The observational dependence between a position of HXR footpoint sources and their energy

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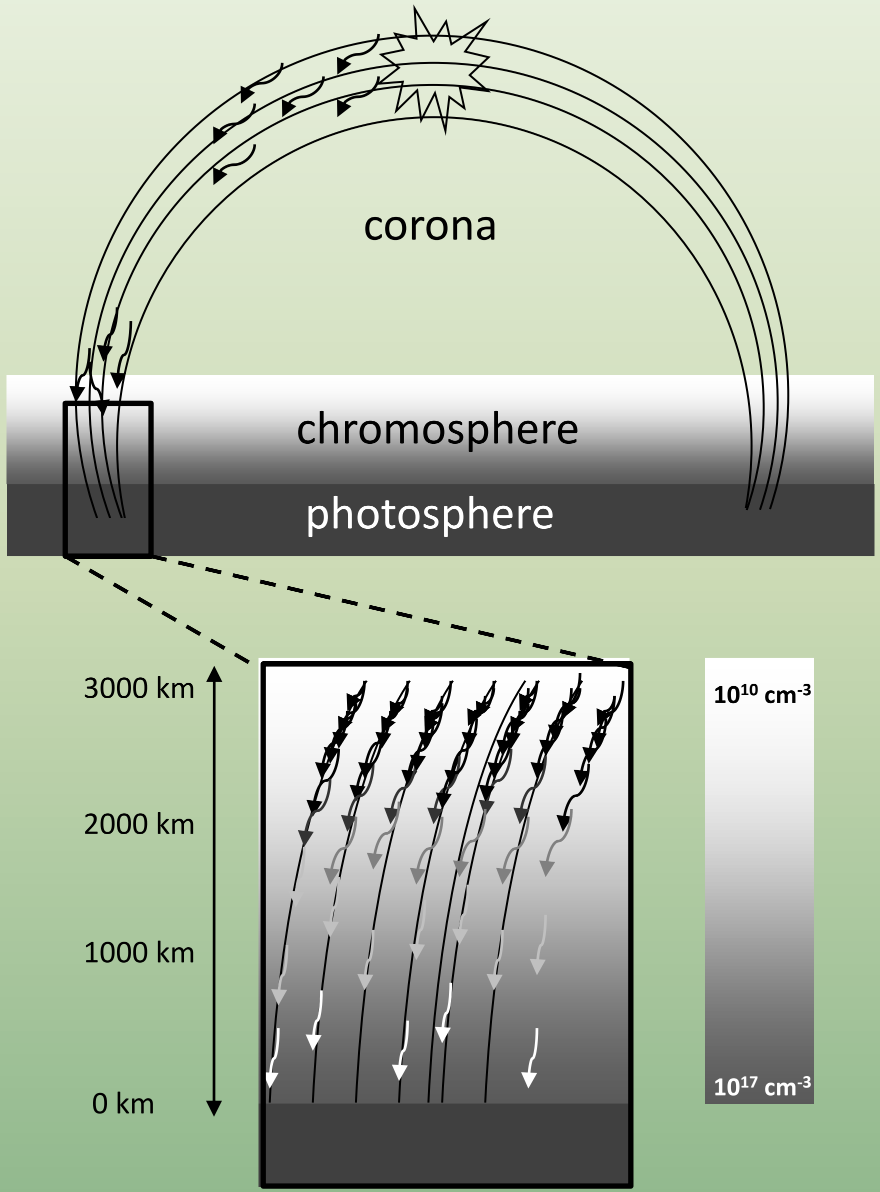
Theory



Brown,J., 1971, Sol. Phys., 18, 489
Brown, J. and McClymont,A.N. 1976, Sol. Phys., 49, 329
Brown, J et al., 2002, Sol. Phys., 210, 373

From collisional transport (simplified):

$$E(E_0, N) = \left(E_0^2 - 2KN\right)^{1/2}$$

Stopping depth for electron of energy E_0:

$$N_s(E_0) = \frac{E_0^2}{2K}$$

Relation between a height and an energy of the source should be observed.

Observed relation gives opportunity for measuring the density in a collision region

Observations before RHESSI

Takakura, K., Tanaka, K., Nitta, N., Kai, K., and Ohki, K., 1987, Sol. Phys. 107, 109

- * HINOTORI 20 - 40 keV
- * $h=7.0 \pm 3.5$ Mm

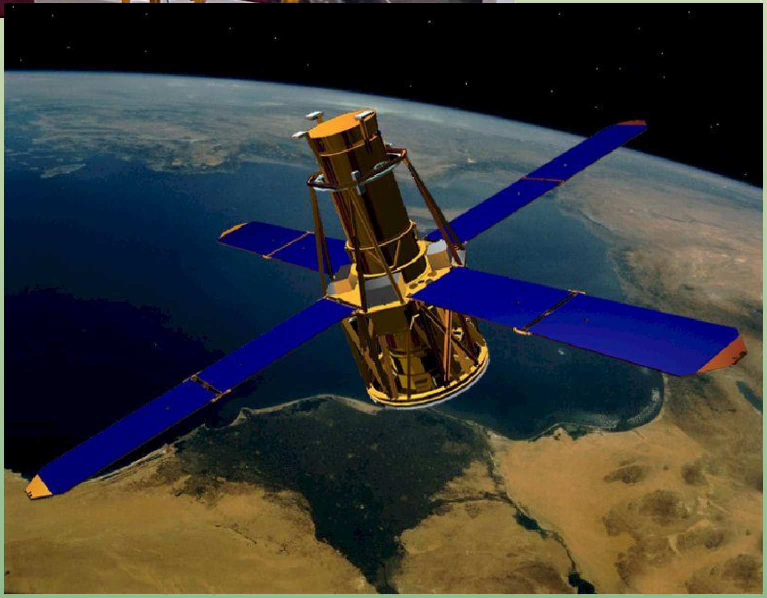
Matsushita, K., Masuda, S., Kosugi, T., Inda, M., and Yaji, K., 1992, Publ. Astron. Soc. Japan 44, L89

* YOHKOH	
* $h_{14} = 9.7 \pm 2.0$ Mm	(L: 15-23 keV)
* $h_{23} = 8.7 \pm 0.3$ Mm	(M1: 23-33 keV)
* $h_{33} = 7.7 \pm 0.5$ Mm	(M2: 33-53 keV)
* $h_{53} = 6.5 \pm 0.7$ Mm	(H: 53-93 keV)

