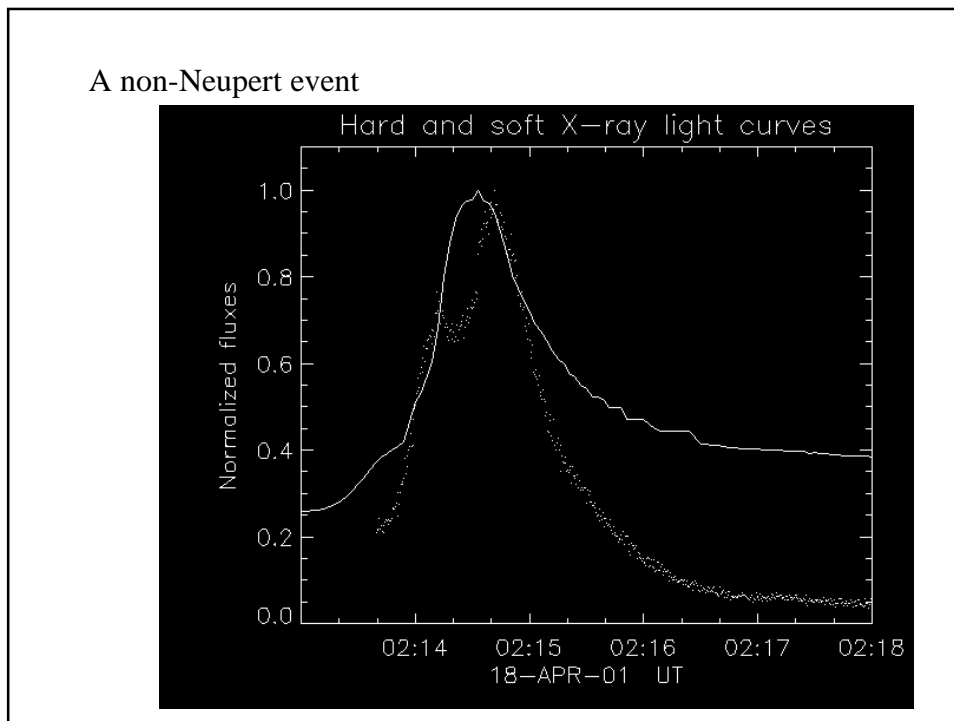
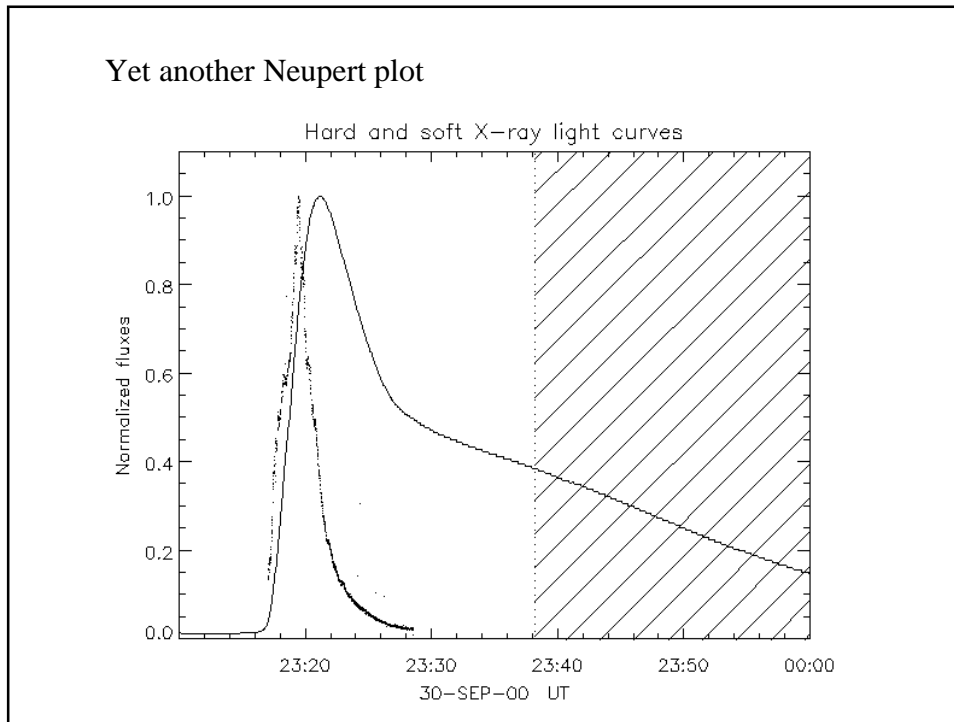
Standard Neupert plot for the Bastille Day 2000 flare



