Investigation of the energy-height relation for solar flare footpoints observed by RHESSI

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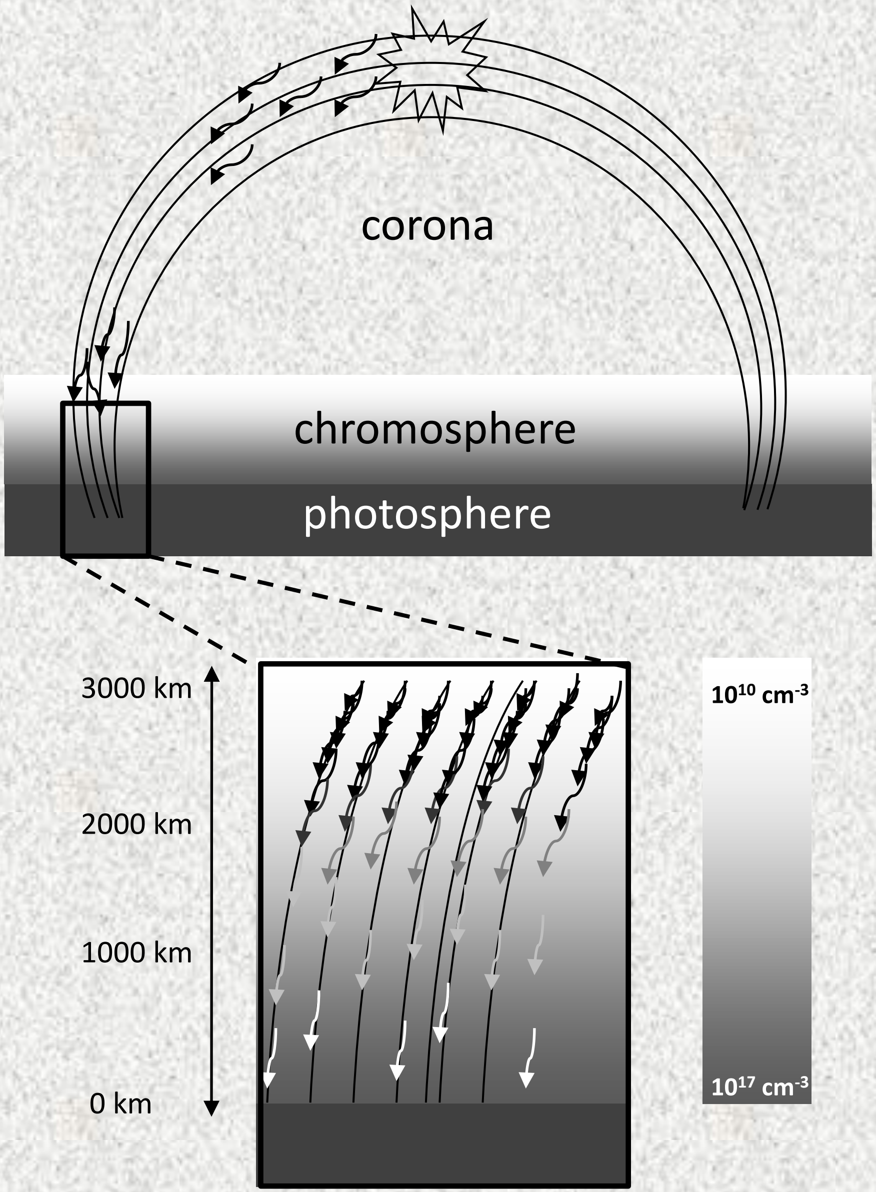
Theory



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):

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

Stopping depth for electron of energy E_0:

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

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**

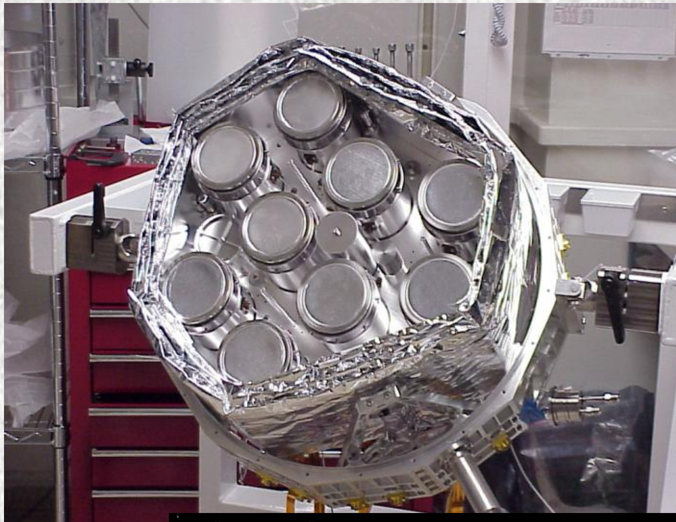
Matsushita, K., Masuda, S., Kosugi, T., Inda, M., and Yaji, K., 1992, Publ. Astron. Soc. Japan 44, L89