Fletcher, L., 1996, Astron. Astrophys. 310, 661

- * $n_e = 2\times10^{10} - 3\times10^{11}$ cm^{-3}
- * L = 13 - 27 Mm

RHESSI



- launched: February 2002

- 9 large germanium detectors

- energy resolution ~ 1 keV

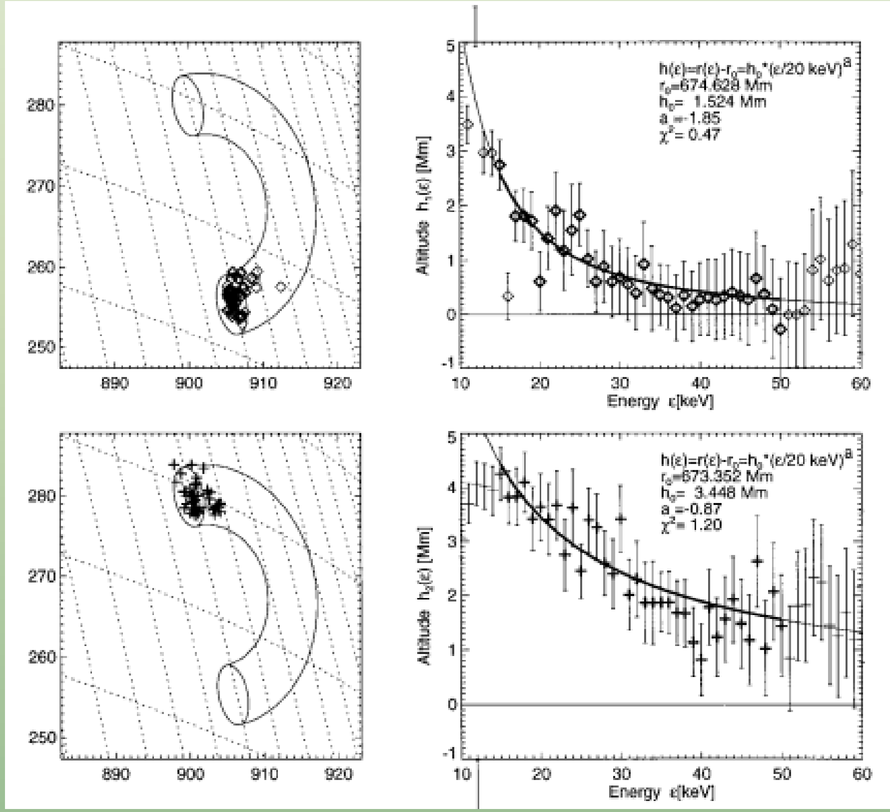
- spatial resolution depends on detector selection:
  ~2.5'' (maximal)
  ~7'' (in practice)

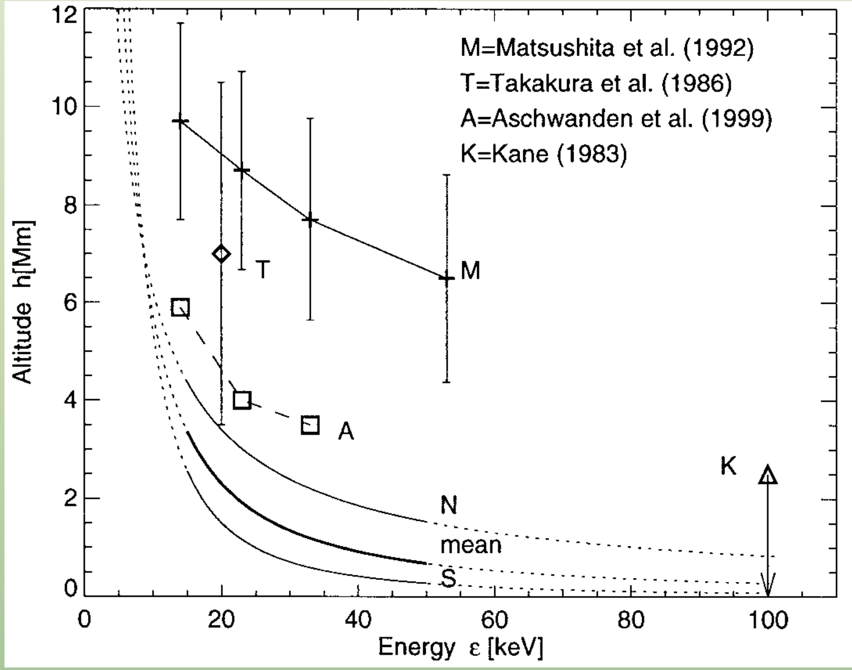
- temporal resolution for imaging depends on photon statistic, but must be equal at least ~2 s (half of the RHESSI rotation)

Observations with RHESSI

Aschwanden, M.J., Brown, J.C. & Kontar, E.P., 2002, Sol. Phys., 210, 373

February 20, 2002



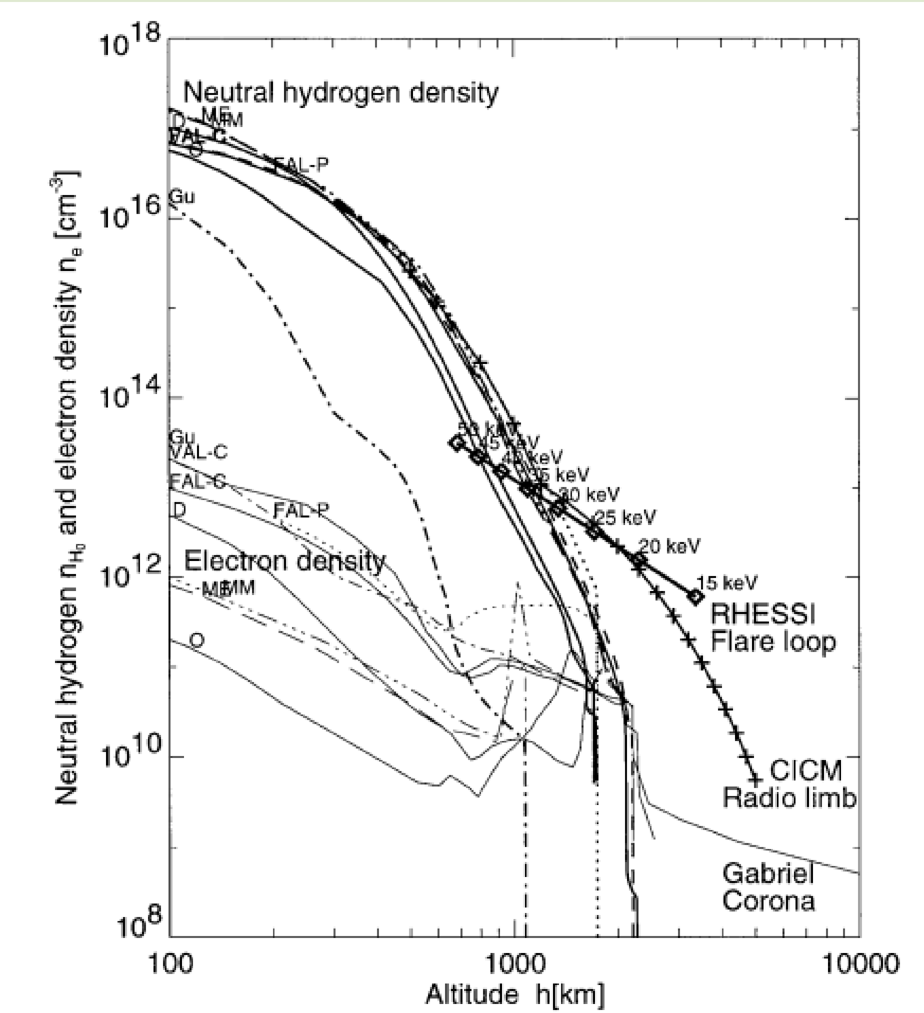


Energy: 15-50 keV, Height: 4000-700 km

Significant difference with regard to previous results is connected with the definition of reference level