Another Neupert plot



Energetic particles HXR emission as a diagnostic for energy release

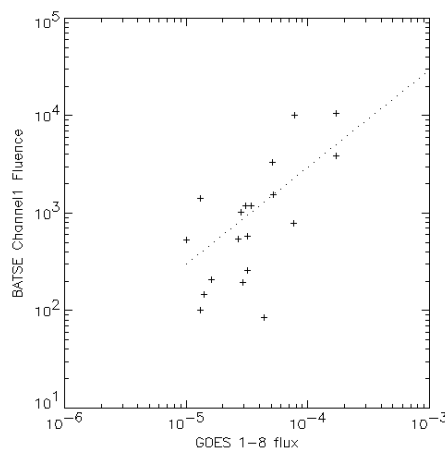


Conclusion

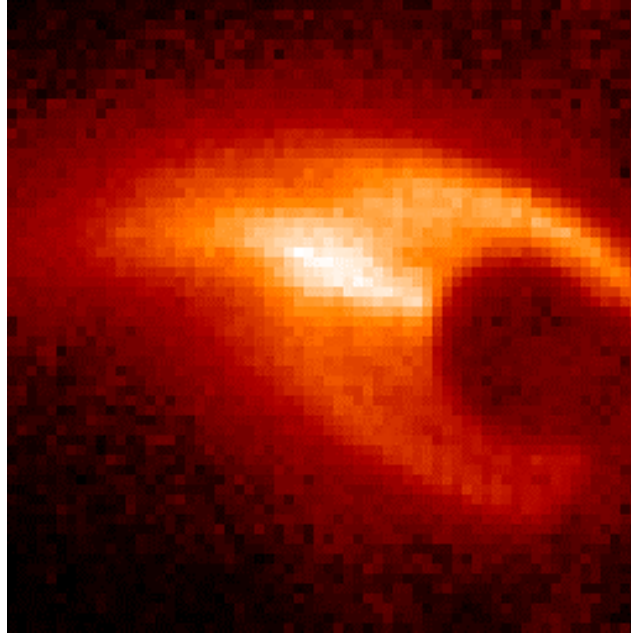
Energy release in the impulsive phase coincides temporally with a distorted electron distribution function.

Neupert Effect - II

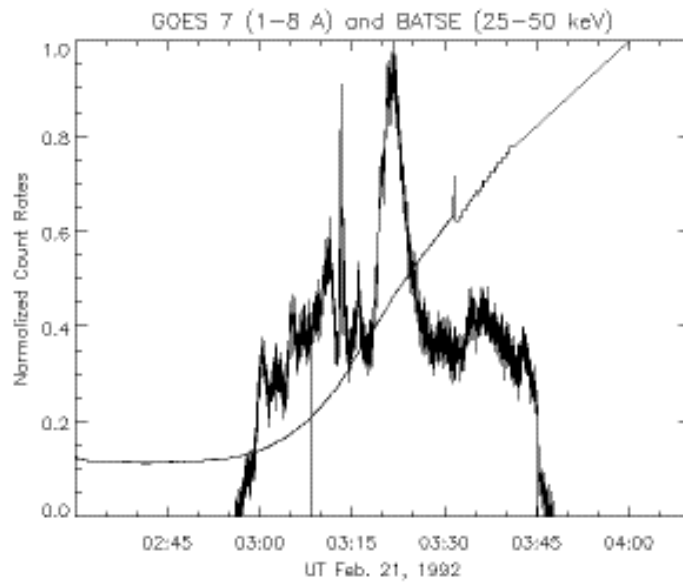
- Correlation plot for hard X-ray and soft X-ray peak fluxes, done for "slow LDEs"



A typical slow LDE, the “candle flame” flare (21-Feb-92)