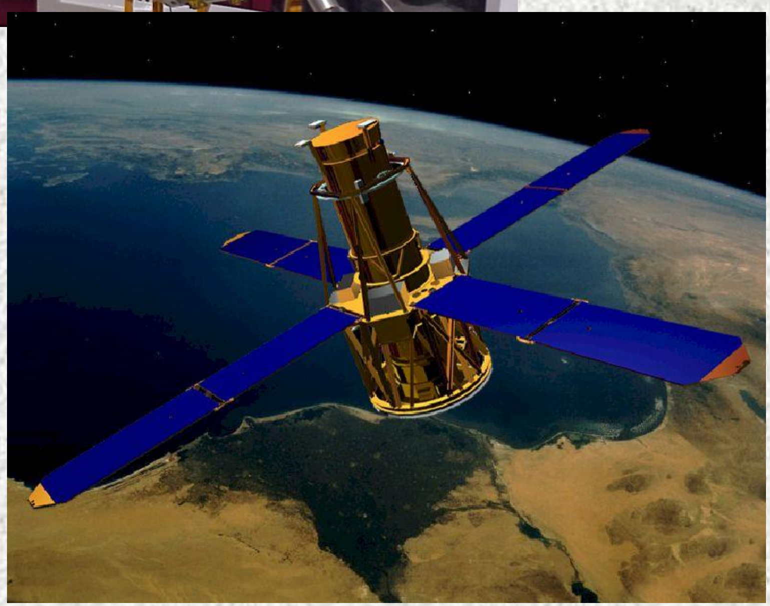
- **YOHKOH**
- **$h_{14} = 9.7 \pm 2.0$ Mm (L)**
- **$h_{23} = 8.7 \pm 0.3$ Mm (M1)**
- **$h_{33} = 7.7 \pm 0.5$ Mm (M2)**
- **$h_{53} = 6.5 \pm 0.7$ Mm (H)**

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)

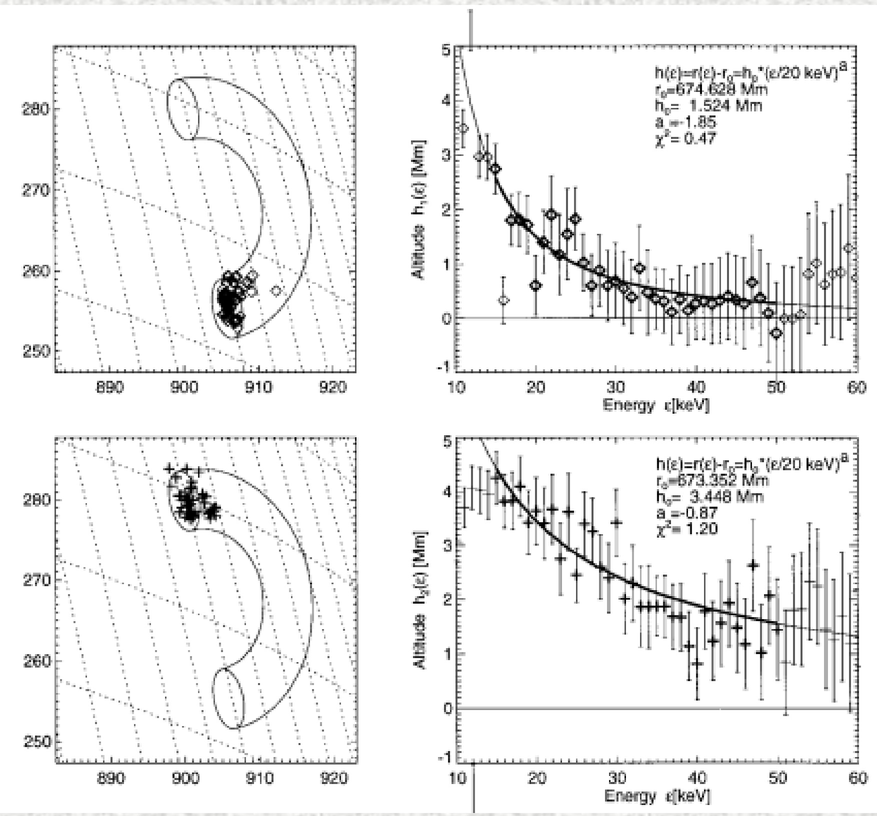
- temporal resolution for
  imaging depends on photon
  statistic, but must be equal
  at least ~2 s (half of the
  RHESSI rotation)

