MULTI-TEMPERATURE MODEL FOR POST-ERUPTIVE CORONAL LOOPS OBSERVED AT THE EUV-RANGE AND MICROWAVES

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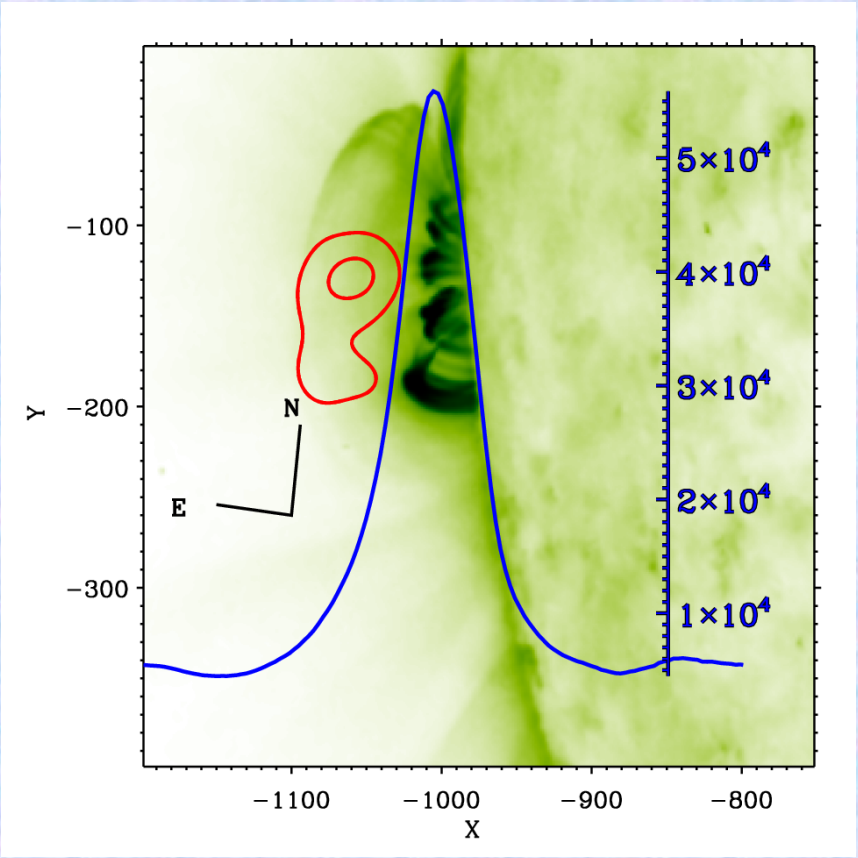
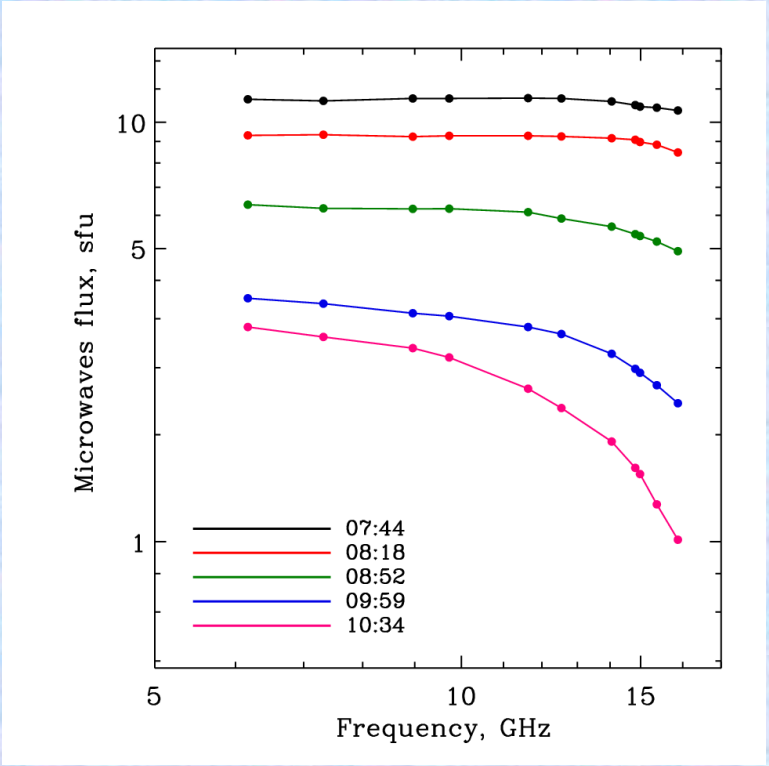
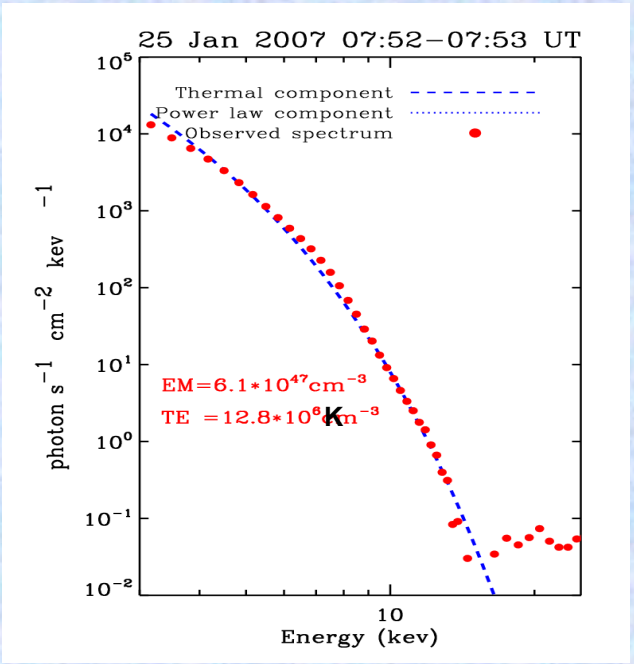
Cambridge, September, 2010