Feb. 21 has a long “impulsive” phase - the Neupert effect



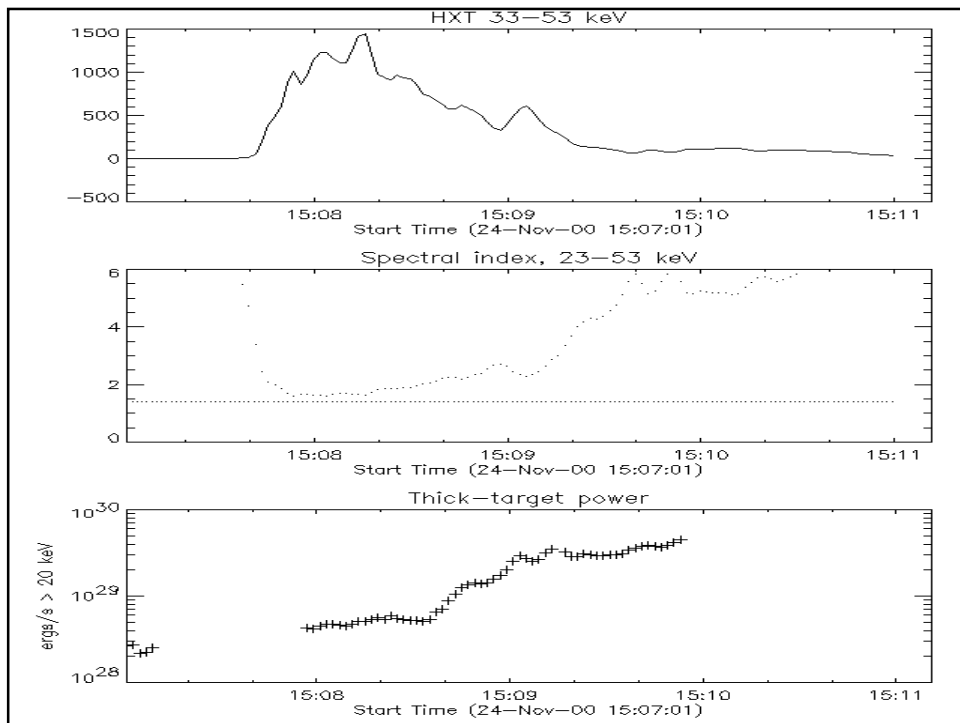
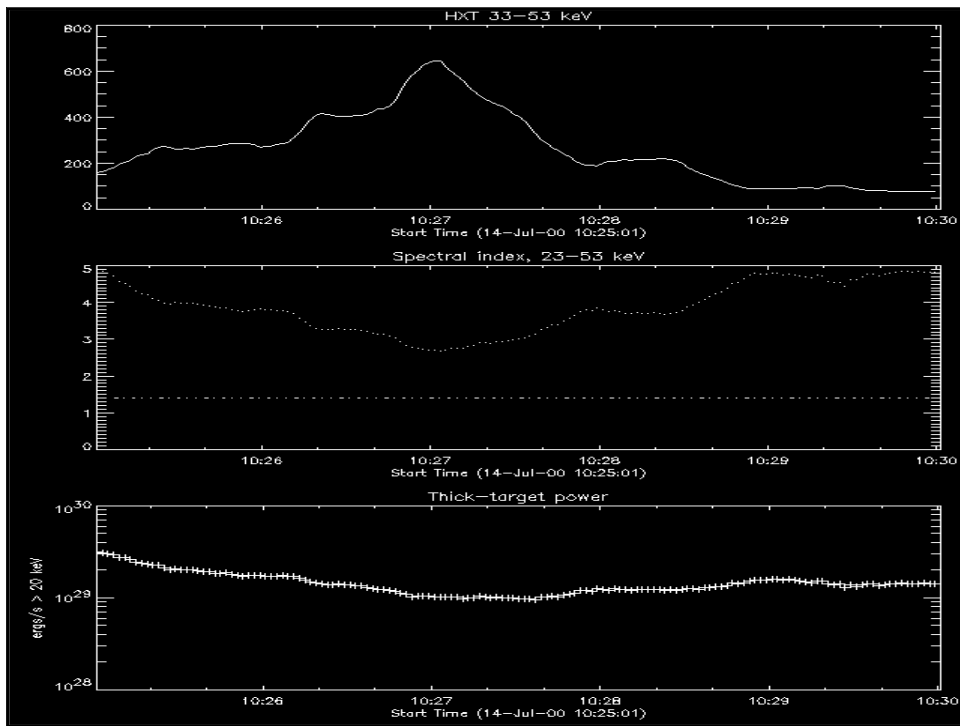
Conclusion

The “impulsive phase” non-thermal effects occur in flares of all sizes and time scales.