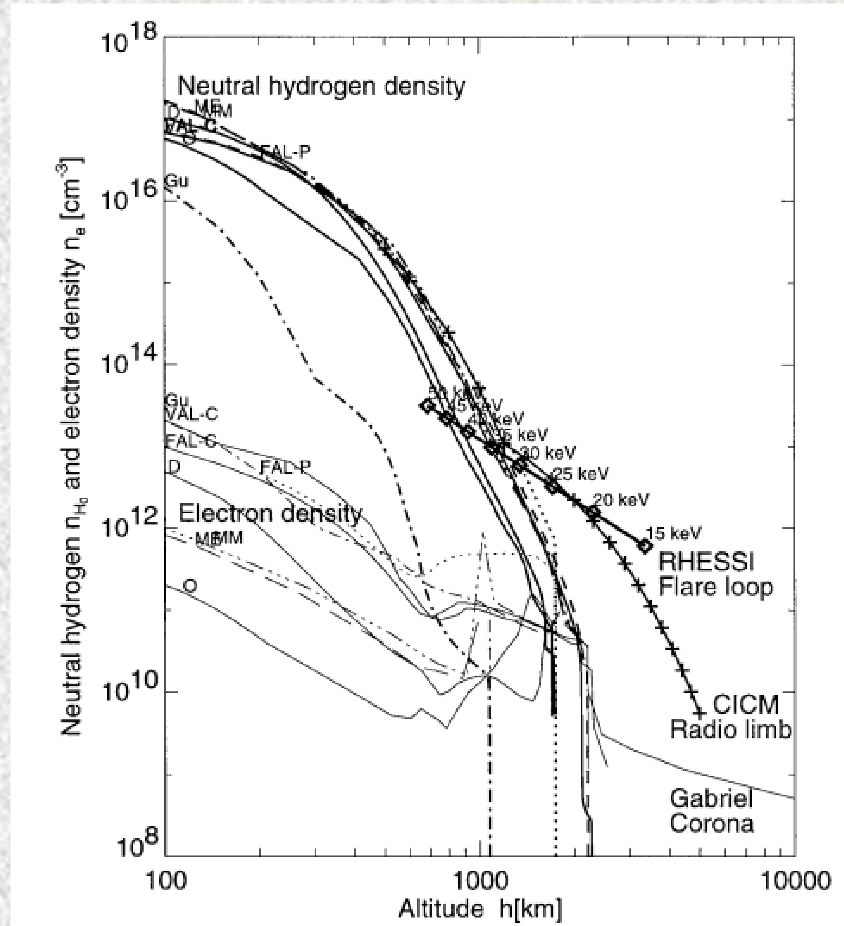
Observations with RHESSI

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

20 Feb 2002

Fit with power-law function
(easy for density calculation)





