Merits and demerits of the so-called (Brown 71) Thick Target Model

THE DEDUCTION OF ENERGY SPECTRA OF NON-THERMAL ELECTRONS IN FLARES FROM THE OBSERVED DYNAMIC SPECTRA OF HARD X-RAY BURSTS

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Past, Present and Future

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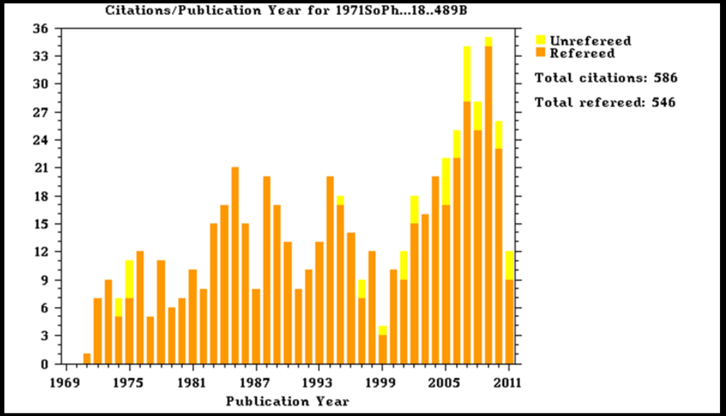
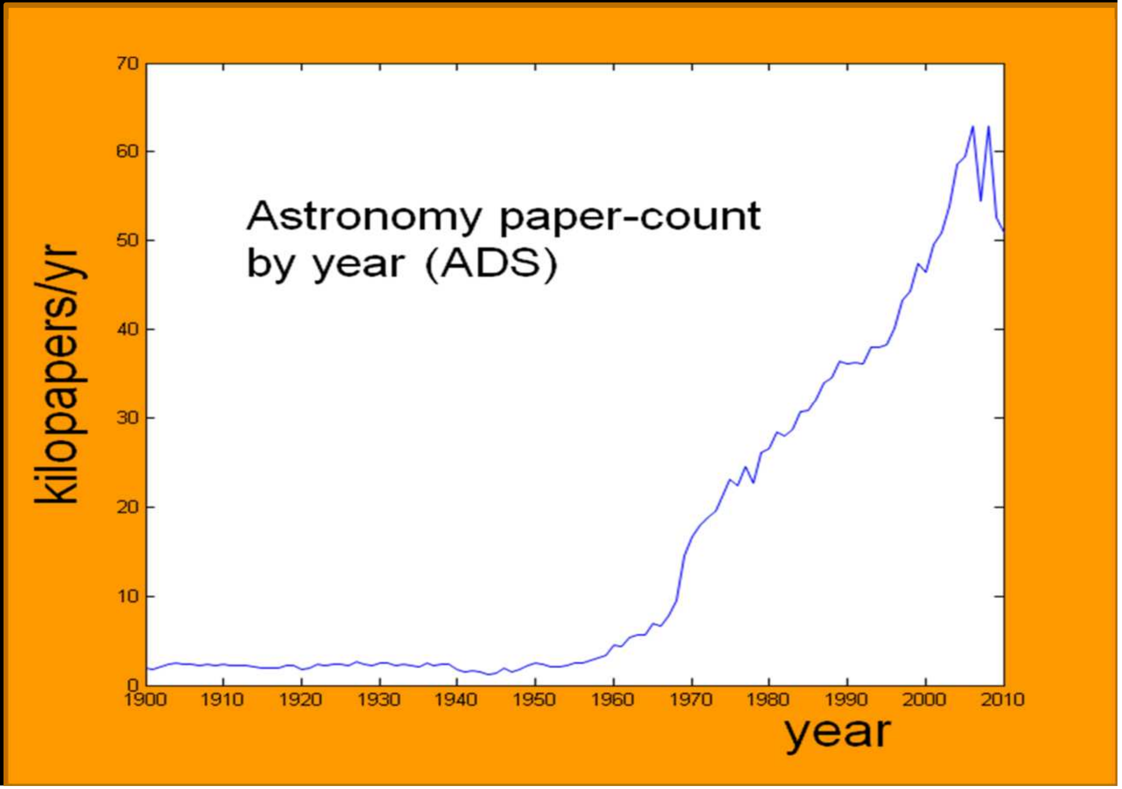
Brown 71

- Who has cited it?
- Who has read it?
- Who has understood it?
- It is NOT THE TTM paper –
- It is about spectral deconvolution



cf
De Jager and Kundu
Brown 72, 73
Hudson 72,
Shmeleva &
Syrovatskii 72



The term 'TTM' is used in THREE senses

- Energy losses in the HXR source (cf AGE remarks) irrespective of geometry
- The usual TTM specific HXR source geometry of INJECTION from a (CORONAL) ACCELERATOR into a (CHROMOSPHERIC) PASSIVE TARGET
- TTM Model for e-beam heating of impulsive phase atmosphere