Observations with RHESSI

Aschwanden, M.J., Brown, J.C. & Kontar, E.P. 2002, Sol. Phys., 210, 373



$$z(\varepsilon) = z_0 \left(\frac{\varepsilon}{20keV} \right)^a$$

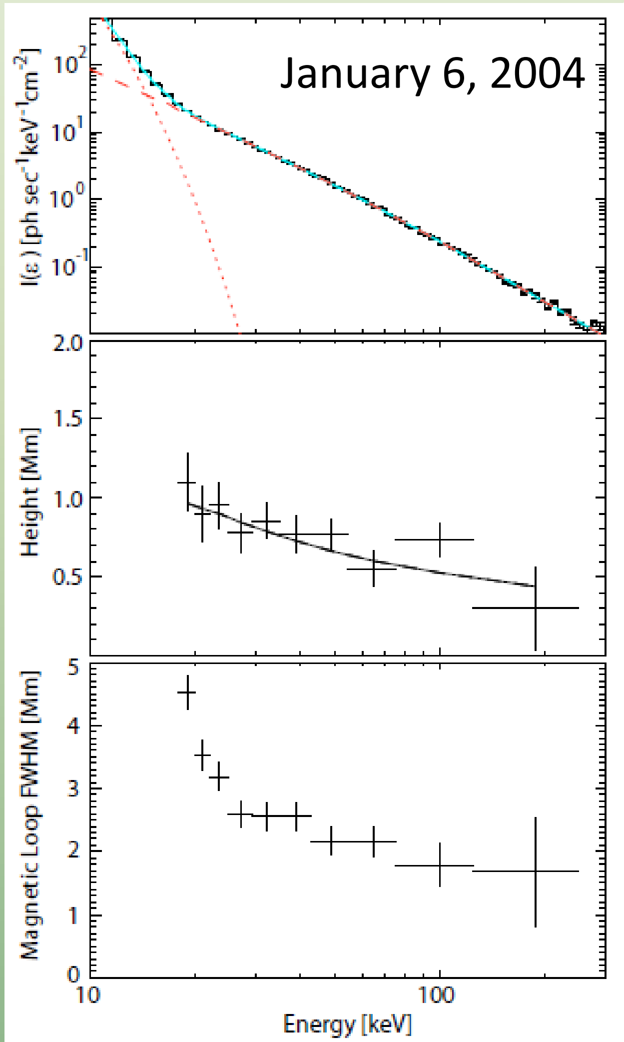
$$n(z) = 1.5 \times 10^{12} \left(\frac{1}{a} \right) \left(\frac{1Mm}{z_0} \right) \left(\frac{z}{z_0} \right)^{-b} \quad \left[cm^{-3} \right]$$

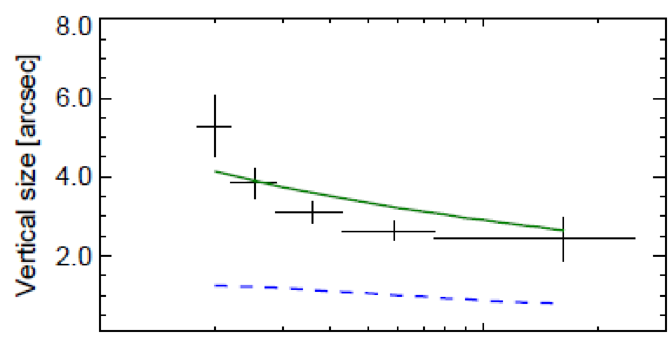
$$b = \frac{2}{a} + 1$$

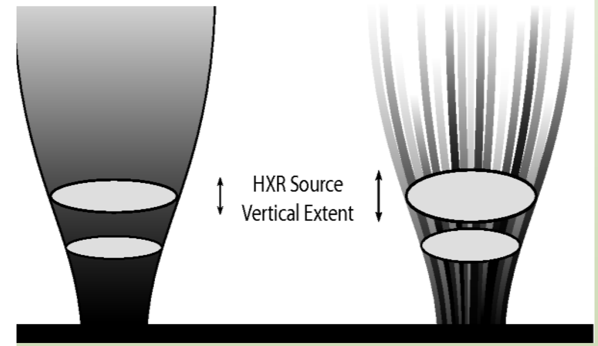
Density distribution in the footpoint can be calculated directly from power-law fit to observed energy-height relation

Observations with RHESSI

E. P. Kontar, I. G. Hannah, and A. L. MacKinnon 2002, A&A 489, L57
E. P. Kontar, I. G. Hannah, N. L. S. Jeffrey, and M. Battaglia 2010, draft







E-H relation is useful for mapping magnetic fields in the chromosphere

Locations of centroids of HXR sources are consistent with simple collisional transport in single density scale height chromosphere

FWHM size given by the multi-thread chromosphere model is closer to observational points