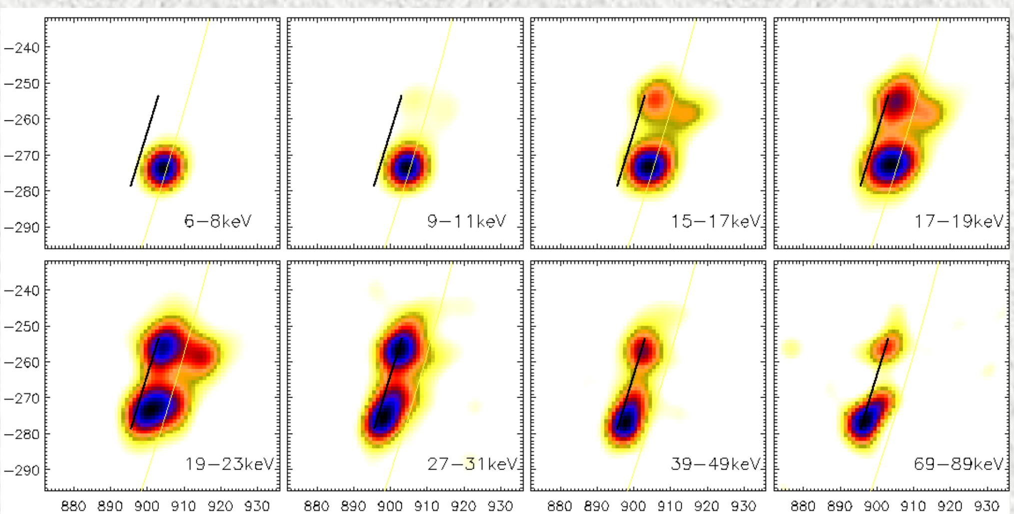
Energy: 15-50 keV
Heights: 4000-700 km

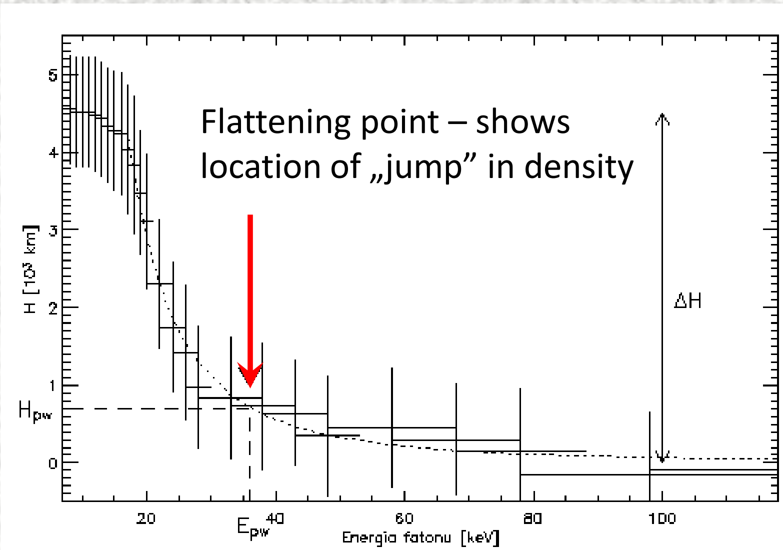
Observations with RHESSI

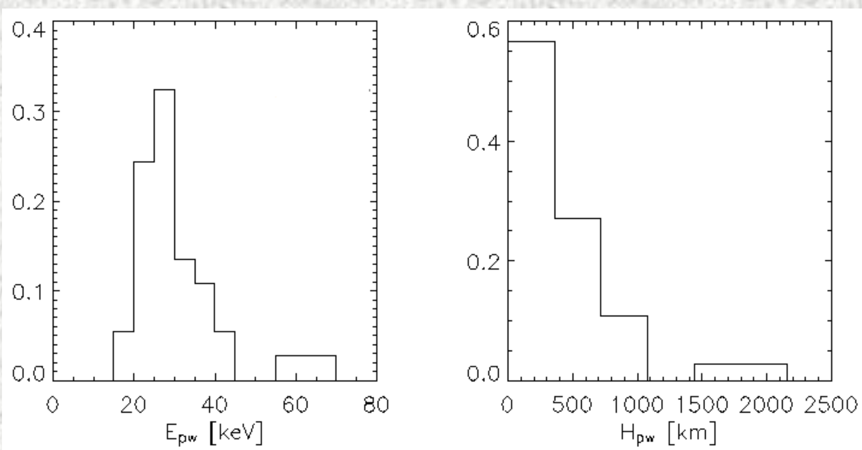
Mrozek, T. 2006, Adv. in Space Res. 38, 296

17 flares, 37 E-H relations

3 Aug 2002





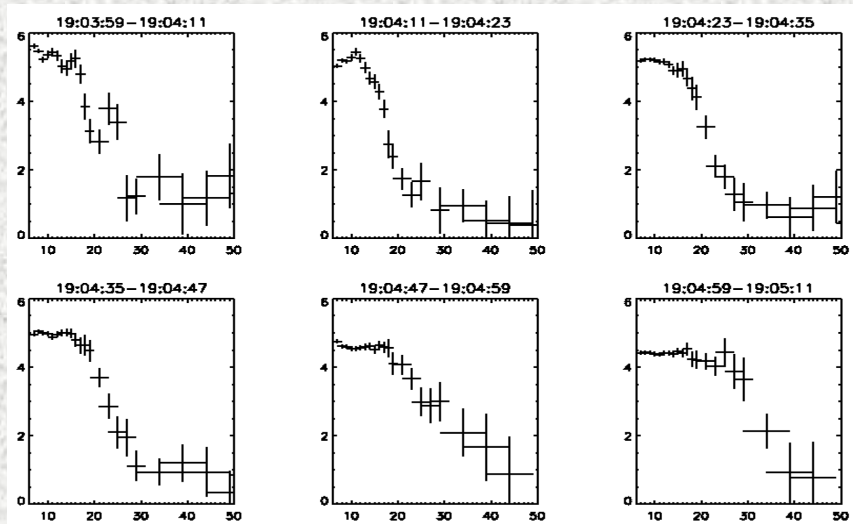


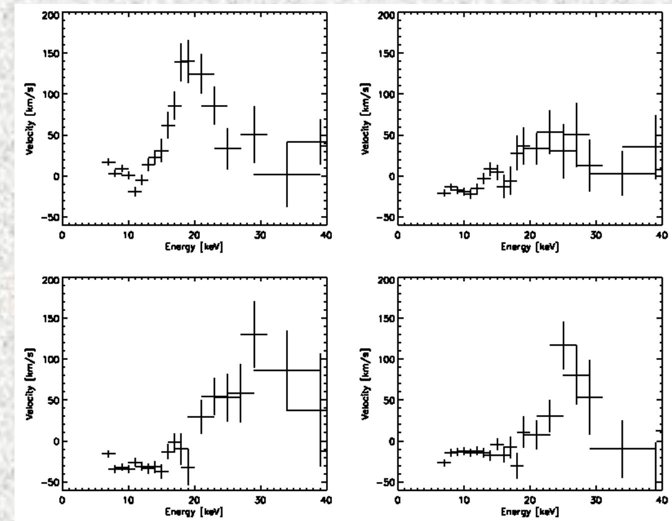
Energy: 20-40 keV
Height: <1000 km

Heights measured above the reference level defined by footpoints visible in highest energies – no absolute heights