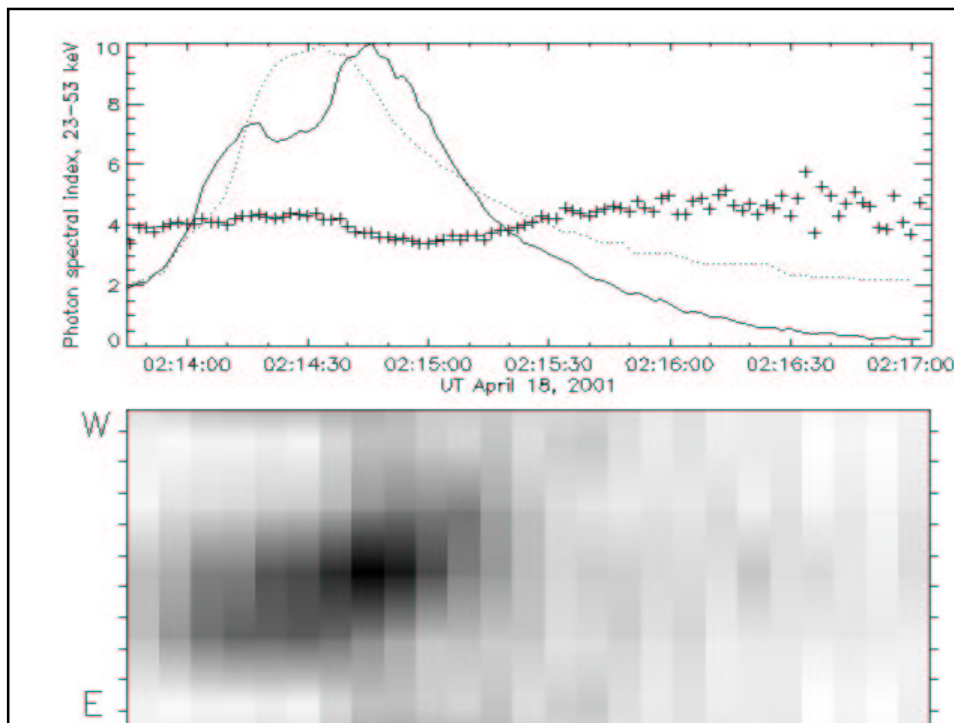
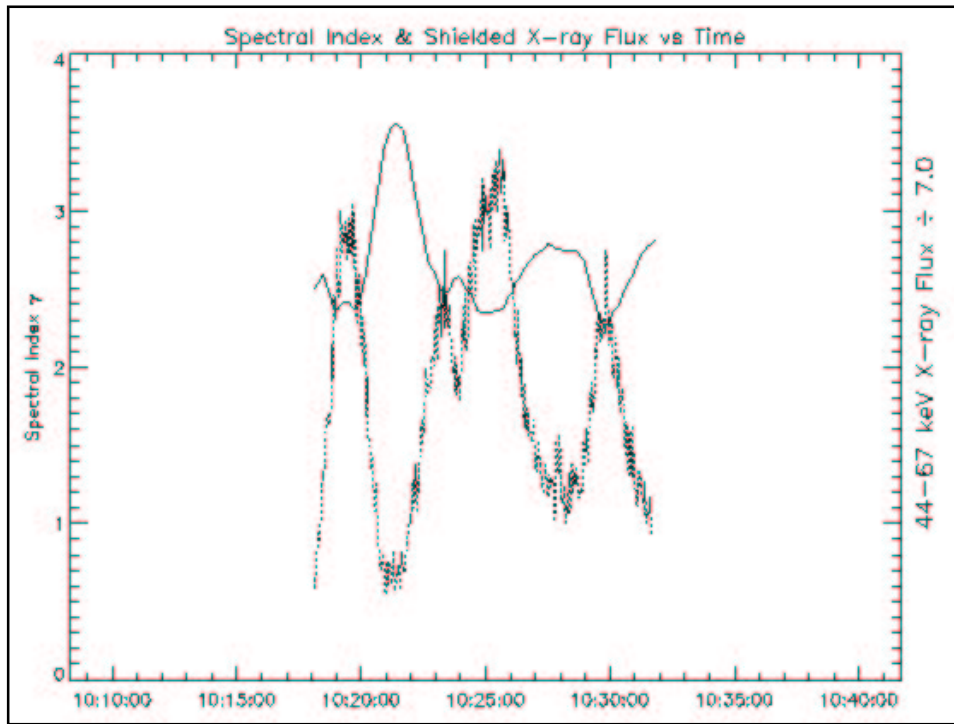
Soft-hard-soft

- The hard X-ray spectrum correlates strongly with the flux
- Here are three examples
- Plus a counterexample

Energetic particles HXR emission as a diagnostic for energy release



Energetic particles HXR emission as a diagnostic for energy release



Conclusion

Soft-hard-soft spectral evolution is something fundamental that is modelable, but which has not yet been modeled.