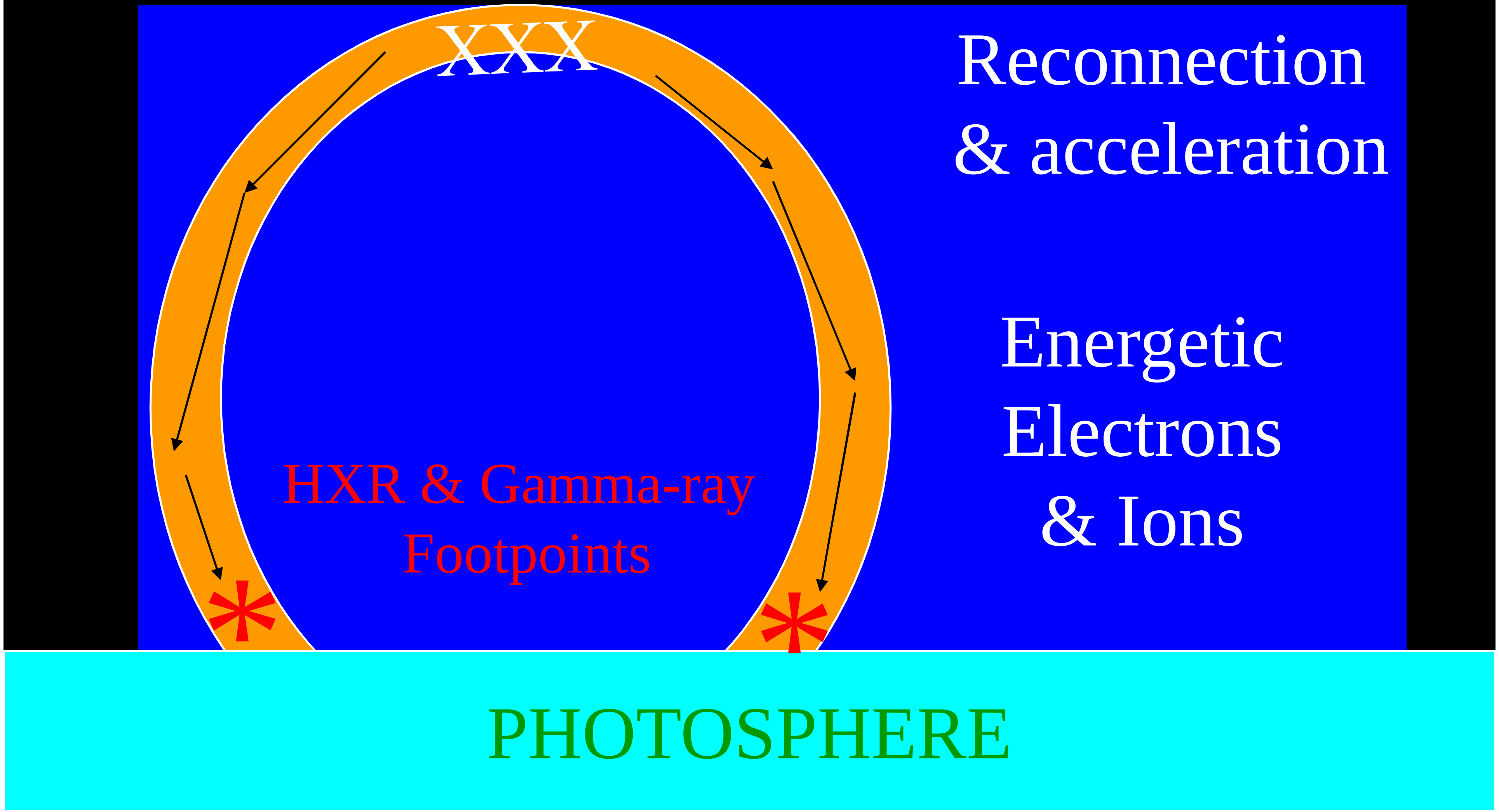
What IS the (Collisional) TTM?

(Brown 1971,1972,1973; Hudson 1972; Syrovatskii and Shmeleva 1972)