25.01.2007

X-Ray Flare C 6.3 E-limb 6:33-7:58 UT

RATAN–600 8:18 UT

SOHO/EIT 8:12 UT 195 A

RHESSI 6 -12 keV

Contour levels are 90% and 60% of maximum

I.Y.Grigoryeva, V.N.Borovik, M.A.Livshits et al.

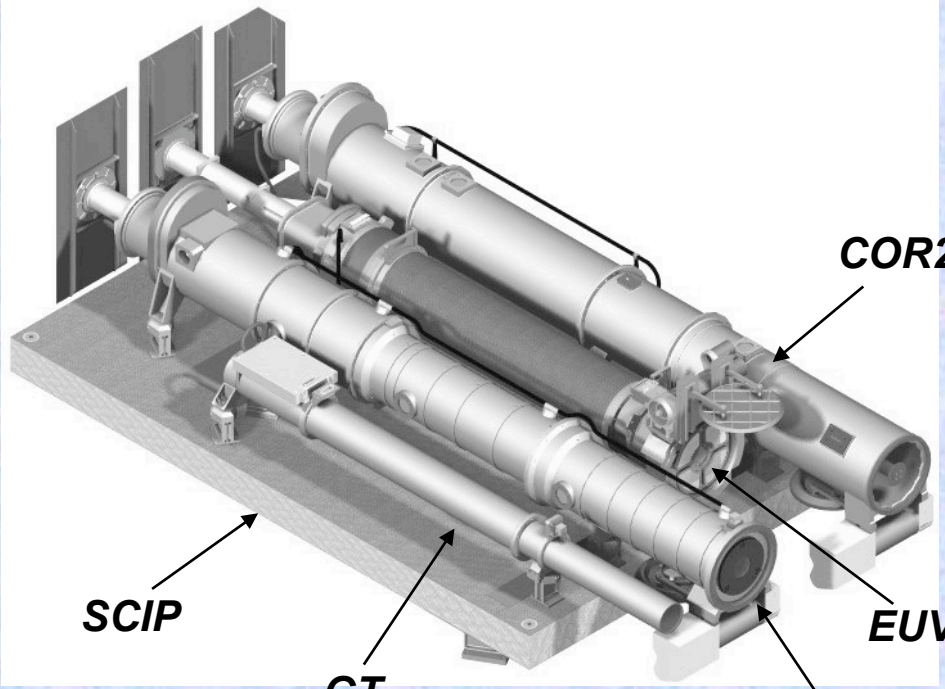
Solar Phys. 2009, 260, 157-175

STEREO (Solar TErrestrial RElations Observatory)

SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation)