Hard X-rays during flare onset

- "Heating" implies a distortion of the velocity distribution function
- Case study of September 24, 2001
- Case study of October 16, 2000
- Kappa distributions and a comment about Dzifcakova-Kulinova paper (Solar Physics 203, 53, 2001)

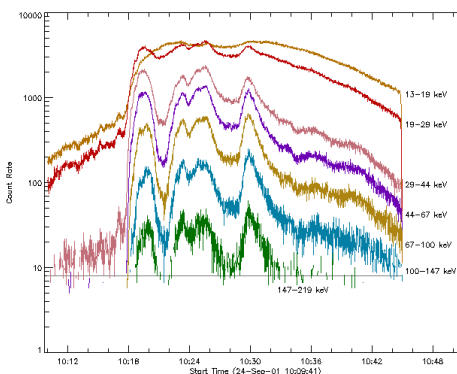
The kappa distribution (Vasiliunas?) - a typical empirical representation of particle spectra in the heliosphere; a generalized Lorentzian

$$f(v) \sim \left[1 + \frac{v^2}{\kappa v_e^2}\right]^{-\kappa-1}$$

$$\lim(\kappa \rightarrow \infty) \left[1 + \frac{v^2}{\kappa v_e^2}\right]^{-\kappa-1} = \exp(-v^2/v_e^2)$$

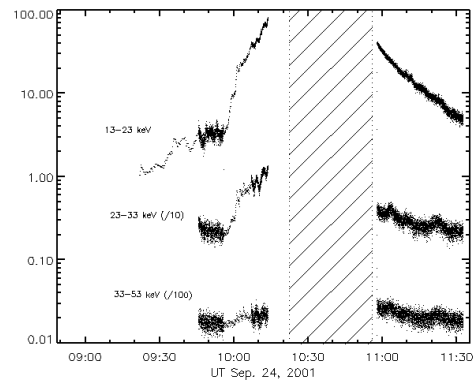
September 24, 2001

- A nice flare was found by the Czech hard X-ray instrument on the MTI spacecraft

