THE NEED FOR HARD X–RAY IMAGING OBSERVATIONS AT THE NEXT SOLAR MAXIMUM

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OUTLINE

1. Canonical Models of Solar Hard X–ray Bursts

2. Associated Length and Time Scales

3. Previous Observations – their adequacies and inadequacies

4. Theoretical Modeling – Predictions to be tested

5. What Can be Learned from Arc–second Imaging of Solar Hard X–Rays

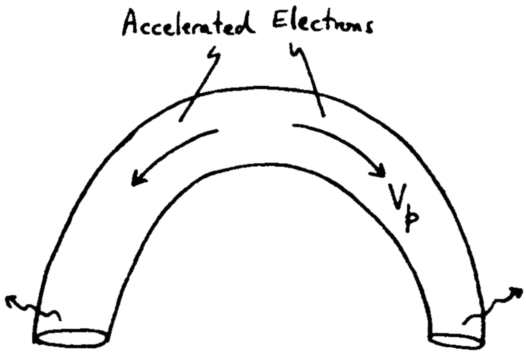
    a. Location of Energy Release Site

    b. Nature of Aceeleration/Heating Mechanism

    c. Nature of Transport Processes.

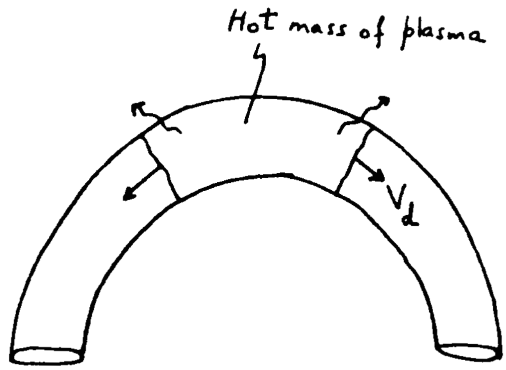
CANONICAL (SPELT "GROSSLY OVERSIMPLIFIED") MODELS OF SOLAR HARD X–RAY BURSTS

"Non–Thermal"



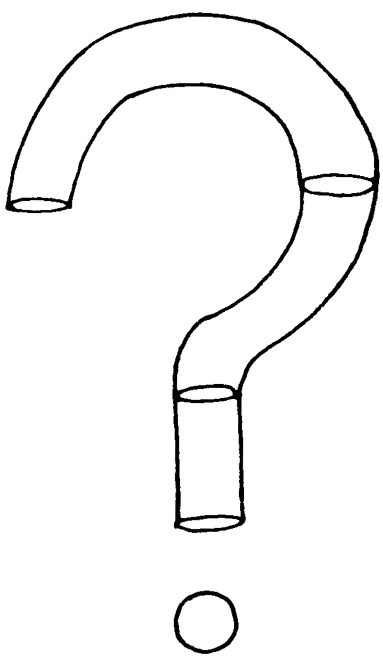
$V_p \simeq 10^{10}$ cm s^{-1}

"Thermal"



$V_d \simeq 10^{8}$ cm s^{-1}

REAL MODEL OF SOLAR HARD X–RAY BURSTS



LENGTH AND TIME SCALES

(1) **Non–Thermal Model**

- Electron travel time $\simeq$ 0.1 s (too short for direct imaging time sequence)
- Collision time given by energy loss equation

$$\frac{dE}{dt} = -\frac{K}{E} n v$$

$$E^{3/2} = E_o^{3/2} - \frac{3}{2}\left[\frac{2}{m_e}\right]^{1/2} K n t.$$

For $E_o = 20$ keV, $E = 15$ keV, $t = \dfrac{4 \times 10^9}{n(cm^{-3})} \simeq 0.04$ s for $n = 10^{11}$ cm^{-3}

- Collisional Length

$$E^2 = E_o^2 - 2 K n z.$$

For $E_o = 20$ keV, $E = 15$ keV, $z = \dfrac{3 \times 10^{19}}{n(cm^{-3})} \simeq 3 \times 10^8$ cm $\simeq$ 4" for $n = 10^{11}$ cm^{-3}