Angelo ***Secchi (1818-1878)***

EUVI (Extreme UltraViolet Imager) –
the chromosphere and the low corona
COR1, COR2 (coronographs) – 1.4 -15 R_O
GT (Guide Telescope)
SCIP (Sun Centered Imaging Package)



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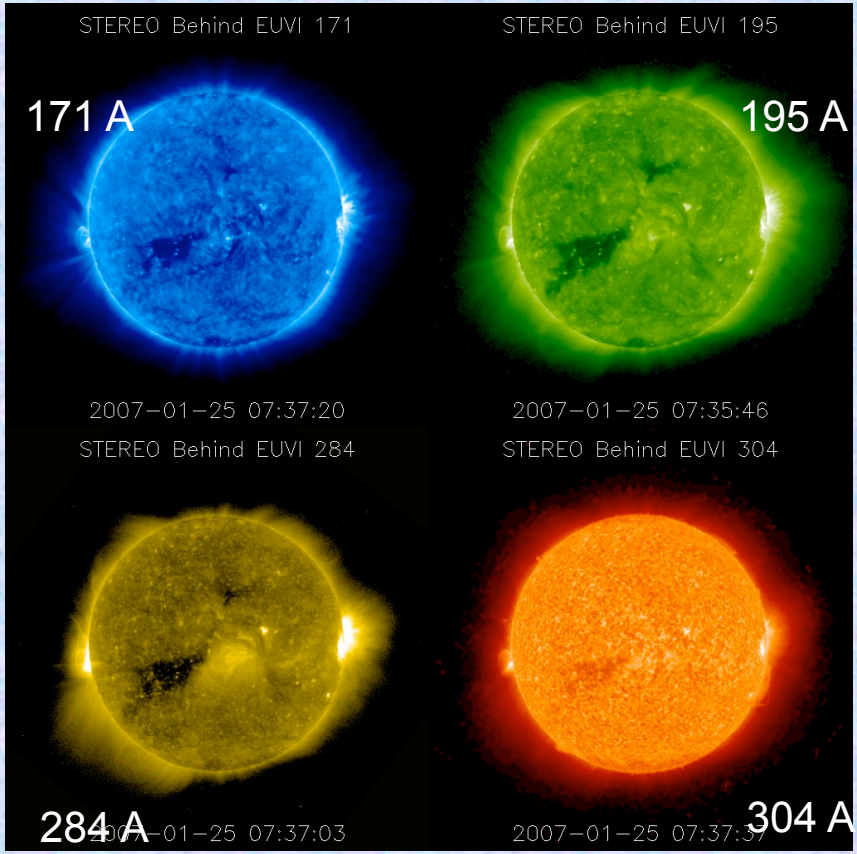
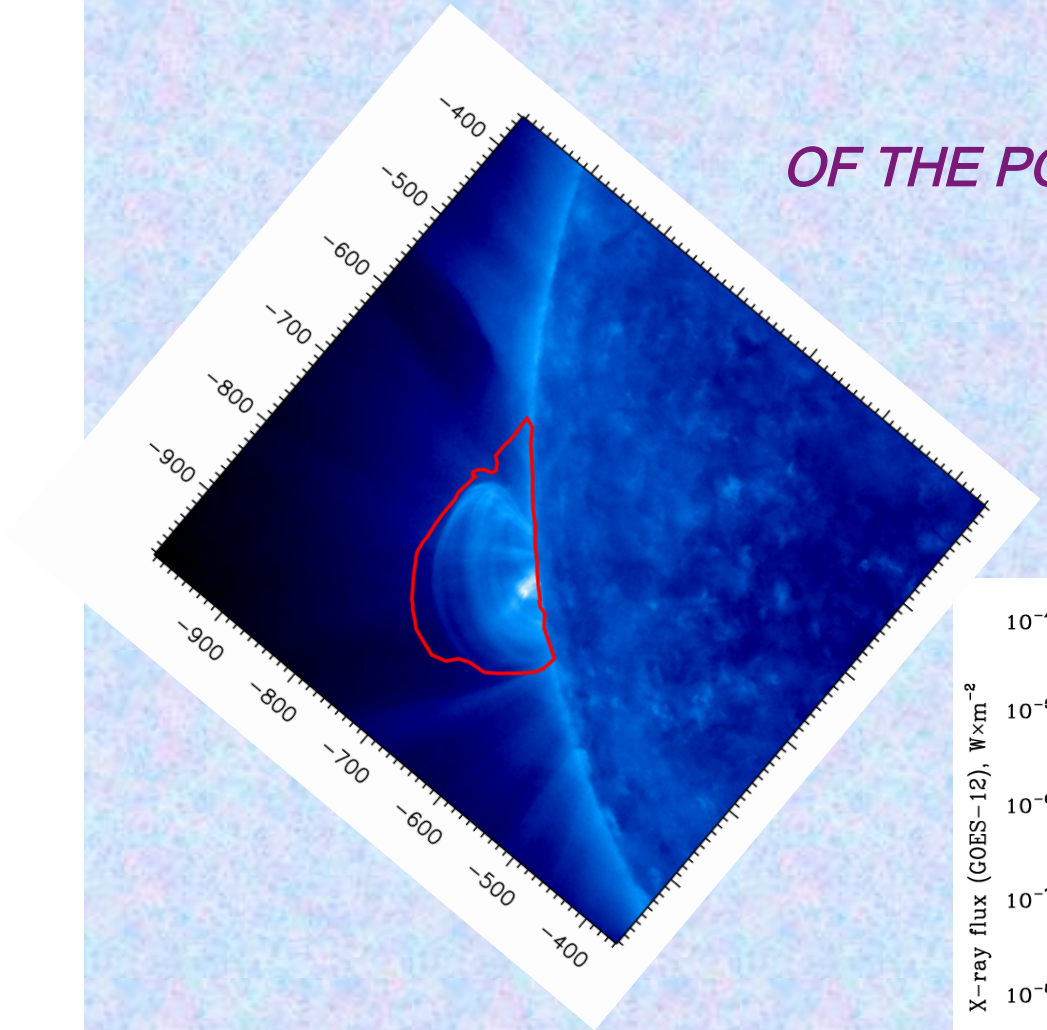
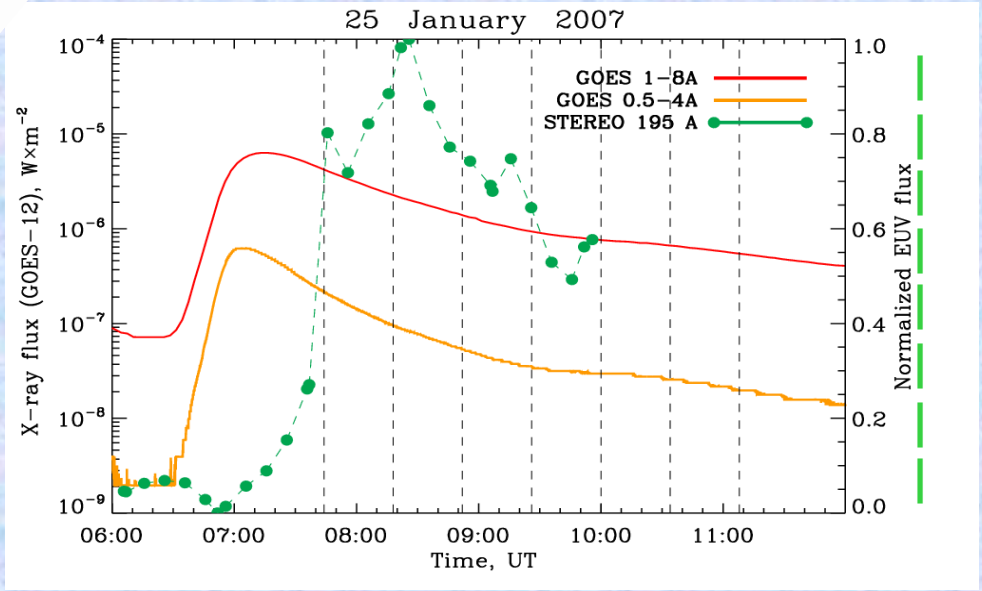