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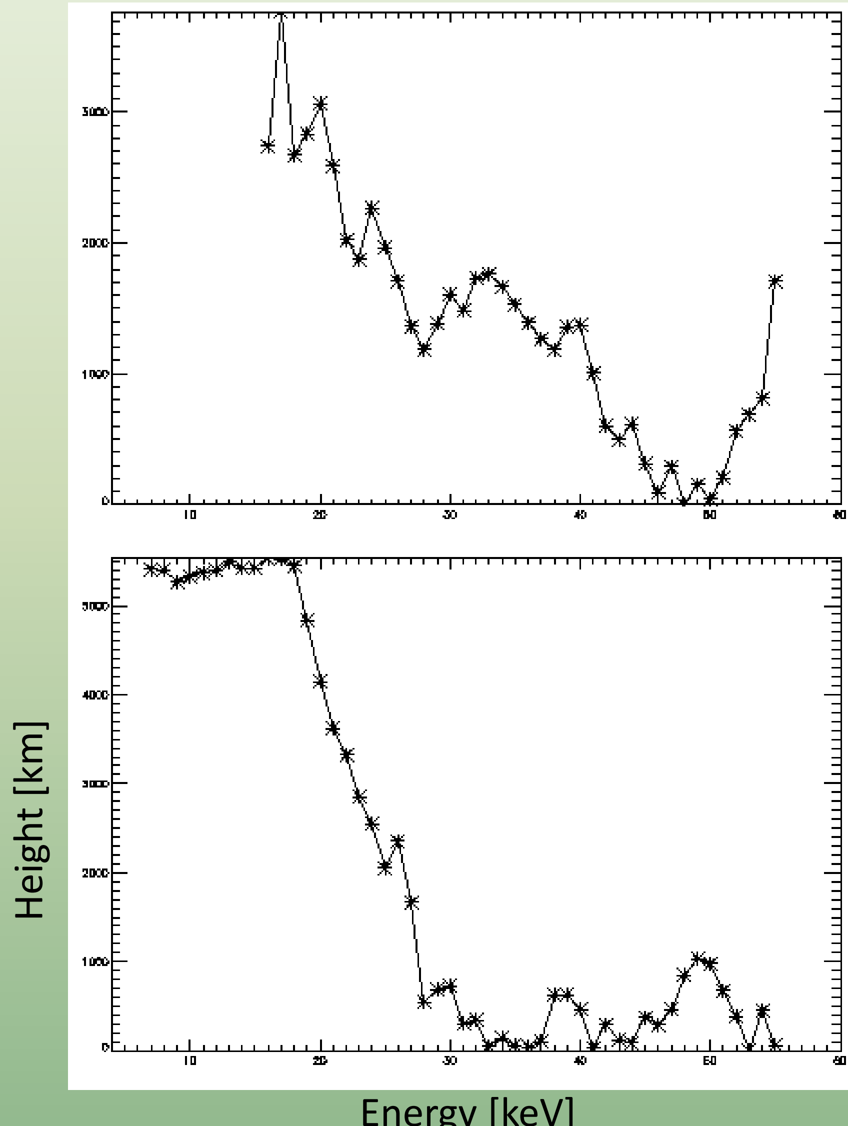
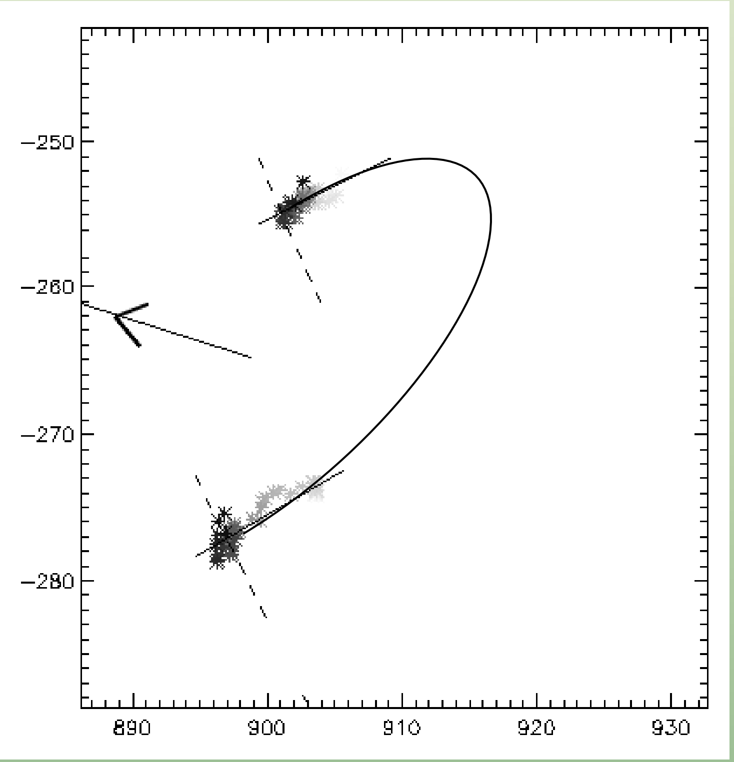


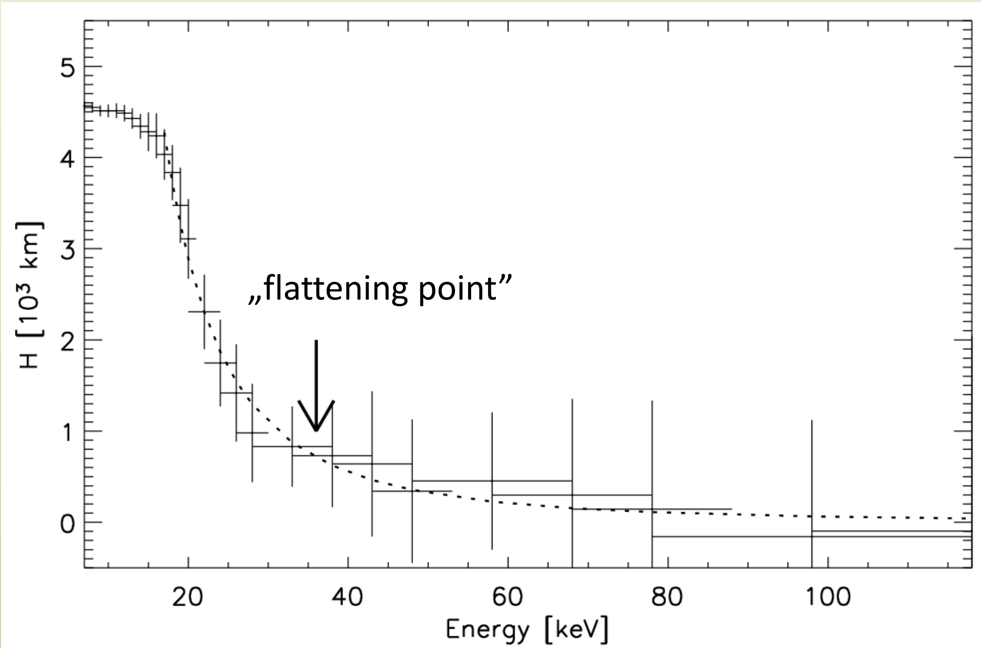
Feb 2002 – Jan 2006

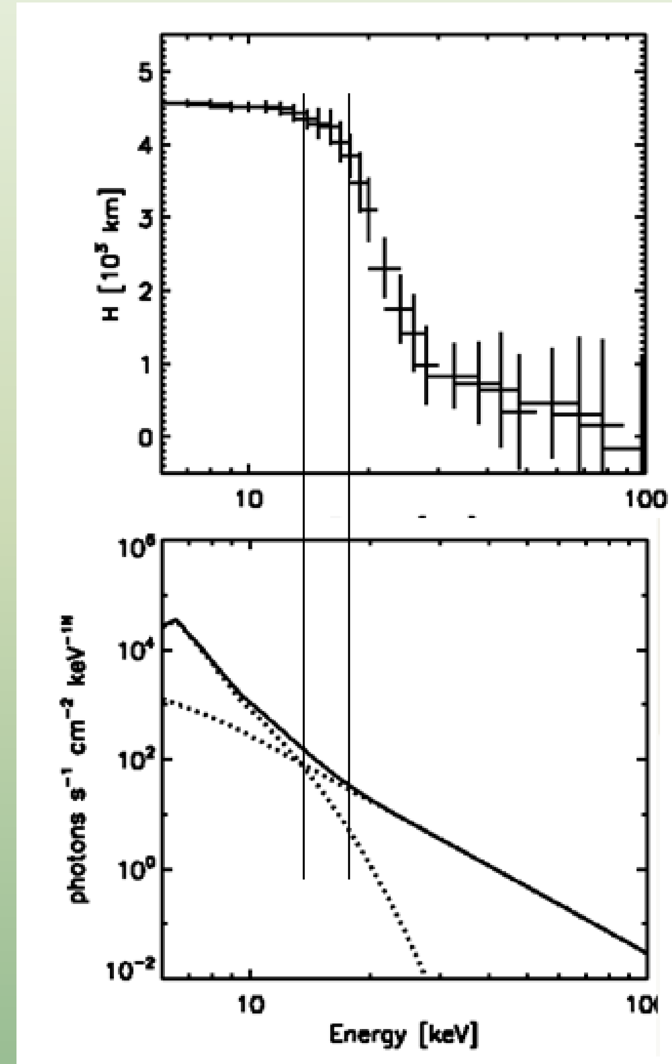
33 flares
73 E-H relations



Height is measured locally. It is not related to the Sun center.