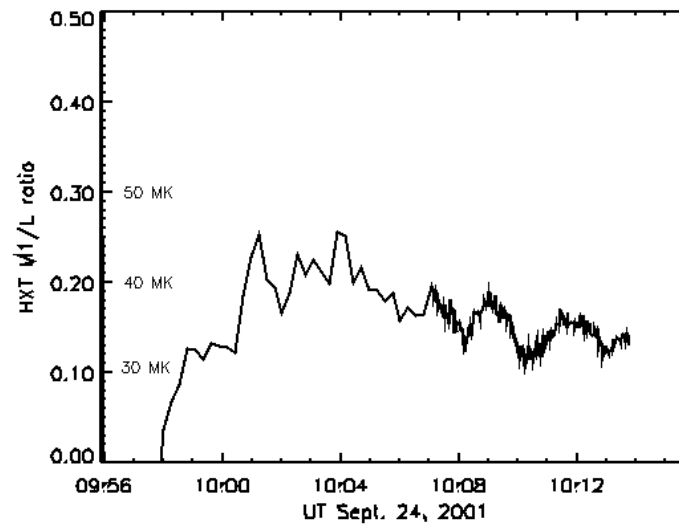


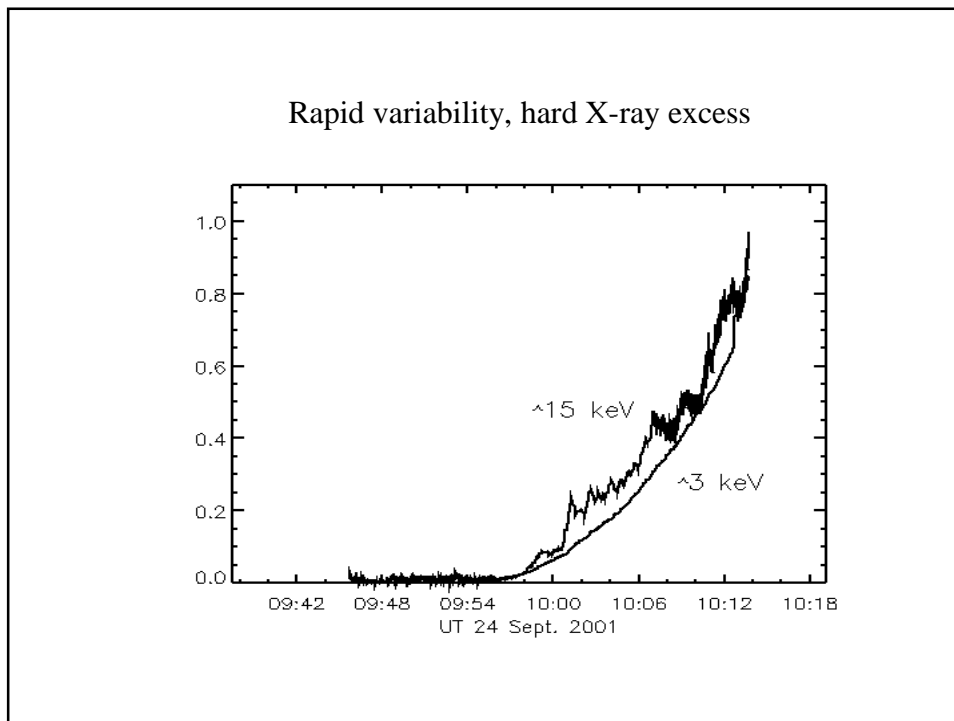
September 24, 2001

- HXT observed a rapidly-variable source with a soft spectrum at the onset phase



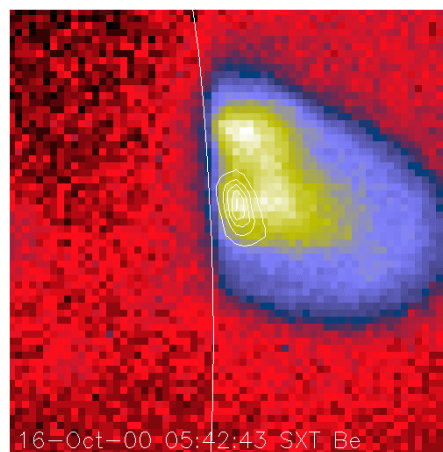
“Superhot” temperatures