Space Sci Rev. (2008) 136: 67–115
Proc. of SPIE Vol. 5171: 112 -122

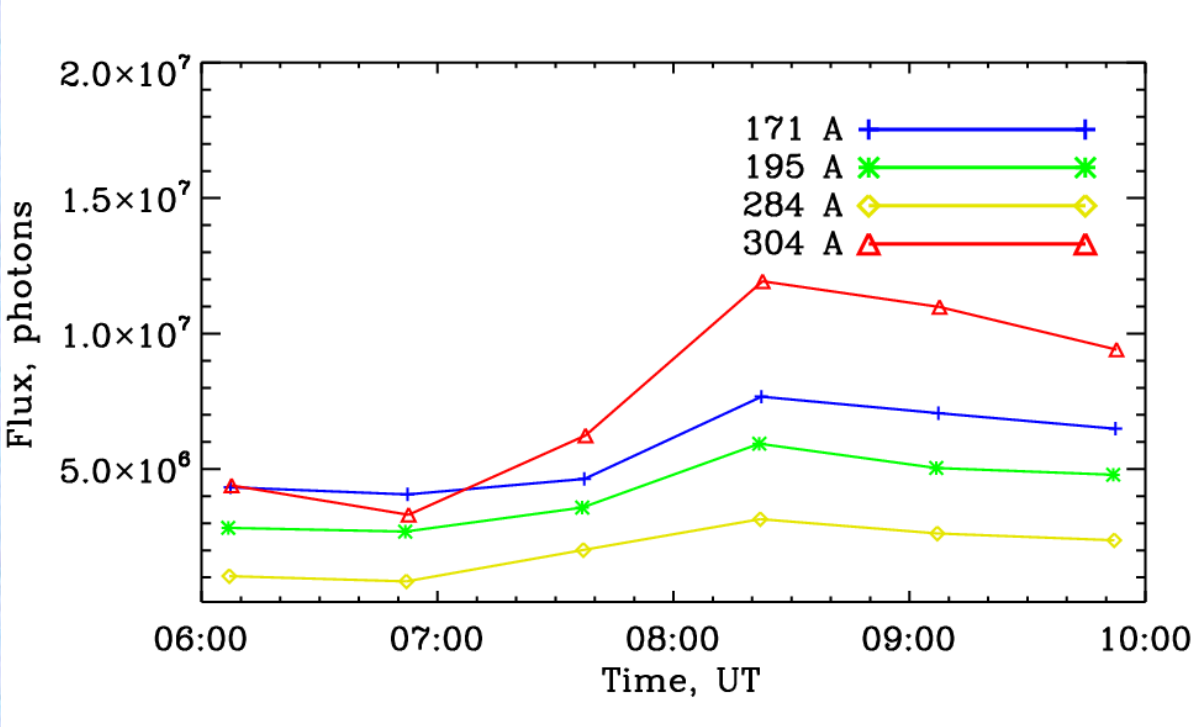
EMISSION FLUXES OF THE POST-ERUPTIVE ARCH SYSTEM





7 RATAN – 600 scans

TEMPORAL BEHAVIOUR OF FLUXES FROM SECCHI/STEREO DATA



DEM analysis

- To obtain the temperature profile of the DEM the probabilistic approach have been applied. This approach provides different mathematical formalization of the same physical (inverse) problem as the standard (“algebraic”) one.

  Within the probabilistic approach the iterative method based on the Bayesian theorem was used (Bayesian Iterative Method, BIM). For more details see ***Urnov et al.*** *Astronomy Letters, 2007, Vol. 33, No. 6, pp. 396–410* ; ***Goryaev et al.*** A&A, 2010 (in press).

  The calculations were made on the basis of the CHIANTI database

Standard ("algebraic") approach to the spectral inverse problem

Fredholm equation of the first kind:

$$F(l) = \int_{\Delta T} G(l \mid T) \cdot y(T) dT$$

F*(*l*)** is the measured flux in the spectral channel ***l;
G(*l*|*T*) is the plasma luminosity ("contribution function") for the channel ***l*** at the temperature ***T*** given by a theoretical model;
y*(*T*)=DEM(*T*)** is the density distribution function of matter over ***T.