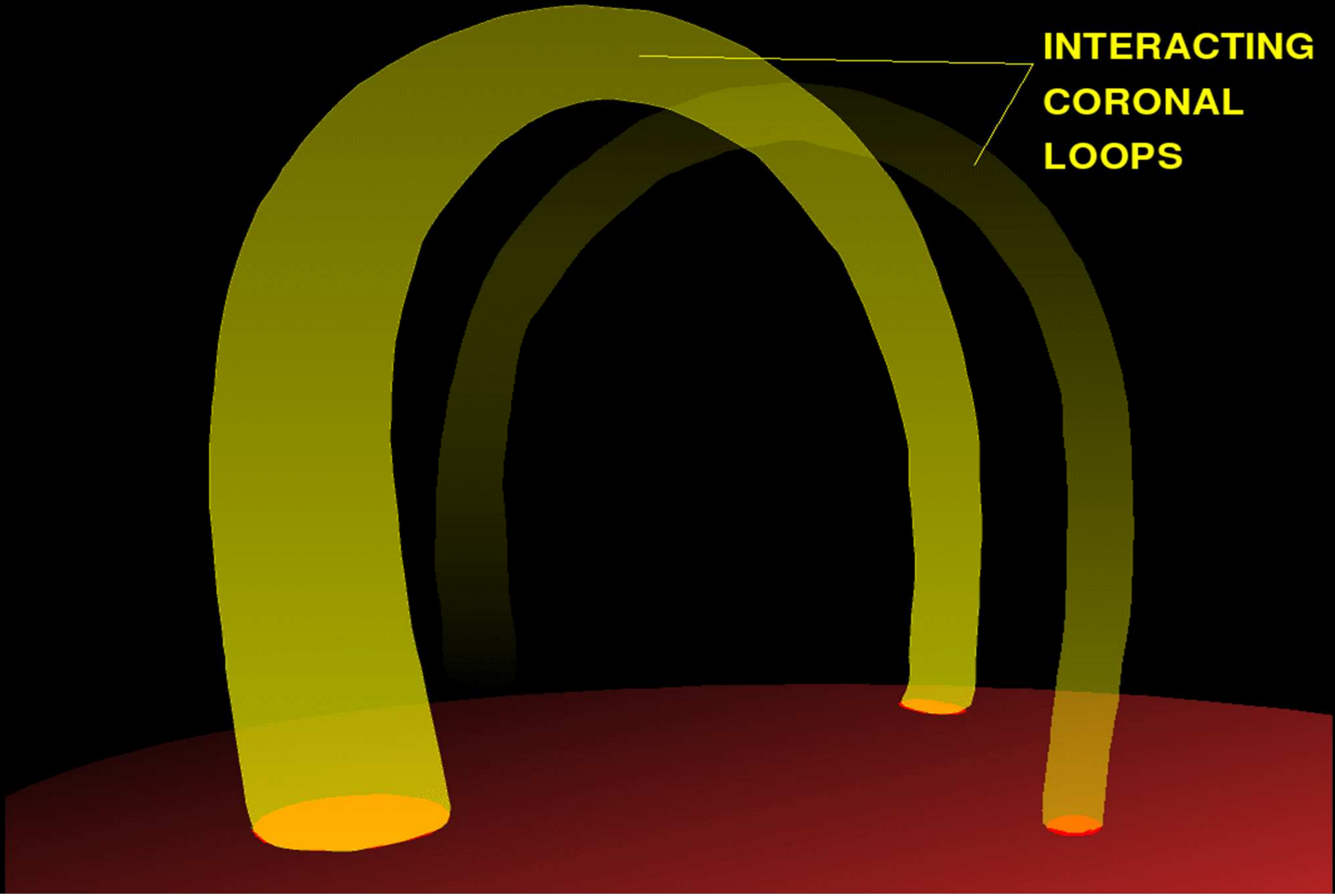
ASSUMPTIONS –

- Electrons accelerated by unspecified mechanism in tenuous corona with only weak HXR emission
- Electrons stream down into dense chromosphere causing HXR emission, flare heating and evaporation
- Electrons lose entire energy in the HXR source (thick target) without any further acceleration
- In CTTM the transport is further assumed purely collisional
- Extended CTTM includes beam electrodynamics such as return current electric fields (e.g. Zharkova et al, Emslie)

Thick Target Model – Arnoldy et al 1969, Brown 1971,Hudson 1972, de Jager and Kundu 1973



TT Beam electrodynamics (from Zharkova et al.)



This passive ‘target’ assumption is a source of some of TTM’s problems

Quick summary of TTM status

LIMITATIONS

- The CTTM with acceleration -> injection-> collisional propagation only is inadequate
- A mononolithic TT loop is ruled out (Fletcher/Hudson)
- Overall fast electrons are not very anisotropic (Kontar)
- Non-collisional transport effects matter (Zharkova, Kontar …)
- How are flare and IP electron numbers and spectra related
- There is NOT an electron NUMBER problem but there IS a TTM BEAM DENSITY problem

STRONG PLUSES?

- Kontar et al say - Mean HXR source vs height is close to CTTM prediction – BUT I DOUBT THIS – SEE BELOW
- Aschwanden says TTM Time of Flight fits data

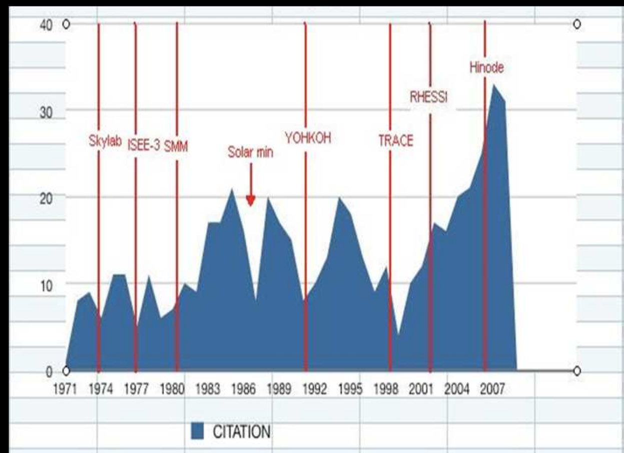
THINGS WE HAVE NOT DONE BUT SHOULD

- Model & include collisional energy dispersion in transport models (cf Rausaria)
- Routinely include return current effects (Zharkova)
- Include nonthermal recombination HXRs (Mallik)
- Routinely include plasma wave effects once we understand them in the right context (Kontar)

WHY IS THE CTTM THRIVING?

BECAUSE IT IS SIMPLE !
AND SEEMS TO BE NOT TOO FAR FROM REALITY

Provides a SIMPLE useful starting point for interpreting impulsive phase emissions roughly fitting observations. SO, despite known Limitations it is widely used !



- BUT Occam’s Razor misleads
- Maxwell’s and Plasma Eqns SIMPLE
- However, solutions V COMPLICATED

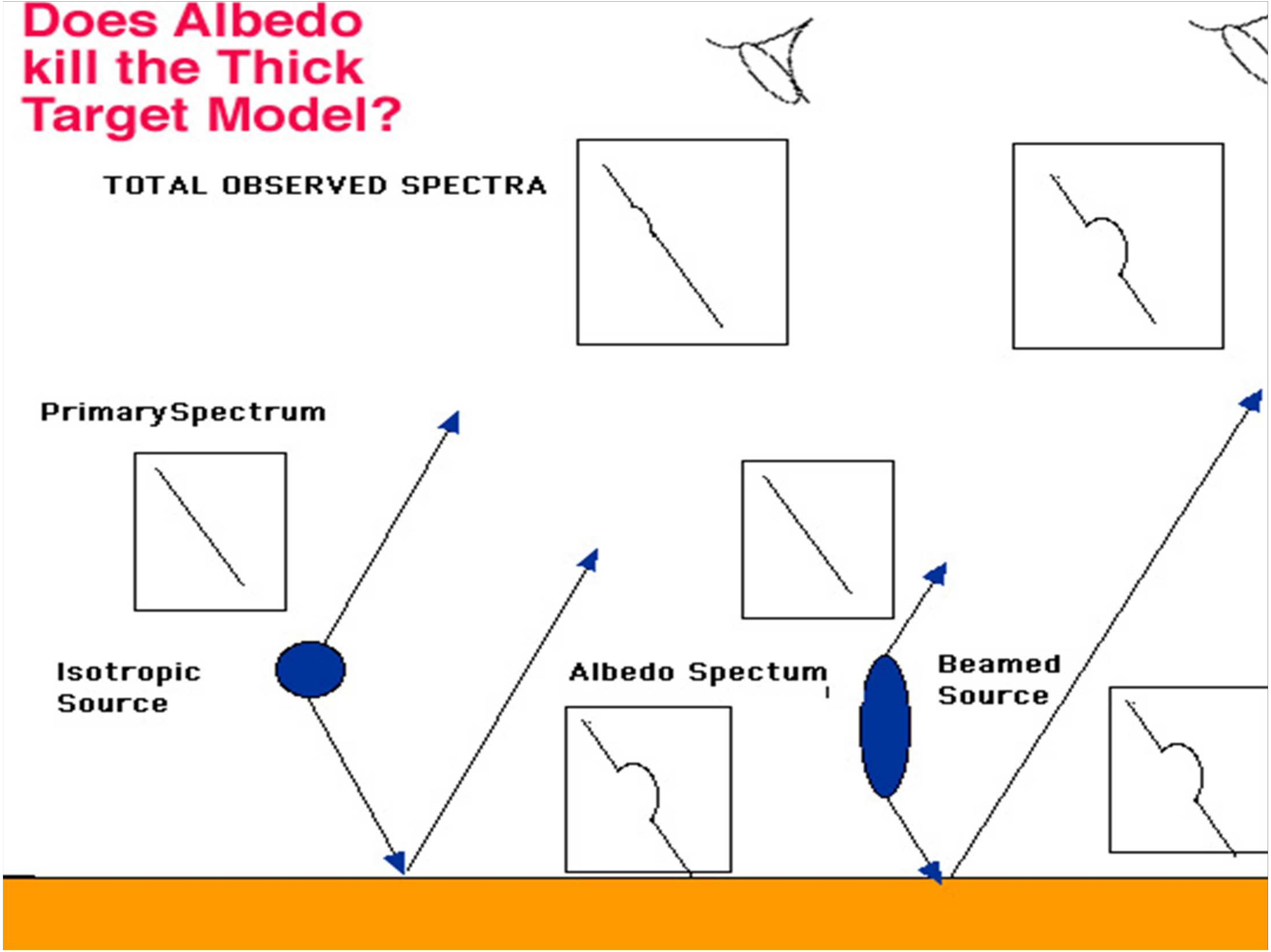
Do I now believe in the CCTM?