Mrozek & Kowalczuk 2010





The E-H relation traces the column density in the flux tube.

The steep part is connected to low density region and the flat part occurs when density drastically rises.

The flattening point is a border between these two different parts of the relation

Thermal part do not show E-H relation

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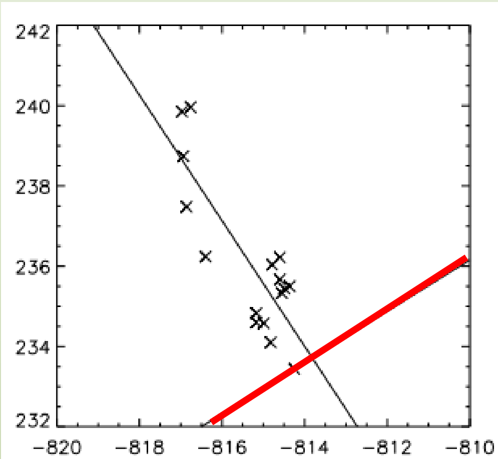
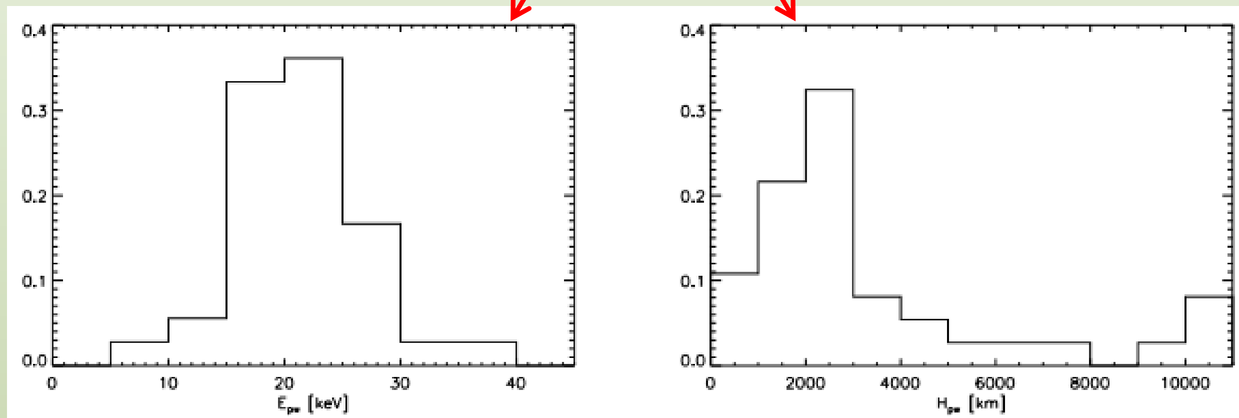
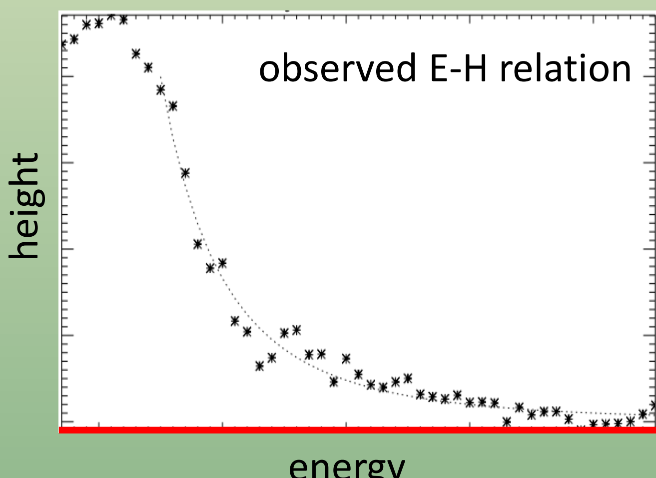


Energy and height of the flattening point





Reference level is determined by the centroid obtained for the source of the highest energy

Such reference level is not related to any level of the solar atmosphere

To do this we can use density distribution obtained from observed E-H relation

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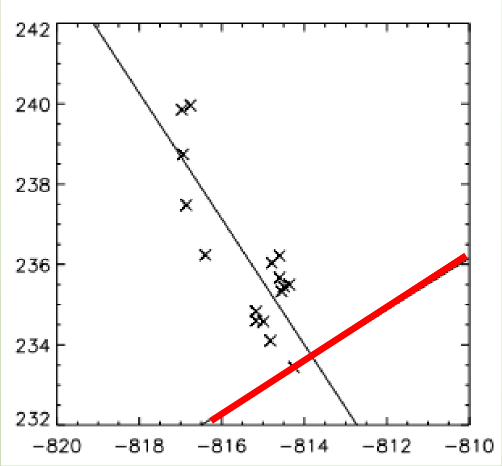
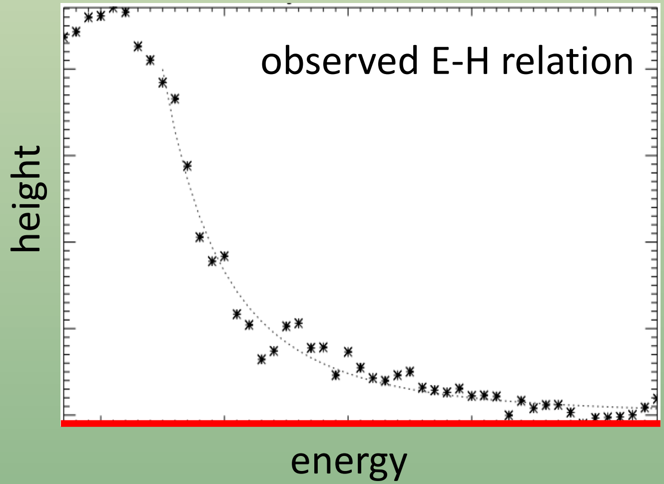
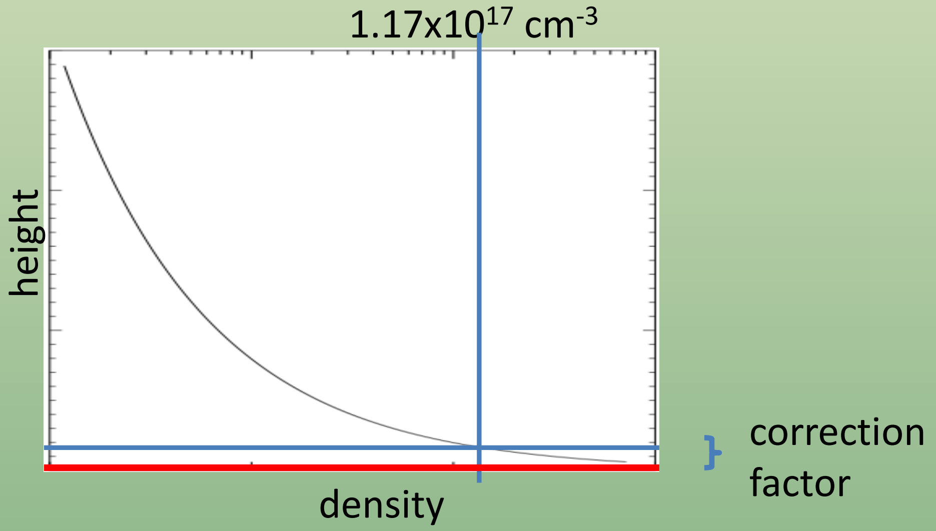