Due to the ill-posedness of this problem various regularization methods are used to derive an approximate solution ***y*(*T*)**

Probabilistic approach

Formula of the total probability for the distributions $P(l)$, $P(l|T)$ and $P(T)$:

$$P(l) = \int_{\Delta T} P(l \mid T) \cdot P(T) dT$$

$$P(l) = \frac{F(l)}{F}$$

is a probability distribution for an emitted photon over spectral channels l ($F = \sum F(l)$)

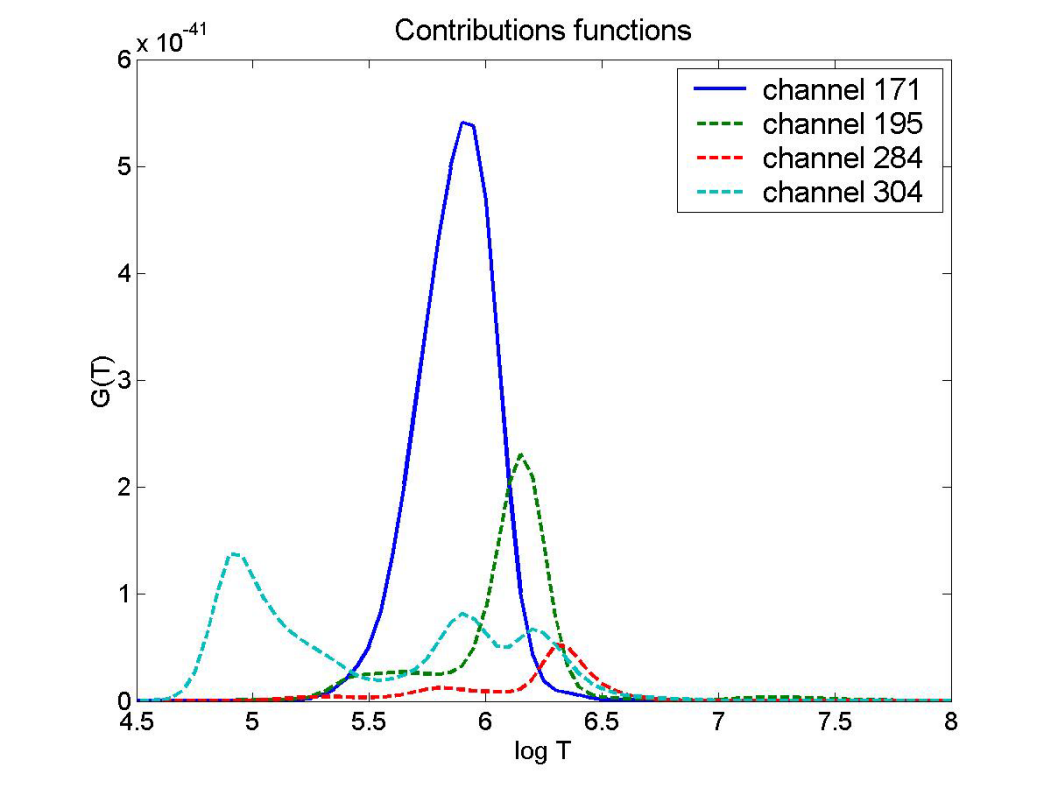
$$P(l \mid T) = \frac{G(l \mid T)}{G(T)}$$

is a probability for a photon to be emitted in the channel l at the condition to be emitted at the temperature T ($G(T) = \sum G(l|T)$)