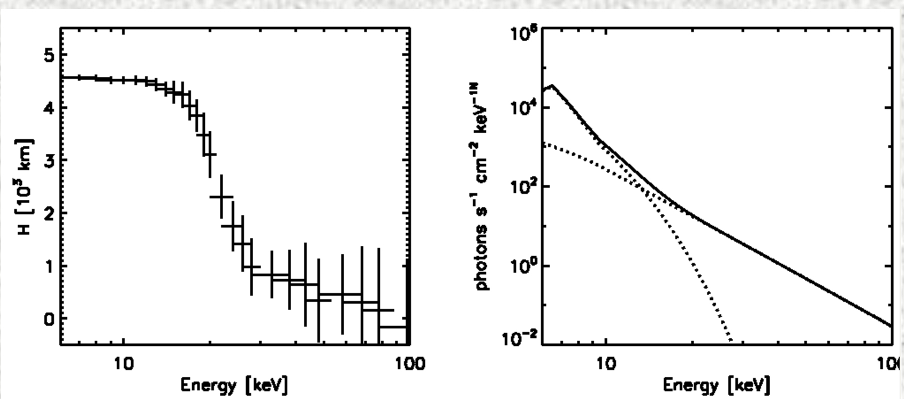
RHESSI

Mrozek, T. 2006, Adv. in Space Res. 38, 296





Details of velocity field in a footpoint



Two components in a spectrum of a footpoint

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Event selection

1	06 III 2004	12:11:56	M 1.3	S15E89	987
2	18 III 2004	06:00:40	C 3.7	N15E89	972
3	17 V 2004	04:13:52	C 7.0	S07W85	943
4	17 VII 2004	19:16:20	C 5.3	N07E85	943
5	18 VIII 2004	17:31:24	X 1.8	S13W89	964
6	12 IX 2004	18:29:52	C 2.0	S09W68	885
7	01 XI 2004	06:57:44	C 2.9	N12W83	941
8	23 XI 2004	15:04:24	C 6.5	S06E89	989
9	21 I 2005	00:21:08	C 5.8	N17W74	915
10	21 I 2005	10:12:56	M 1.7	N19W89	961
11	05 V 2005	20:11:16	C 7.8	S06W64	857
12	09 V 2005	18:44:44	B 9.7	N14E64	860
13	30 VII 2005	06:27:44	X 1.3	N08E59	822
14	22 VIII 2005	17:01:20	M 5.6	S16W64	865
15	08 IX 2005	16:54:52	M 2.1	S14E89	948
16	19 IX 2005	16:39:16	B 3.2	S12,W77	925

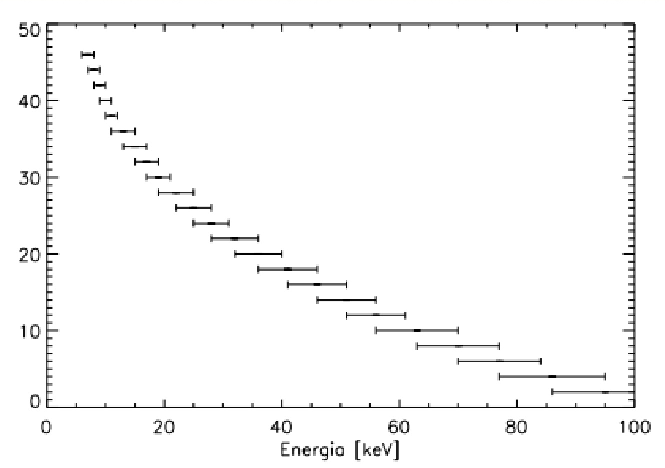
16 flares
36 E-H relations

Jan 2004 – Jan 2006

Radial distance > 800 arc sec

Images reconstructed with CLEAN method

Energy intervals selection:



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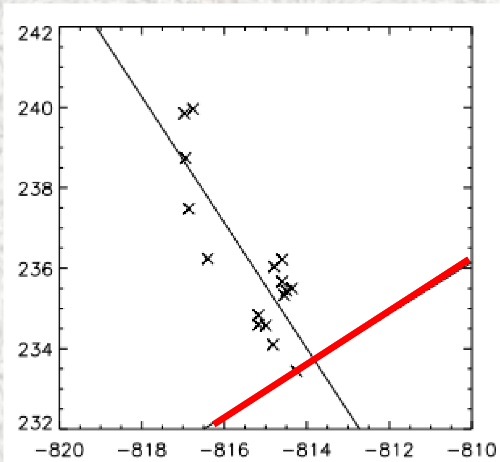
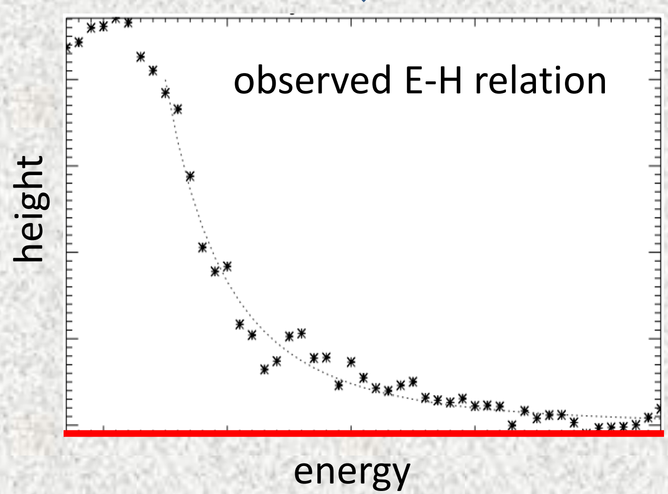
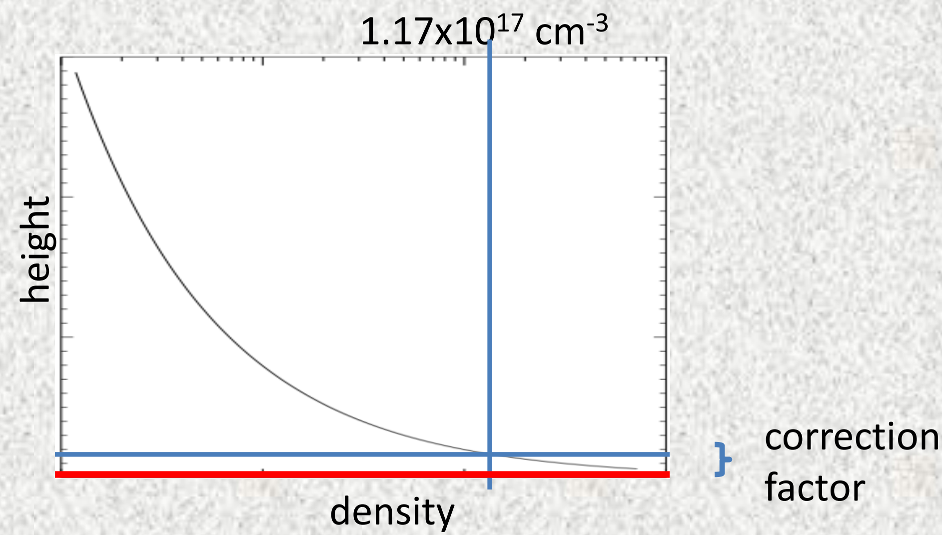
Construction of a reference level