- NO
- But I NEVER did
- Nor in thin or trap or thermal or local reacceleration TTM
- We are not in the belief business but in remote sensing diagnostics and physical modelling of particle distribution functions

ARE WE WAVING GOODBYE TO THICK TARGET MODELS? (Hudson)

- NO
- But we are refining them and proving the simplest versions inadequate
- Even if the chromospheric flare were energised by Alfven waves, the HXRs would still involve TTM aspects

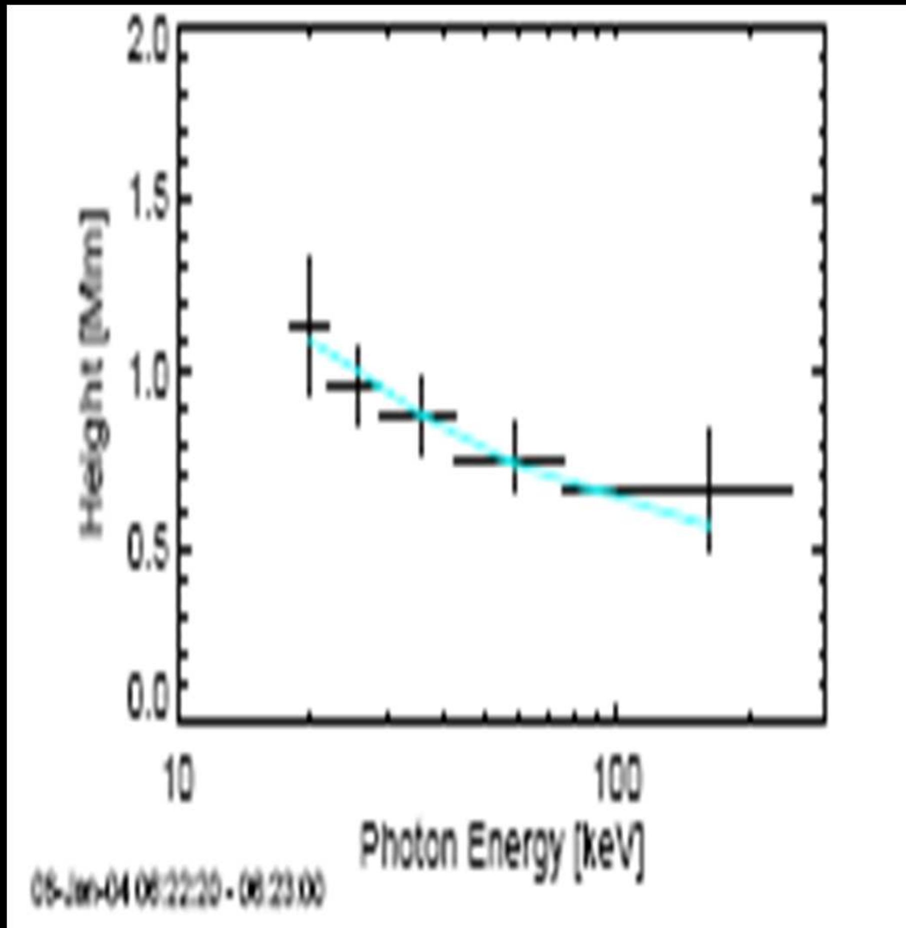
Does Albedo kill the Thick Target Model?



The HXR Source Height Issue

- Kontar et al say - Mean HXR source vs height is close to CTTM prediction – though needs some spatial smearing
- They find 30 keV electrons
  (Ncoll = 10^21/cm^2)
  where scale height
  H ~ 150km =>
  n ~ 10^14/cm^3
  and height z ~ 1000 km

This is consistent with the Vernazza et al 1981 VAL QS model which they use as a height refce (cf Brown & McClymont 1975)