$$P(T) = y(T) \cdot \frac{G(T)}{F}$$

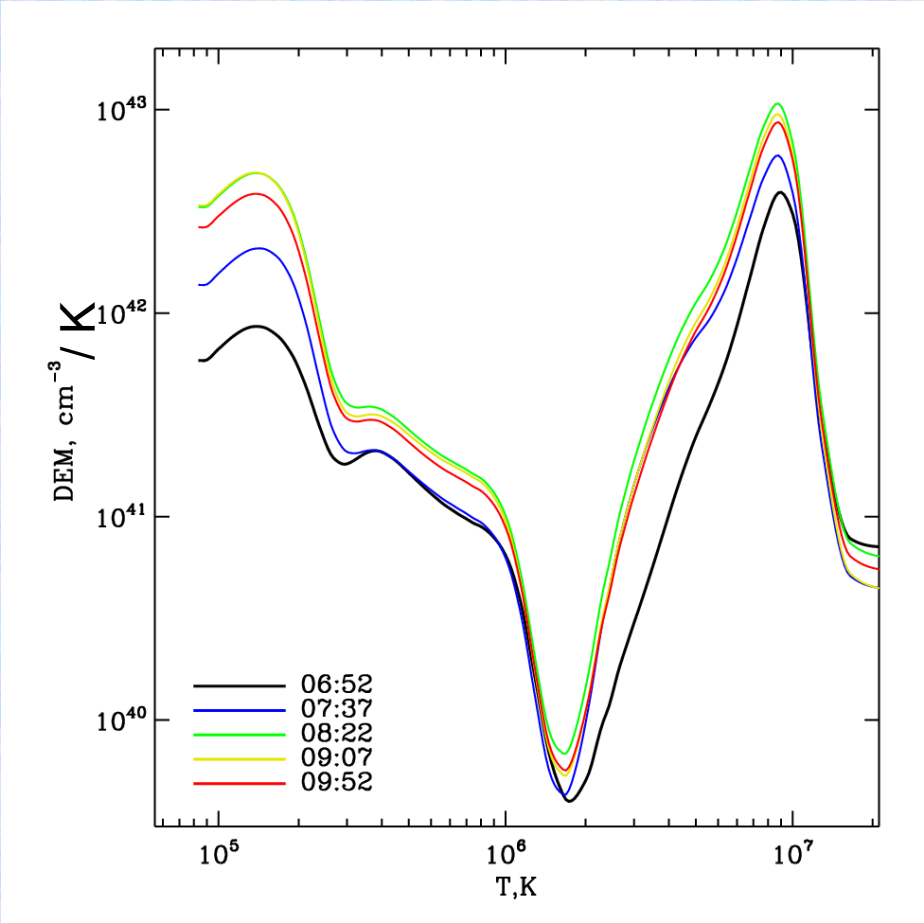
is a probability density for a photon to be emitted at the temperature T.

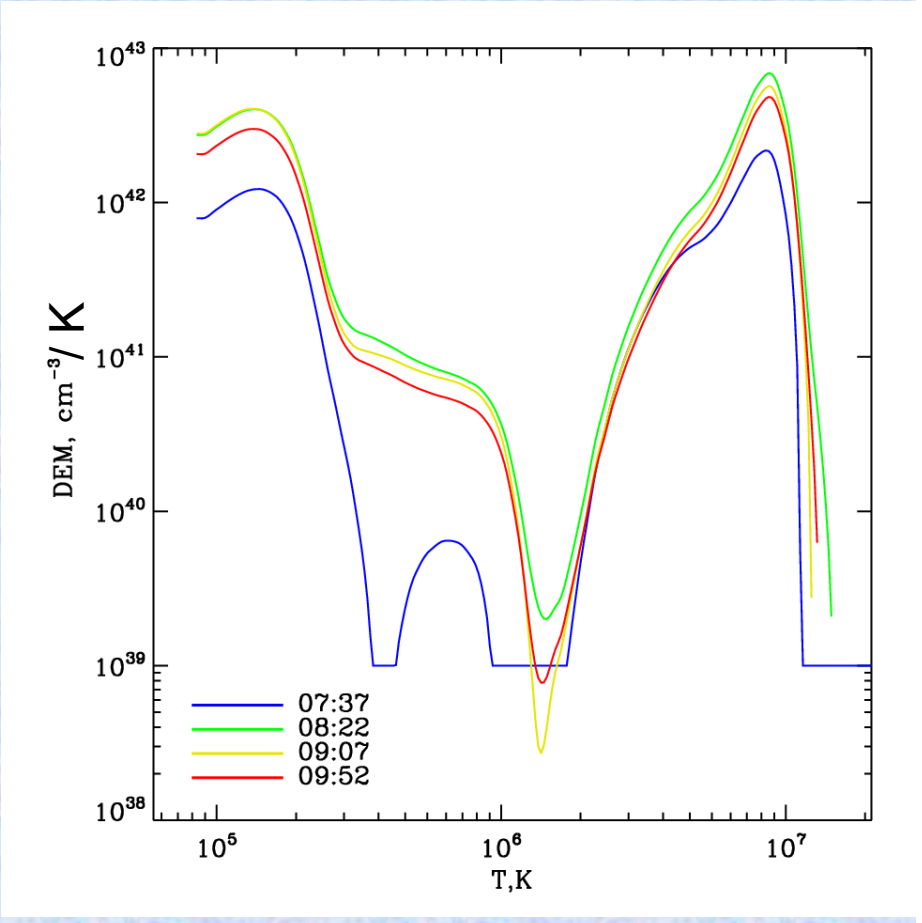
Contribution functions for STEREO spectral channels



- The calculations were made by means of the CHIANTI database

Temperature profiles of the DEM





Left: DEM(T,t) [cm^-3/K]