- Even in steady–state, the 10 – 20 keV hard X–ray spectrum should evolve significantly on size scales of a few arc seconds

(2) **Thermal Model**

- Source diffuses into cool corona at $V_d \simeq c_s \simeq 10^8$ cm s^{-1} $\simeq$ 2"/sec.
- With $\simeq$ 1 second time resolution, should be able to follow evolution of source

PREVIOUS OBSERVATIONS

(1) SMM HXIS/ *Hinotori* SXT

Spatial Resolution $\simeq 8''$

Temporal Resolution $\simeq 10$ s

- Adequate to reveal footpoints in early phase, and amorphous source in late phase, but unable to delineate transformation (evolution?) between the two

- Possible low–intensity background present (comparison of HXIS and HXRBS spectra indicates that only about 10% of the emission in the HXIS energy bands was contained in the transmitted pixels)

(2) ISEE–3/PVO

- Occultation of low part of flare by solar disk. Only a fraction of a percent of the emission at high (100keV) energies comes from above 25,000 km.

- Spectra consistent with thin target nonthermal emission ($\gamma = \delta + 1$) in upper part of loop, and thick target nonthermal emission ($\gamma = \delta - 1$) over entire loop.

THEORETICAL MODELING (THICK–TARGET)

- Electron beam creates direct bremsstrahlung (dashed lines), and also heats atmosphere, leading to thermal bremsstrahlung (solid lines).

- Intensity in middle of loop rises due to *two* reasons: (i) evaporation of the target (non–thermal emission), and (ii) heating of coronal plasma (thermal emission).

Low Energies ($\lesssim$ 15 keV)

- At first nonthermal emission dominates and shows a strong footpoint signature (x = 0 and x = 21 arc seconds in the figure).

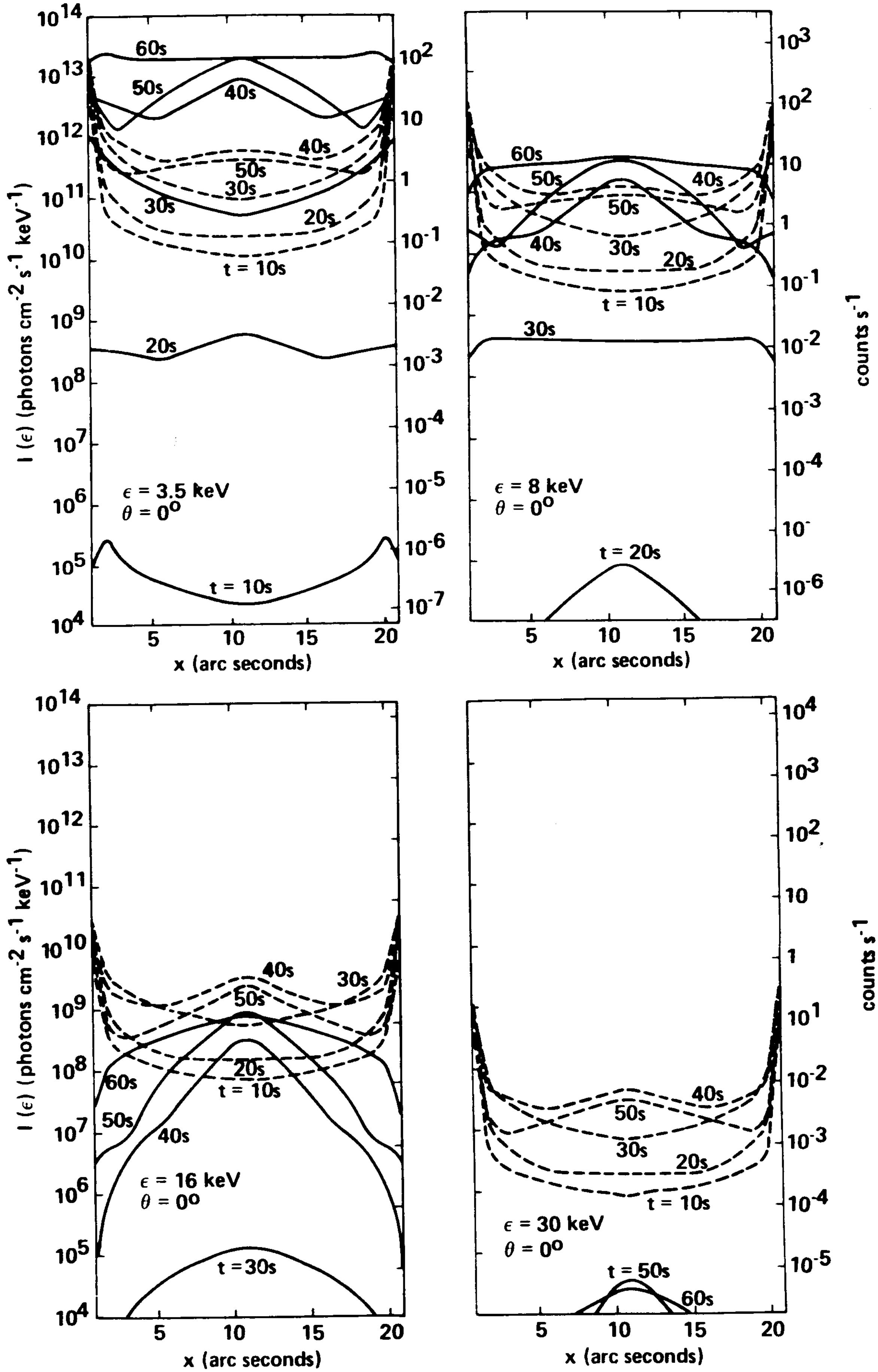
- Later, nonthermal footpoints are still strong, but the thermal bremsstrahlung from the beam–heated plasma starts to dominate.