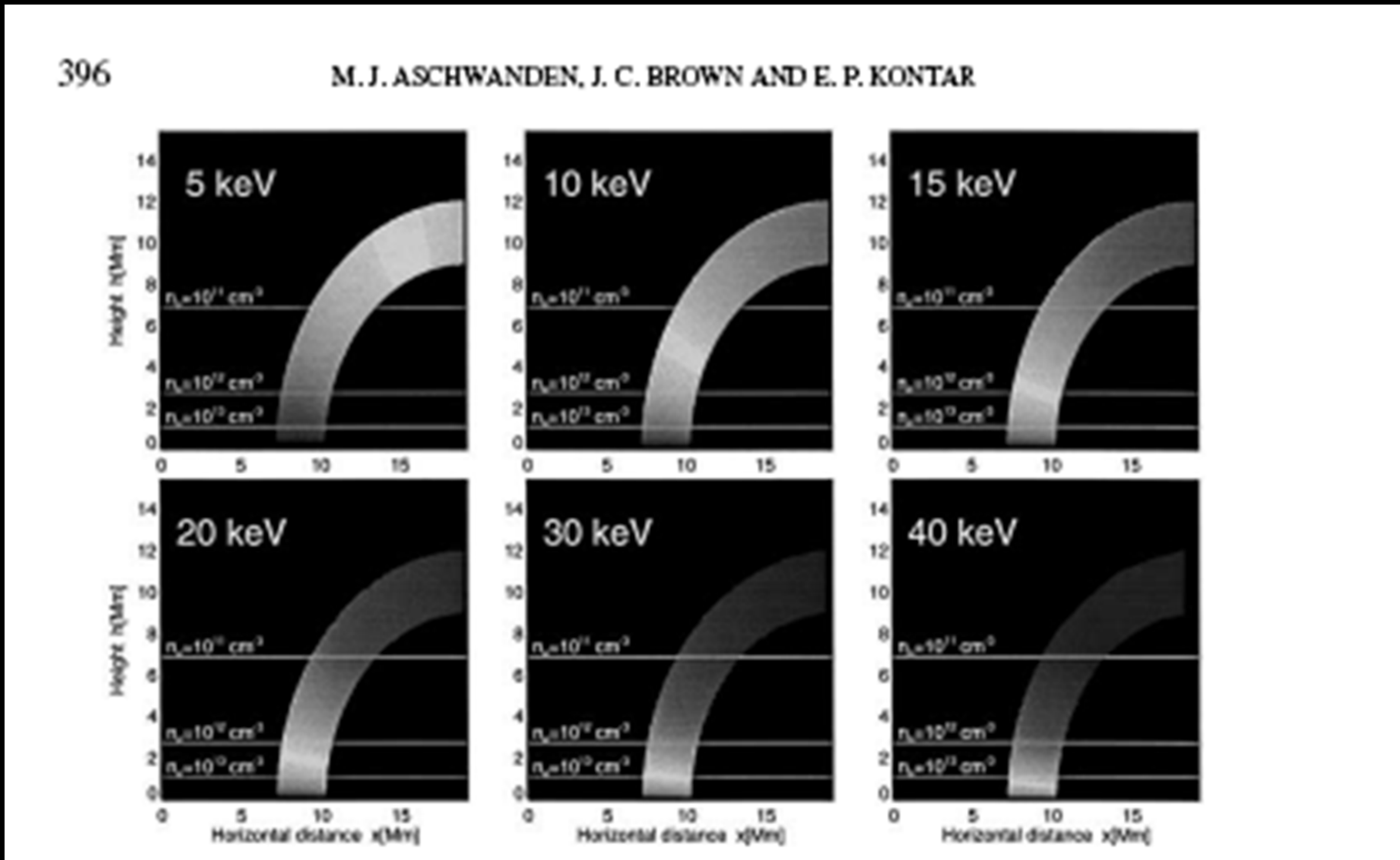
The HXR Source Height Issue 2

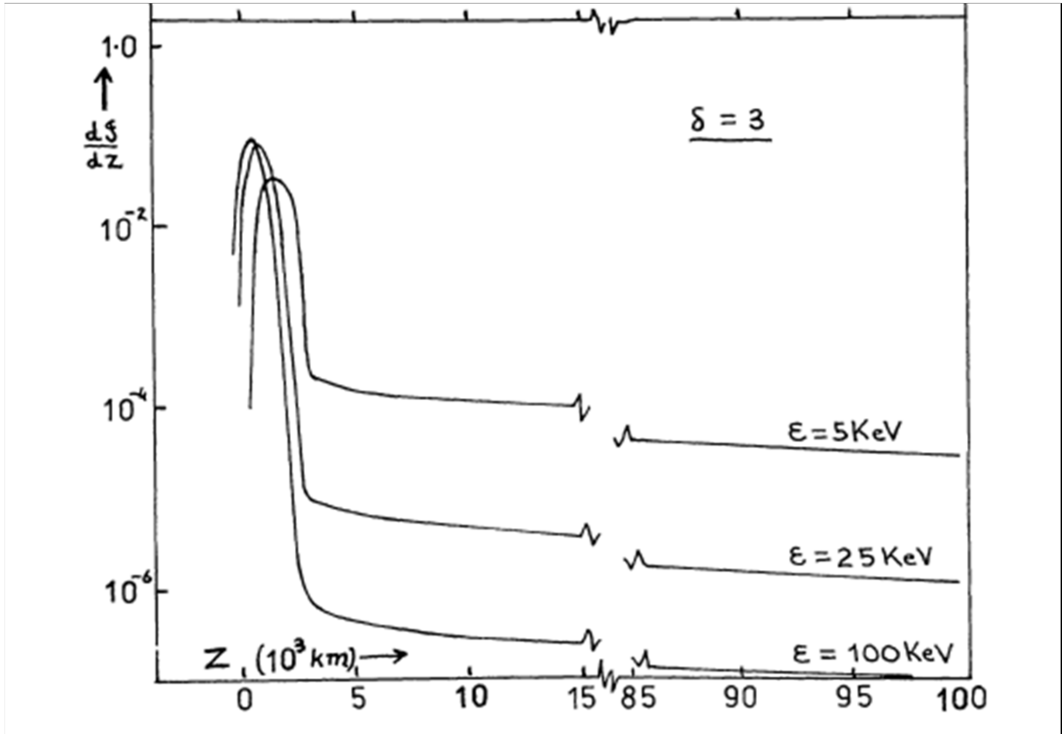
SO – HXR imaging H, z, n are consistent with electrons propagating IN a nearly QS VAL low chromosphere

BUT, in a real flare atmosphere (Machado et al MAVN 1981, Emslie 1980). electrons could never reach that deep from the Corona