Calculating the difference of height between the reference level and the photospheric level we are able to obtain absolute heights of HXR sources

Location of the photosphere is calculated directly from the energy-height relation





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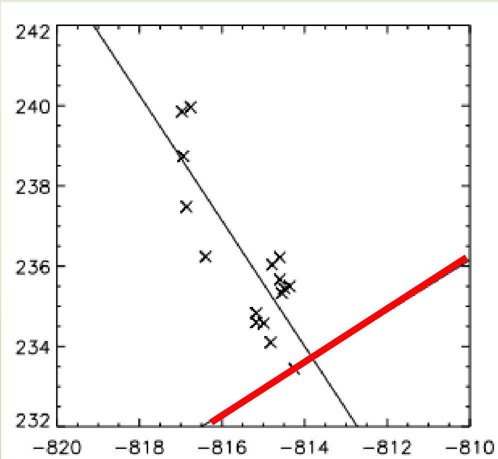
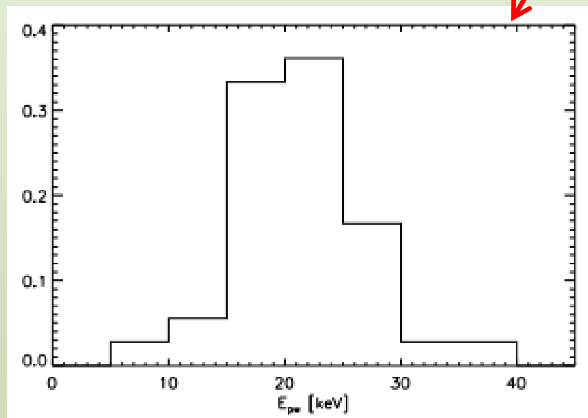
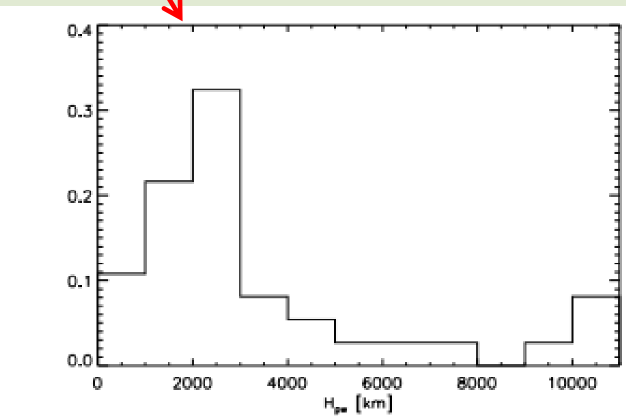
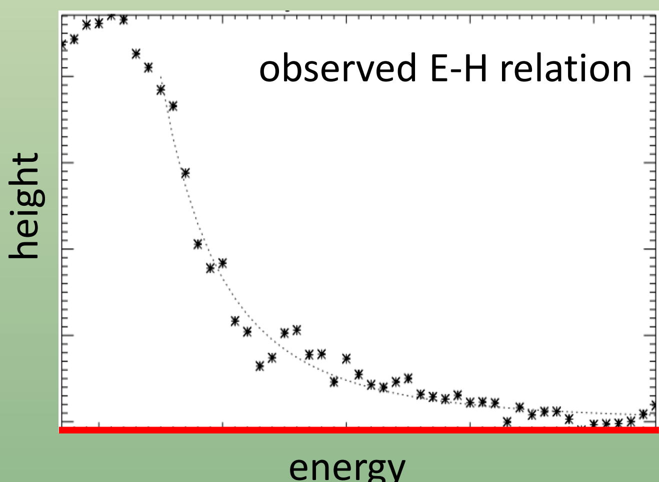
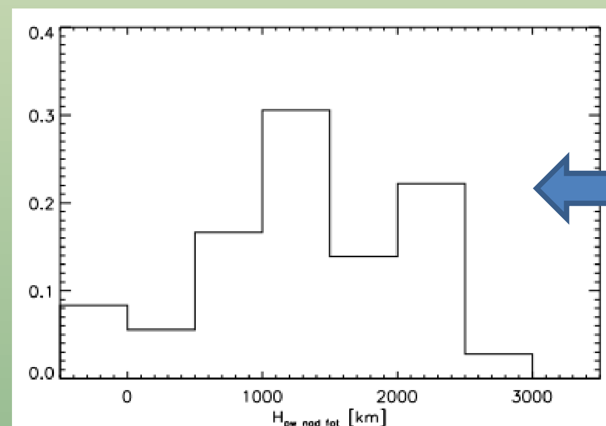


Energy and height of the flattening point









Corrected for
the actual
photospheric level

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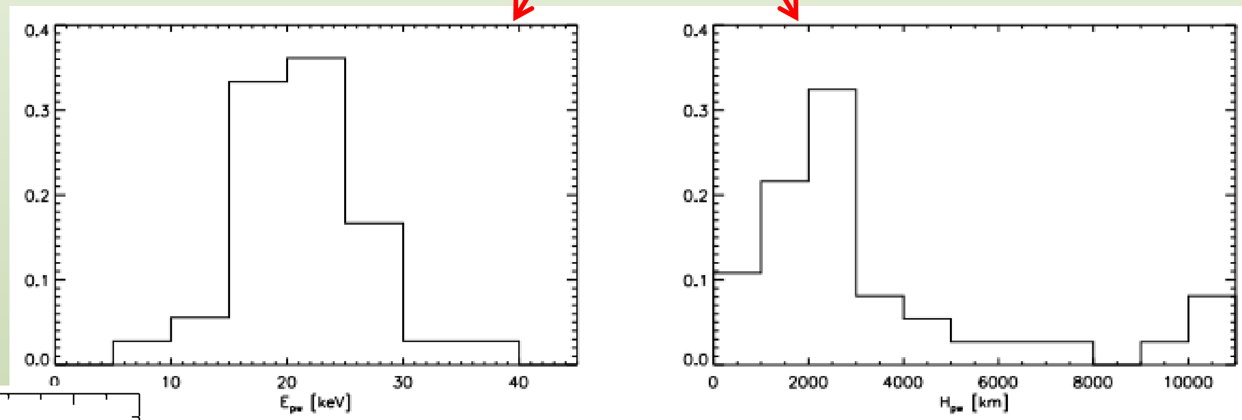
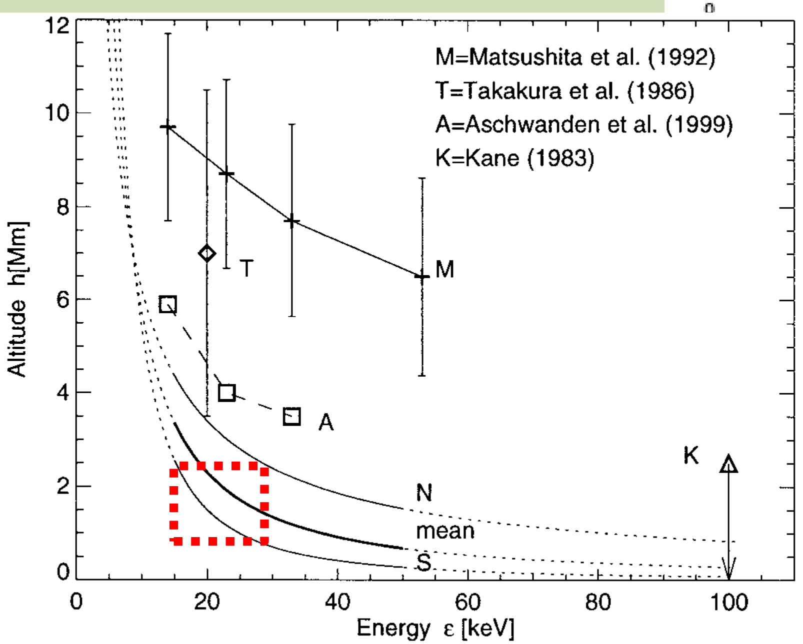
Energy and height of the flattening point