Centroids of HXR sources observed in several energy intervals



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





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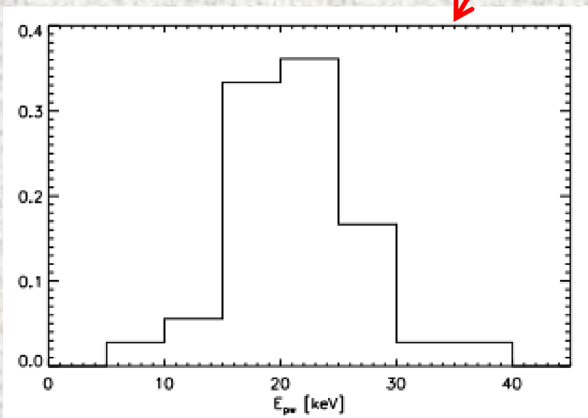
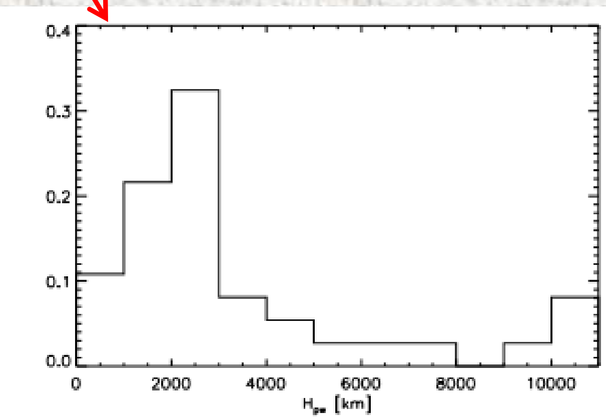
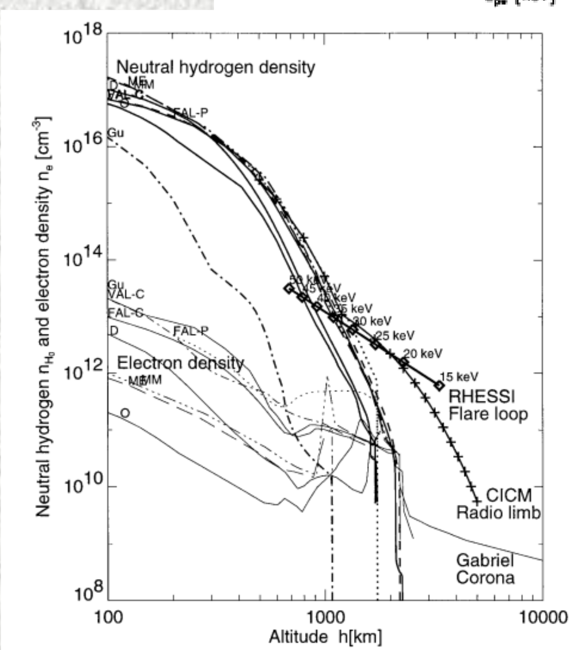
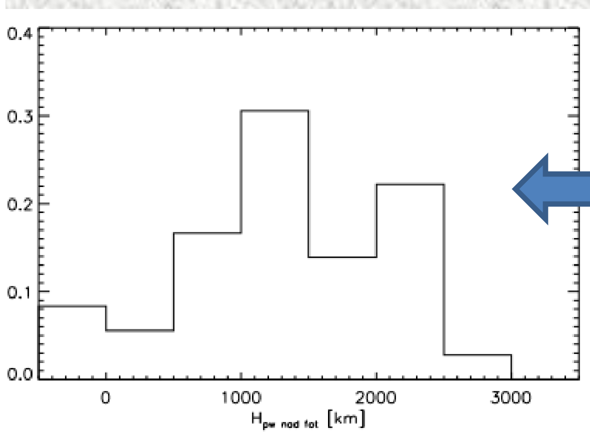
Results