Kontar et al is a refinement

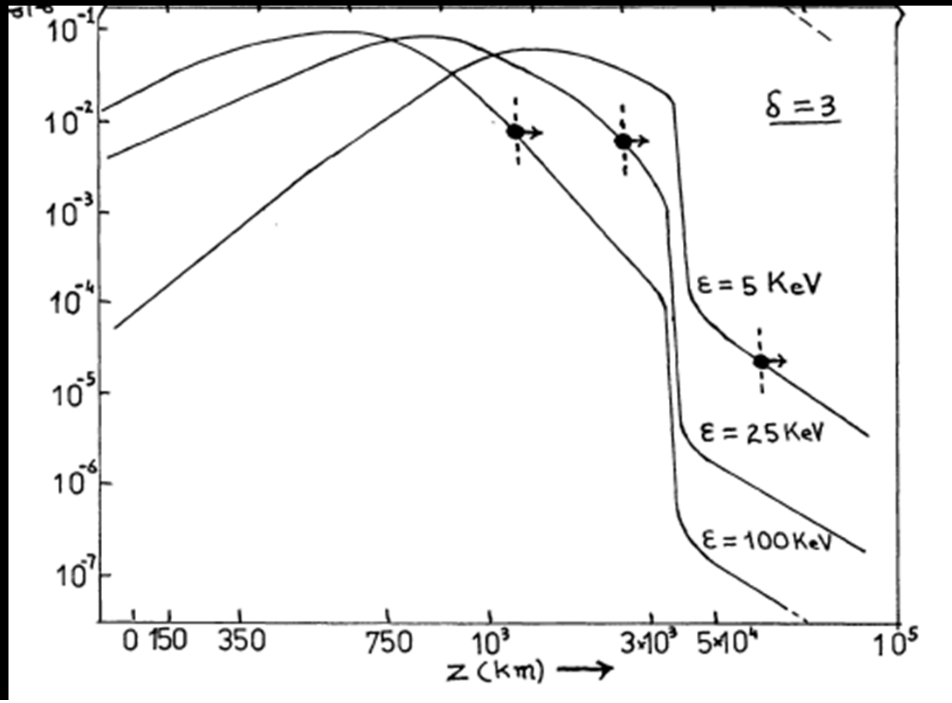
of Aschwanden, Brown and Kontar 2002





Brown and McClymont 1975 predicted CTTM height structure for Quiet Sun n(z) structure

Similar H and n to Kontar et al RHESSI data results



Machado Spectroccopic QS and MAVN flare structures
Evaporation results in 1000 times large N at given T

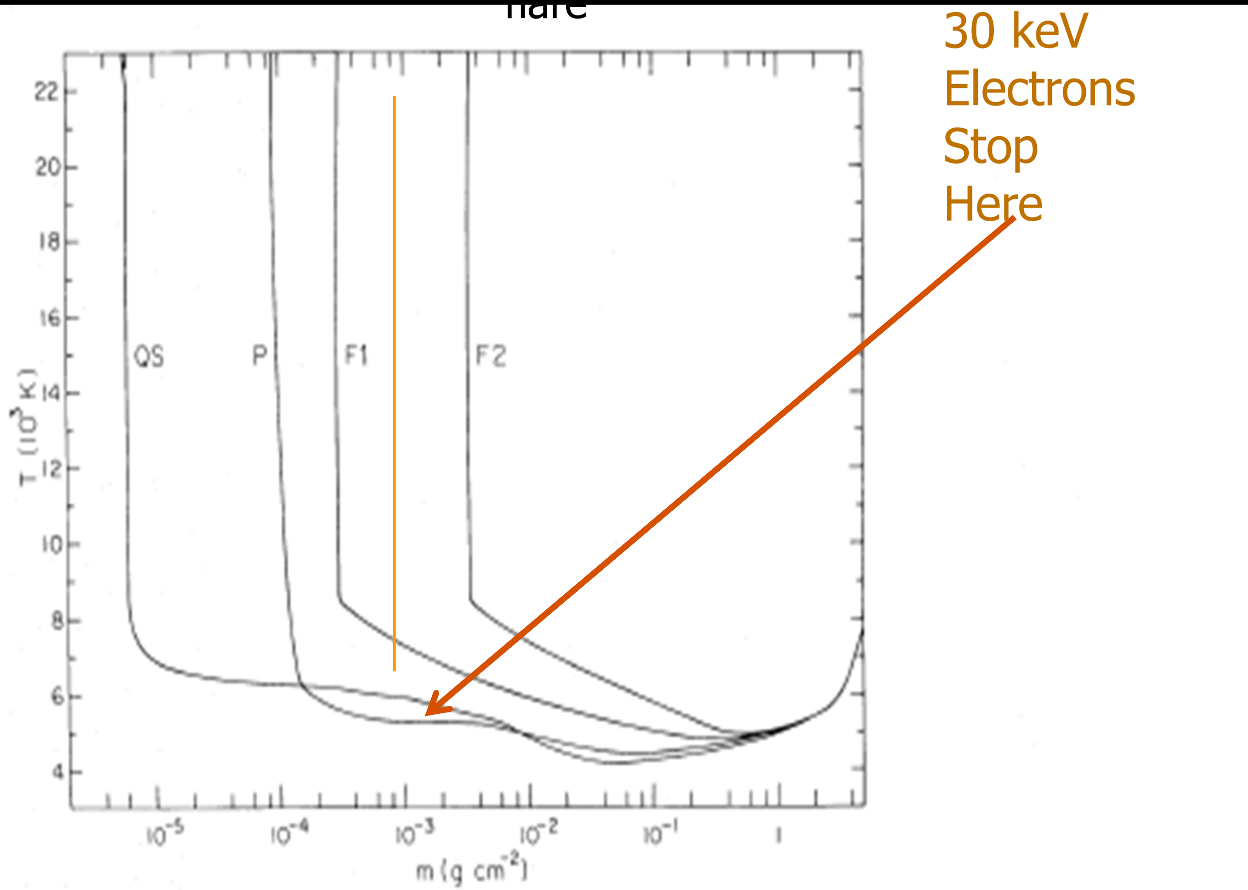


FIG. 1.—Temperature as a function of column mass for flare models F1 and F2, the quiet-Sun model C (here QS) of Vernazza, Avrett, [a]d Loeser (1981), and the plage model P of Basri *et al.* (1979).