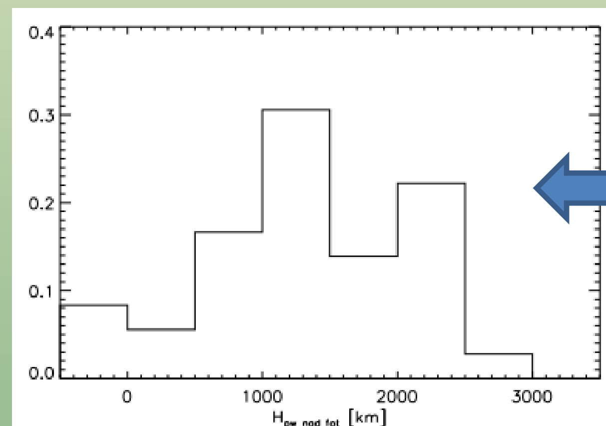


The chromsphere is very dynamic during the impulsive phase. How it will influence the E-H relation?



Aschwanden et al. 2002, Sol. Phys., 210, 373

Corrected for the actual photospheric level



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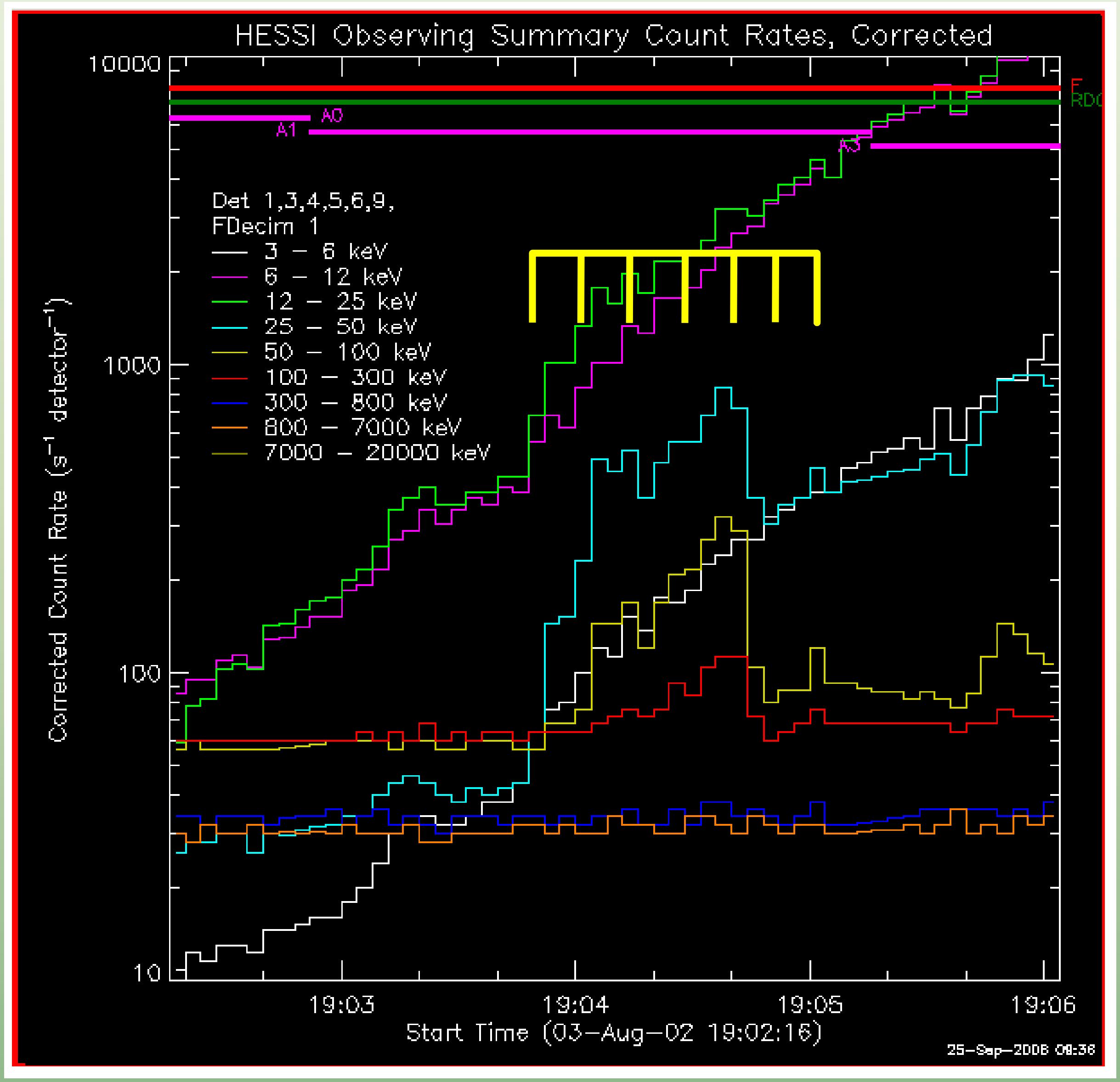