Energy and height of the flattening point









Correction for the actual photosphere level

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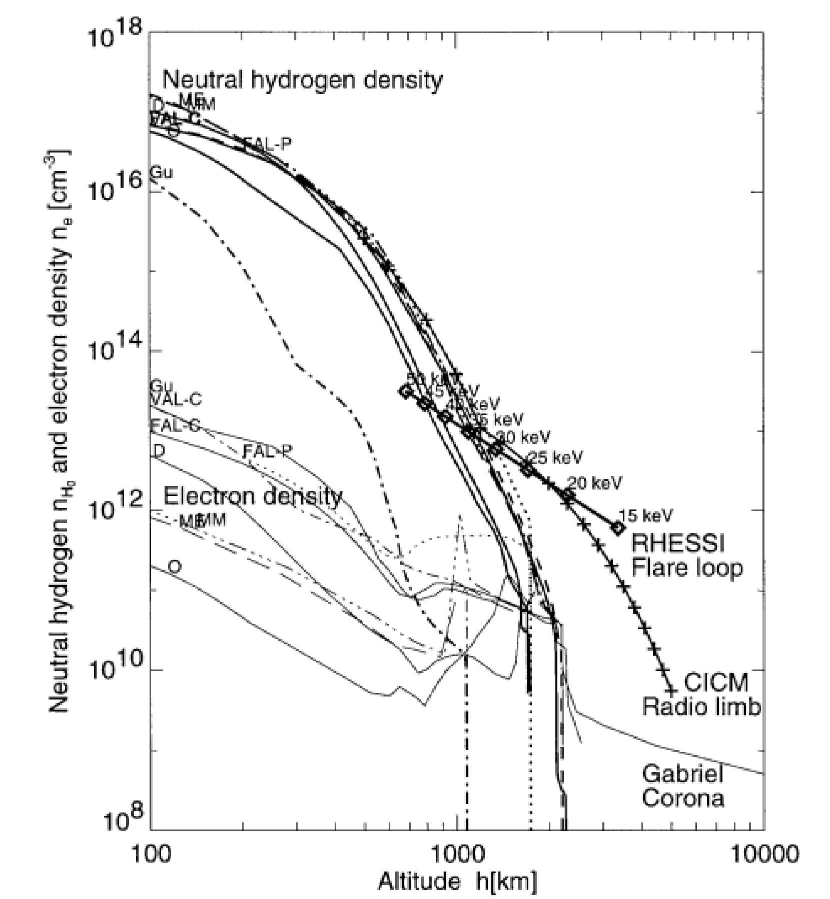
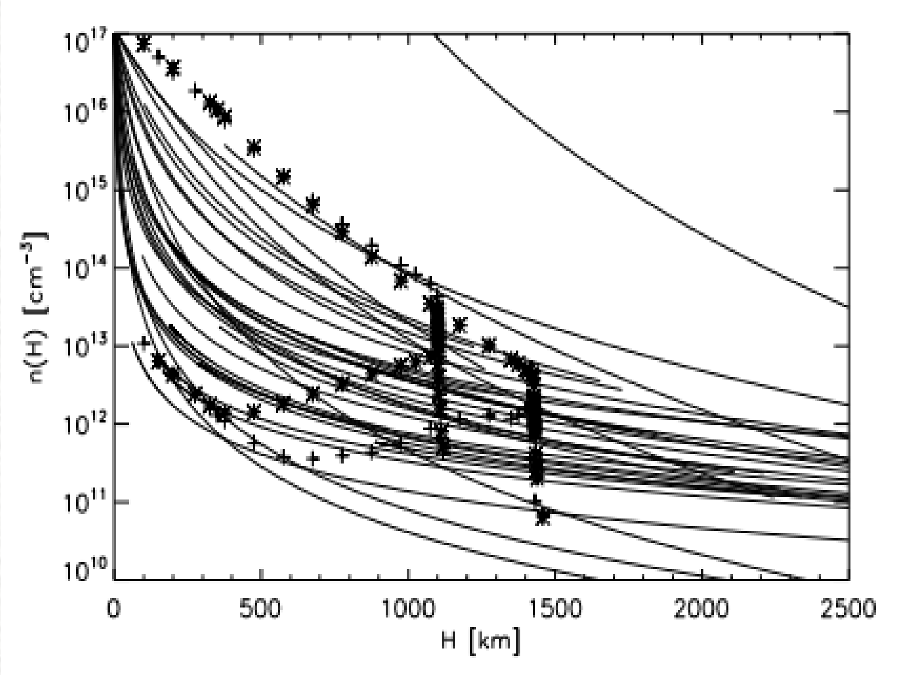
Results