Emslie 1980 Predicted HXR height structure for MAVN 1980 large flare model n(z)

NB
Z here is Downward From Transition zone

HXRs peak MUCH Higher in flares than QS model

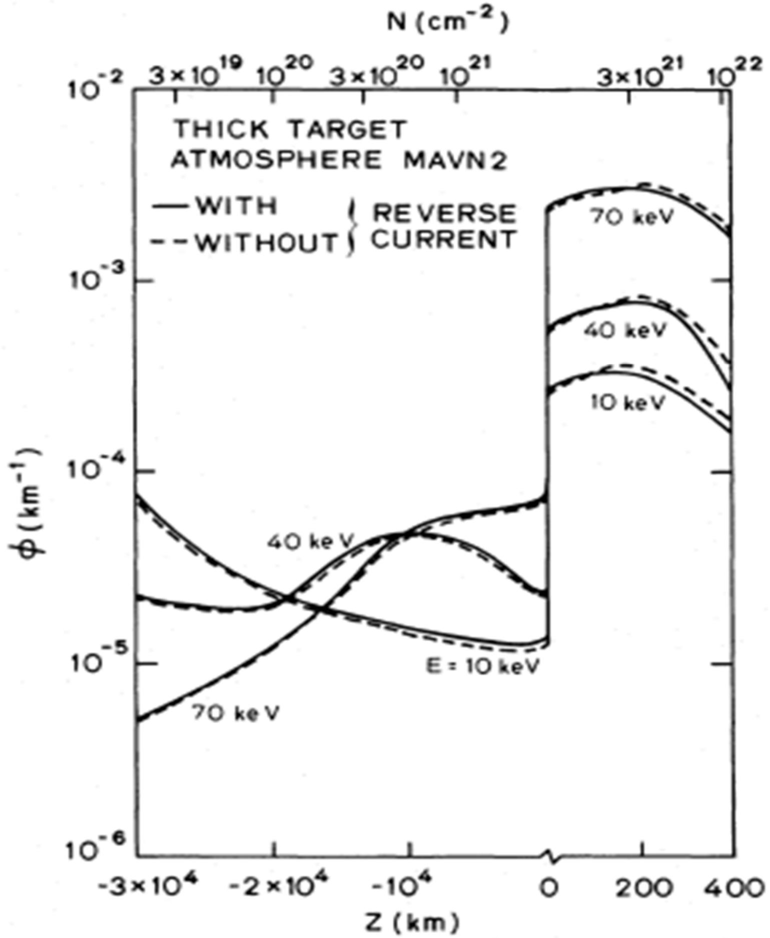


FIG. 2.—As for Fig. 1, except using atmospheric model MAVN2 (Machado *et al.* 1980) as background. Since MAVN2 has a deeper ansition zone than MAVN1, the electron flux has already been significantly attenuated by the time it reaches the transition zone; thus, the gion of maximum bremsstrahlung yield per unit length is very localized and occurs at the base of the transition zone. This result is arkedly different from the results of Brown and McClymont (1975) as a consequence of their adoption of an unrealistic (quiet Sun) ackground atmosphere.

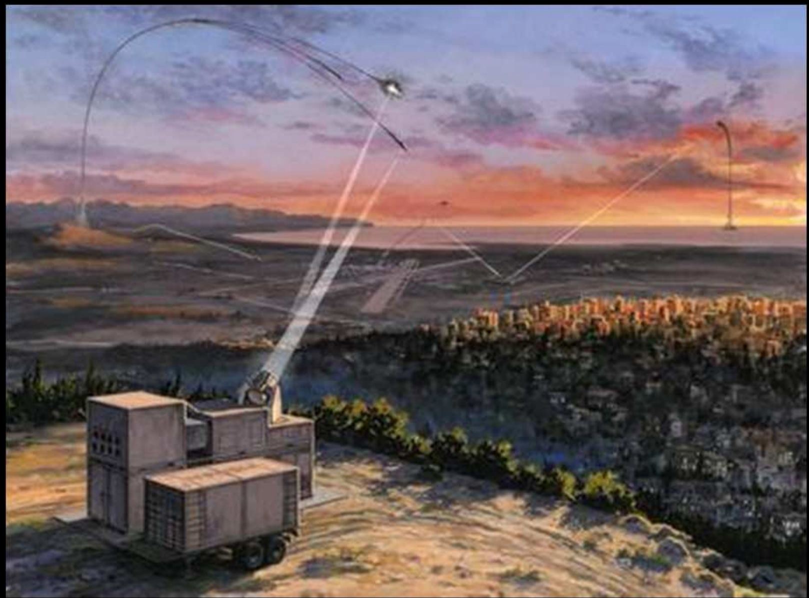
KONTAR ET AL RESULTS ONLY MAKES SENSE TO ME IF ELECTRONS ARE INJECTED LOW IN THE ATMOSPHERE

BUT TIME OF FLIGHT IDEAS THEN FAIL

The TTM 'number problem' myth

- For purely collisional transport with no reacceleration the > 20 keV electron injection rate needed for a large HXR burst is $\boldsymbol{F}_{20} > 10^{36}$ s^{-1}
- So total electrons processed in 1000 sec $\boldsymbol{N} > 10^{39}$
- Electrons in large coronal loop $\boldsymbol{N}_l$ =nV~10^{10}x10^{27}=10^{37}
- BUT these loop electrons are replaced from the dense chromosphere via the inevitable return current driven by the elctrodynamics of beam injection
- So there IS NO number problem
- There are issues of local current closure and neutralisation but it is known from lab , space, and beam weapon experiments, as well as from theory (eg Miller 1982) that return current neutralisation DOES occur.