3-Aug-2002 ~ 19:07

Time interval covering this peak was divided into six 12 s subintervals

The E-H relations show systematical changes

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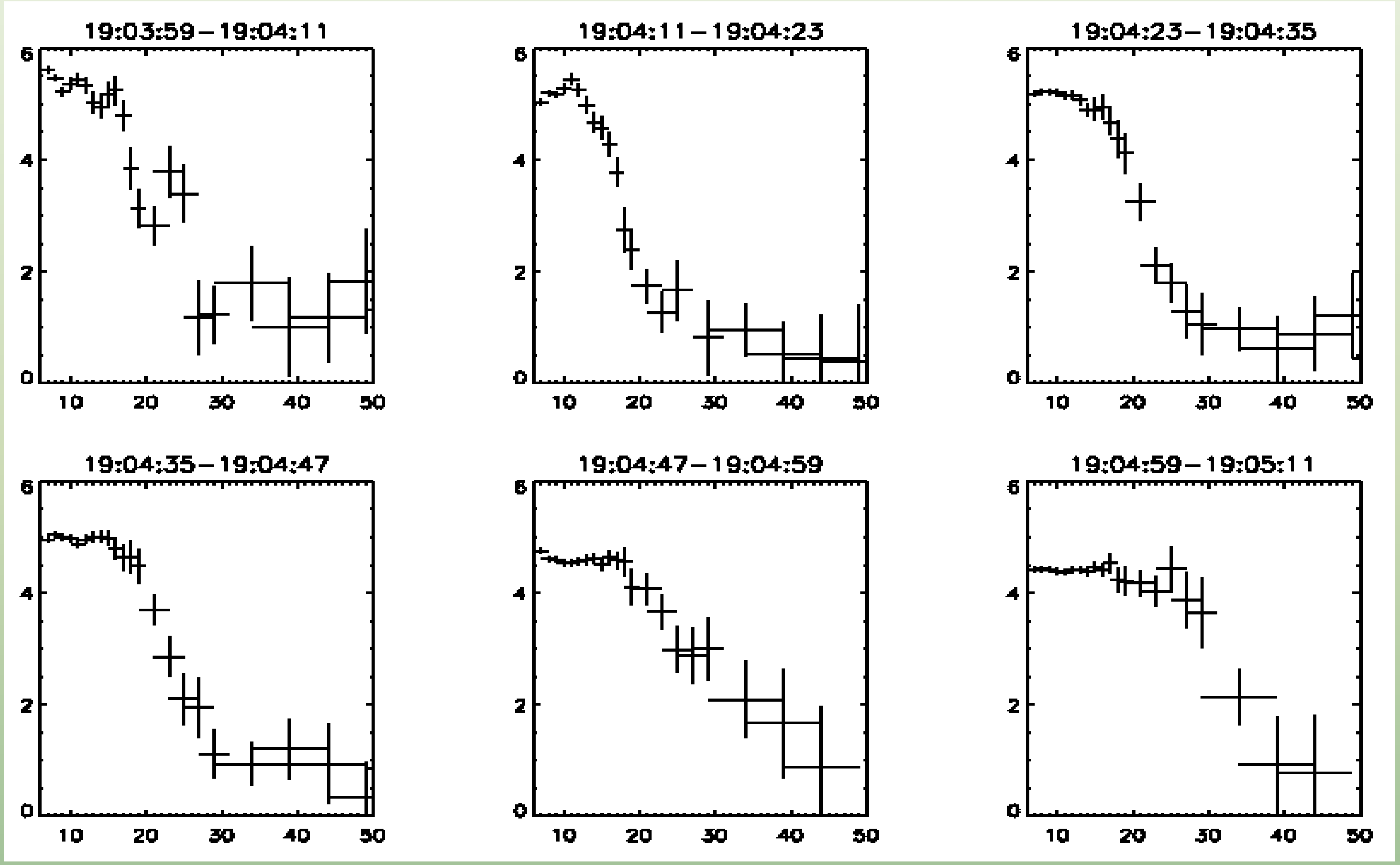

The changes resembles column density changes within chromosphere during the electron beam

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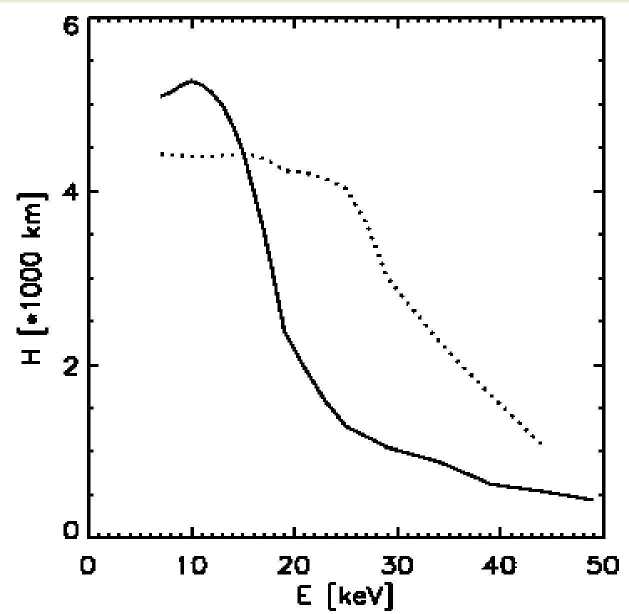
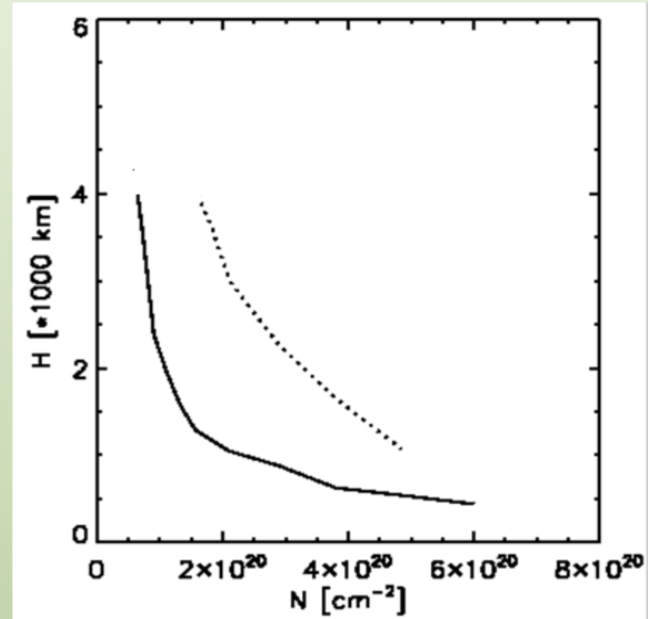


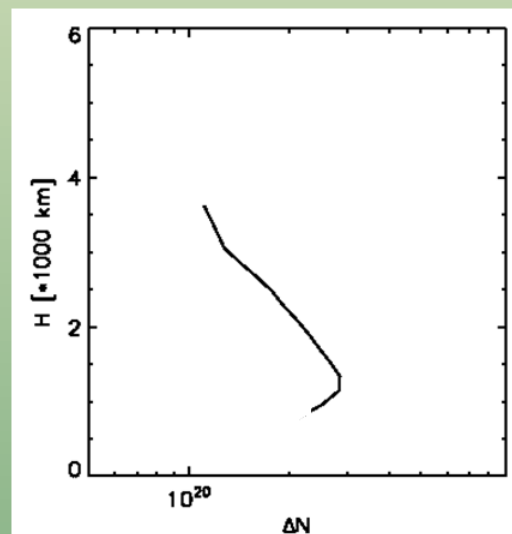
Two E-H relations obtained at the begining and the end of the main peak

$N(h) \sim E^2$

From purely non-thermal sources we calculated the column density-height relation



subtacting these two relations we obtain difference in the column density at several levels



Difference between column densities can be transferred to difference of masses

Additional mass above 1000 km is about 5×10^{13} g

Comparing EM in the loop-top kernel before the peak and during the maximum of the flare we obtained: 8×10^{13} g

Conclusions

Electrons can be trated as a very efficient diagnostic tool measuring physical conditions in the chromosphere.

Absolute heights of HXR sources can be obtained with self-consistent method.

The chromospheric evaporation can be investigated at the very early phase with great details.

The E-H relation gives valuable constraints for theoretical models of the impulsive phase.

Detailed modeling of the E-H relation for large group of events is wanted.