asterisks - *Machado et al. 1980, ApJ 242, 336*
lines – Mrozek & Kowalczuk 20009

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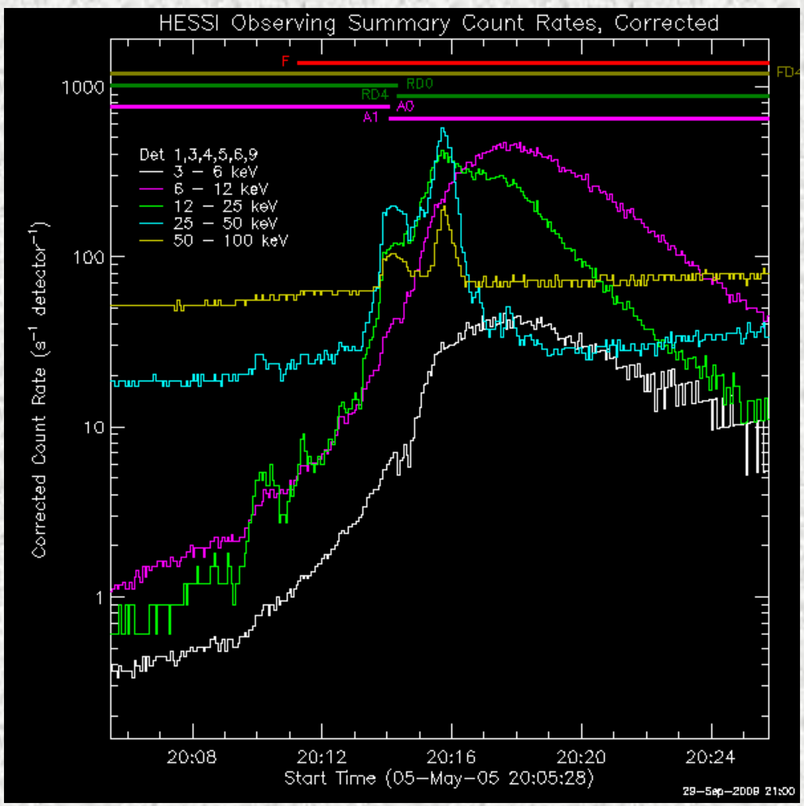
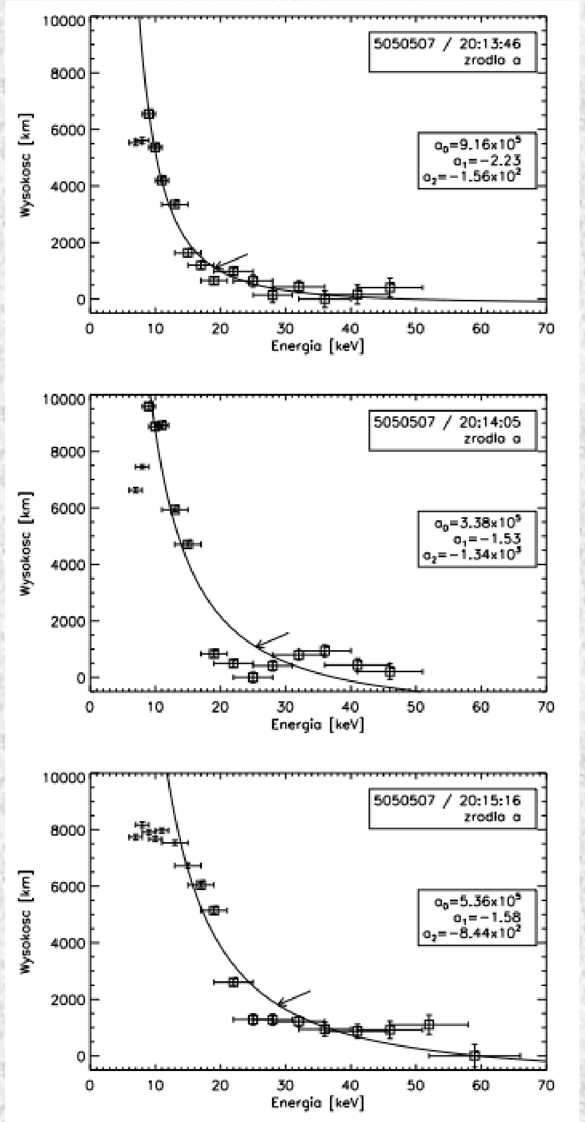
Results

Time evolution of E-H relation





Conclusions

Electrons can be trated as a tool measuring the density in the chromosphere.

The method has a great advantage in comparision with observations made in other wavelengths – the physics of emission is simple and it is optically thin.

Density measurements are in good agreement with previous ones.

The E-H relation gives valuable constraints for theoretical models.

Future:

Analysis of the data from January 2006 up to present (easy work, few flares observed)

Detailed modeling of E-H relation (more realistic cross-sections, spectral dependence)

Repeating a work made by Fletcher but with our better height measurements

Modeling the relation between a height in a solar atmosphere and an energy deposited by non-thermal electron beam, but with use of observed E-H relation – important for flare energy budget