High Energies ($\gtrsim$ 15 keV)

- Whole event dominated by nonthermal emission. Footpoints less dominant as target evaporates.

Implications of Theoretical Results

- Need to observed at high ($\gtrsim$ 15 keV) energies with a few arc second spatial resolution and $\simeq$ 10 s temporal resolution to adequately test predicted features.


I (ε) (photons cm^{-2} s^{-1} keV^{-1})
counts s^{-1}
x (arc seconds)
ε = 3.5 keV
θ = 0°
ε = 8 keV
θ = 0°
ε = 16 keV
θ = 0°
ε = 30 keV
θ = 0°
t = 10s
t = 20s
t = 30s
t = 50s
20s
30s
40s
50s
60s

WHAT CAN BE LEARNED FROM IDEAL DATA?

- If the observed region is sufficiently small, then the emission from the region is thin–target emission, from which it is relatively straightforward to deduce a local electron spectrum.

- We can therefore follow the evolution of this spectrum with space and time, and thereby test the following:

    - Location of Energy Release
    - Nature of Accelerated Particle Spectrum
    - Physics governing Evolution of Particle Spectrum (Transport Processes)

        (i) Collisions

        (ii) Reverse Currents

        (iii) Collective Plasma Processes

        (iv) Magnetic Mirroring

        etc., etc.

- It should also be possible, with sensitive enough data, to observe the backscattered albedo patch and so discern the height of the illuminating source.

SUMMARY

With arc–second imaging of solar hard X–rays, with enough sensitivity to provide a few seconds time resolution at energies of order 15 keV and above, we should make major advances in our knowledge of:

- Whether Solar Hard X–Ray Emission is Predominantly Thermal or Non–Thermal
- Whether the Energy Release itself is Predominantly Thermal or Non–Thermal
- The Accelerated Particle Spectrum (Non–Thermal Model)
- The Temperature Distribution of the Source (Thermal Model)
- The Hydrodynamic Response of the Atmosphere to Flare Energy Input

We can also:

- Publish many papers, conference proceedings, etc, and become very famous.