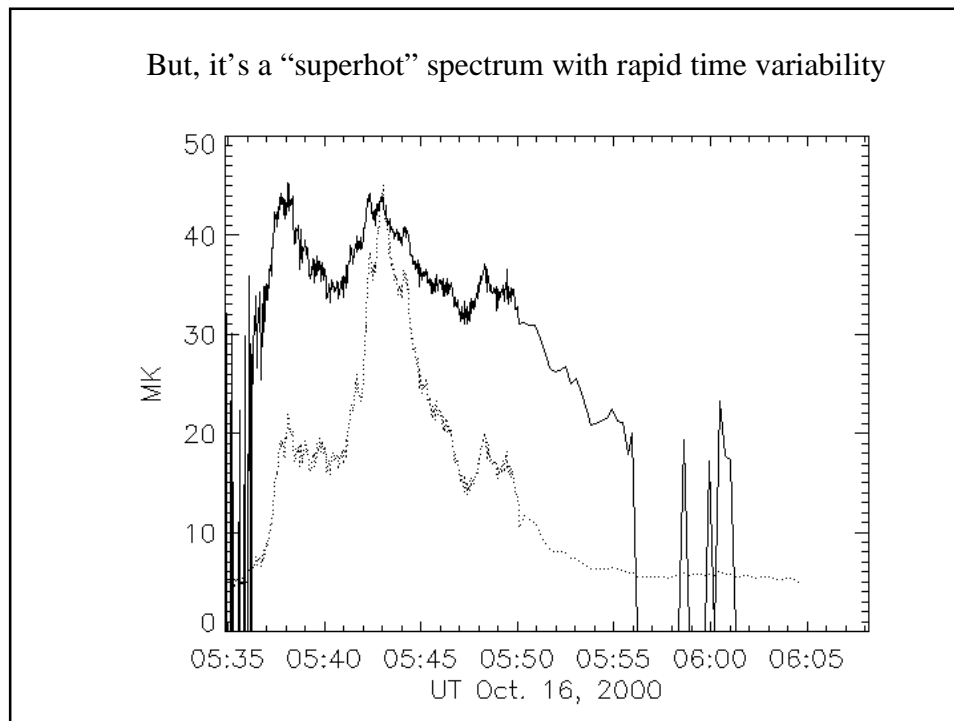




October 16, 2000

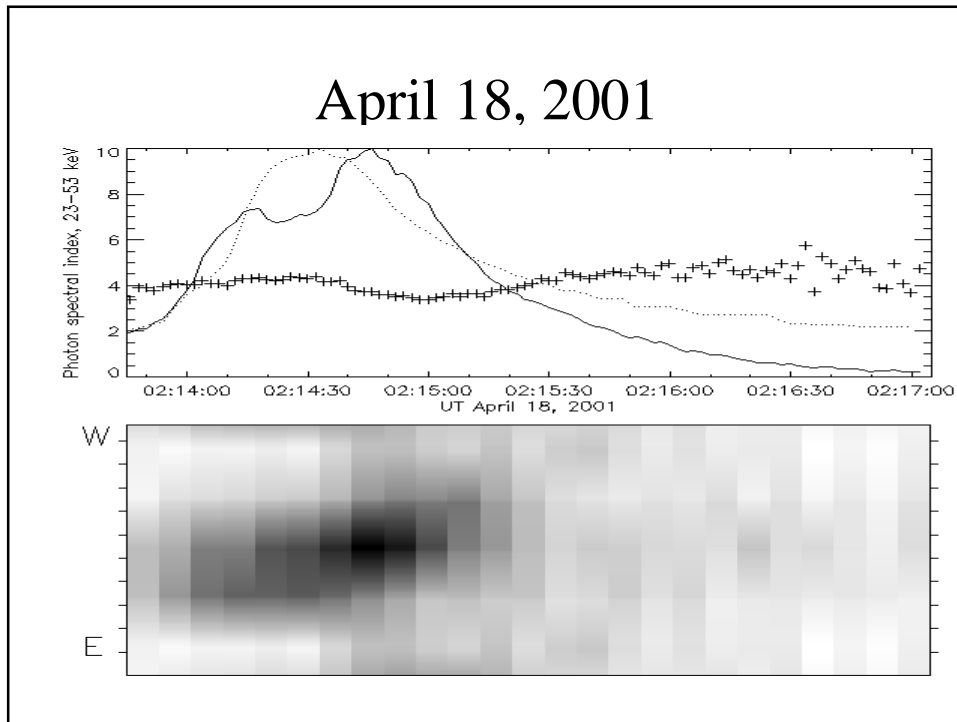
- An over-the-limb flare with similar spectral properties





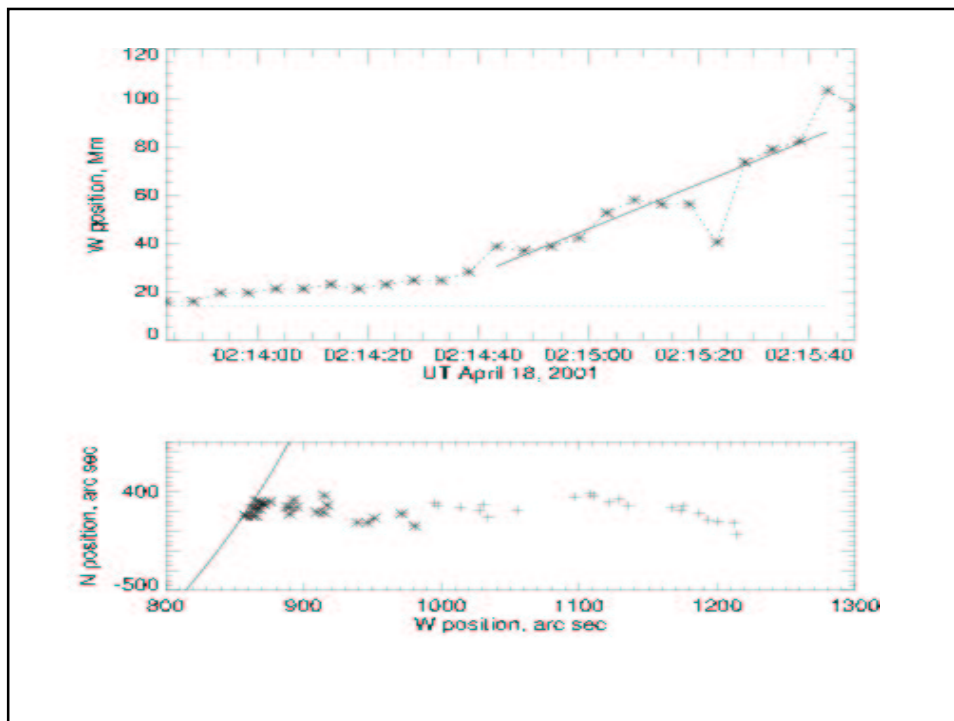
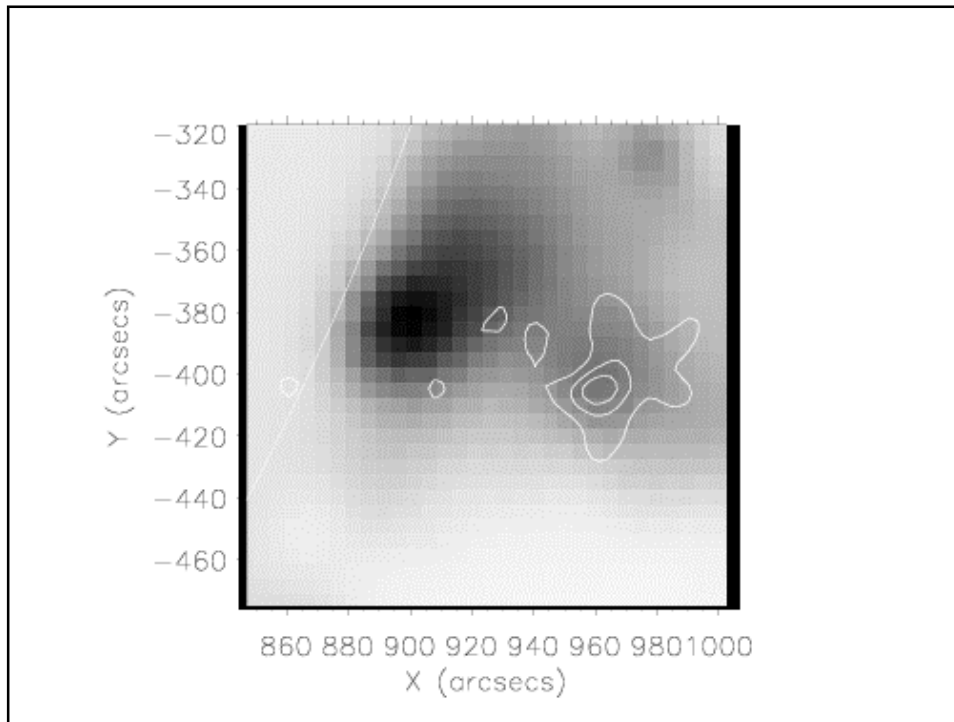
Conclusion