Well known return current situations



Military ion beams only
Propagate through air
if a conducting channel
for the return current is
first created by an
ionising laser pulse

A fountain of 1 m^3 water/sec
would empty a 1000 m^3 pond
in 20 mins and the 0.1 m^3
Pump in 0.1 sec but for the fact
that pond is constanlly
replenished by the
gravity driven return current of
fountain water

The problem of TTM beam density

A beam rate $\boldsymbol{F}_{20} > 10^{36}\ s^{-1}$ of electrons of mean speed $v \sim 10^{10}$ cm s^{-1} over a cross sectional area A $\sim 10^{17}$ cm^2 (1-2'' square suggested by areas of HXR, UV, WL & other impulsive burst areas) implies > 20 keV beam density

$$n_{20} = \boldsymbol{F}_{20} / Av > 10^9 \ cm^{-3}$$

This is > 10% of the coronal loop plasma density & may be excluded by instabilities, UNLESS coronal flux tube areas A are >> chromospheric A as HXR data themselves suggest to be the case (Kontar et al)

How many fast electrons N does a large HXRB flux ACTUALLY need AT ONE INSTANT

FOR THE CTTM $N \sim 10^{33}$

- HXR EM => $Nn = f^{1/2}\, nL^{3/2} > 10^{23}$ cm$^{-3/2}$
- Optically thin => $nL < 10^{24}$

These only imply $L > 0.01/f$ cm , $n < 10^{26}$ cm^{-3}

eg $n=10^{17}$, $L= 10^{6}/f^{1/3}$, so $N = 10^{23}/f^{1/3}$

N ~ no of electrons in a sugar cube, spread thro 10 km

BUT high n => these electrons have to be driven very hard to offset collisions for 100 s

How might CTTM be modified by reacceleration to reduce electron requirements and to agree better with data?

NB The CTTM bremss model electron power demands can NOT be reduced since long range Coulomb losses (to plasma heating) scale with bremss output

BUT the key TTM assumption that makes electron numbers large is that electron energies E(t) decay monotonically by collisions (and other losses) in the HXR source, ignoring any energy gain processes in the HXR source which could prolong radiation lifetimes beyond collisional and hence increase HXR output per electron.

Such a Local Reacceleration Thick Target Model LRTTM was proposed by Brown, Turkmani, Kontar, MacKinnon and Vlahos (2009 A&A 508,993)

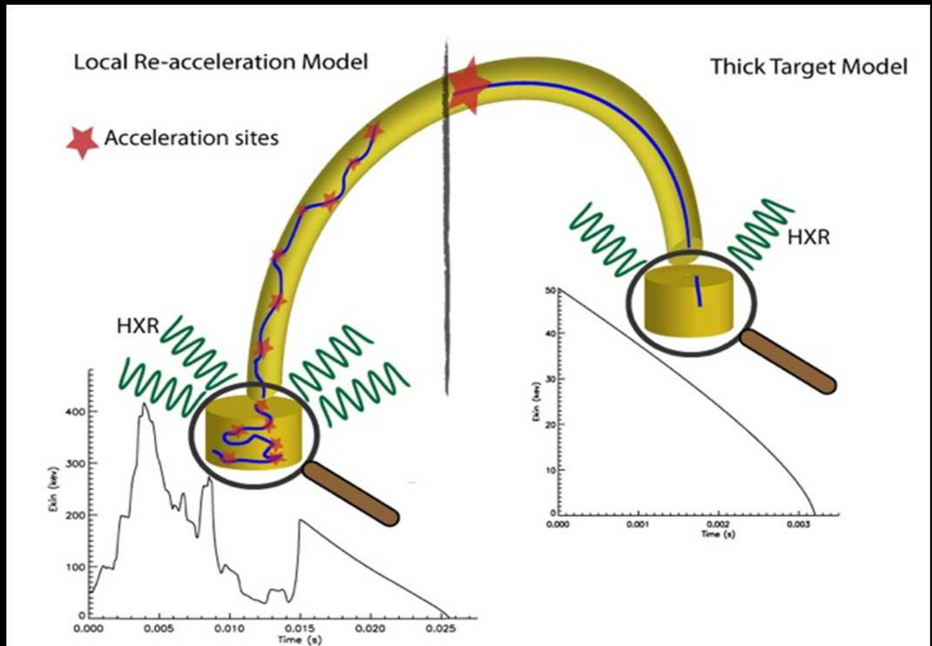
Properties & Issues re LRTTM versus CTTM

- LRTTM HXR source electrons have much smaller numbers and anisotropy than CTTM and different spectra
- Most of the magnetic energy going into fast electrons is now released in the chromosphere
- This, and the extended electron lifetimes and range might allow an electron heating explanation of WLFs
- It would also modify evaporation and SXR evolution
- Only if electrons are accelerated in the corona and fed into chromospheric reacceleration does LRTTM offer a natural explanation of Aschwanden’s time of flight claims
- On the other hand, evaporation would tend to choke off electron supply from the corona

Conclusions

(Re)acceleration in TTM footpoints allows a large increase in photon yield and a reduction in electron number/beam density

Theoretical mechanisms for this and testable predictions for them need to be developed



What about energy dependent time delays and ToF?

- Energy dependent time delays in $J(\varepsilon,t)$ might be due solely to changing accelerated energy spectrum $F(E,t)$

- If $F(E,t) = f(t)\, E^{-\delta(t)+1}$

then $d\log J/dt = [d\log f/dt - d\gamma^2/dt/2\varepsilon]$

and varying $\gamma(t)$ shifts maxima in J by an amount which decreases with enery

Brown JC, Conway AJ, Aschwanden, MJ 1998
ApJ 509, 911
Costa, J. E. R.; Correia, E.; Kaufmann, P.; Brown, J. C 1990
ApJ Suppl 73, 19

Height distribution of HXRs and flare heating in LRTTM?

Electron lifetiimes in footpoint HXR source are increased
=>
Lower rate of injection needed and electron range increased
=>
Loop limb/footpoint HXR ratio reduced
AND
Fast electrons may reach deeper in the atmosphere (WLF)