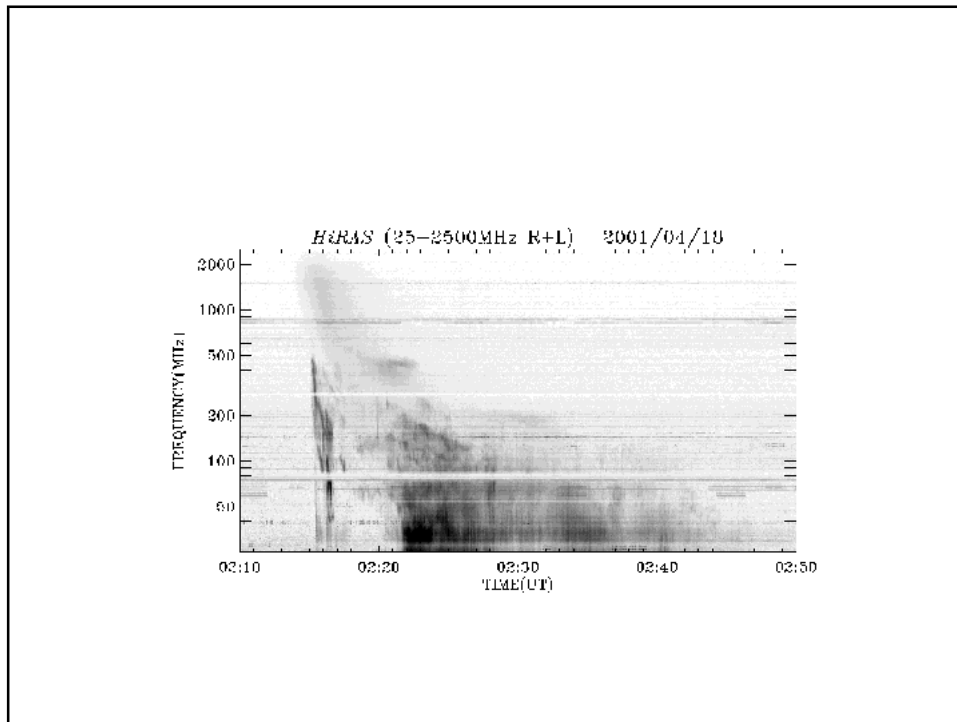
There are strong suggestions that the basic physics of pre-flare excitation is not "heating," but rather particle acceleration



Movies

Energetic particles HXR emission as a diagnostic for energy release





Significance of April 18

- The hard X-rays in the April 18 event reveal fast electrons entrained in an expanding CME structure
- The electrons require *in-situ* acceleration
- These particles are energetically important
- They may also be *dynamically* important

Conclusions

- Non-thermal electrons show particle acceleration with copious energy in the impulsive phase
- “Superhot” hard X-ray spectra may point to the breakdown of the electron distribution function during preflare excitation
- Non-thermal electrons may help drive CMEs