Right: ΔDEM(T,t)=DEM(T,t)-DEM(T,t_o)

Cyclotron radiation of thermal plasma in the post-eruptive arch system

- Difference between DEM(T) at the beginning of development of the post-eruptive arch system and at its maximum allows us to estimate amount of the hot plasma

- We propose the simplest multi-T model of the coronal source: lower parts of loops are considered as two vertical columns with the hydrostatic density distribution and the temperatures of 4 MK and 8 MK respectively. We ignore the cooler plasma (0.1 MK) because it does not contribute into the microwave fluxes. We adopt that these columns are angled to observer at 45 degrees. The magnetic field strength does decrease with the height.

- Then we calculate the cyclotron radiation of the source similar to one as it carries out for the atmosphere above the spot.

$n_e = 2 \cdot 10^{10}\ cm^{-3} \exp - h/14 \cdot 10^8$ T=4 MK R= $5 \cdot 10^8$ cm

$n_e = 5 \cdot 10^{10}\ cm^{-3} \exp - h/28 \cdot 10^8$ T=8 MK R= $5 \cdot 10^8$ cm

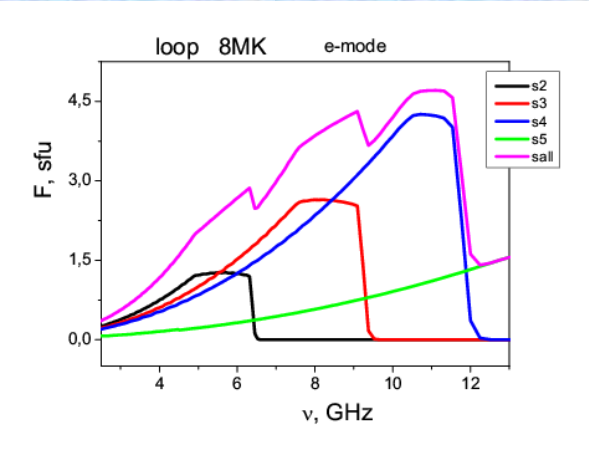
$B = 1000[1 - h/(24 \cdot 10^8)]$ G

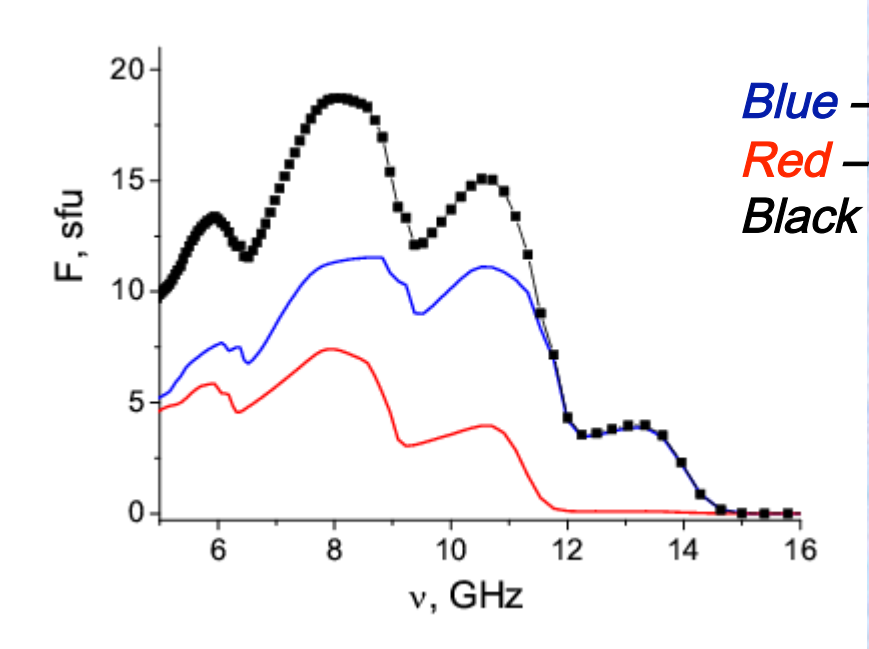
h = 22 000 km, B = 83 G

Adopted model of the source (post-eruptive arch system)

This model considering a source as a set of two columns is presented for illustration only.

The Spectrum of the Cyclotron Radiation

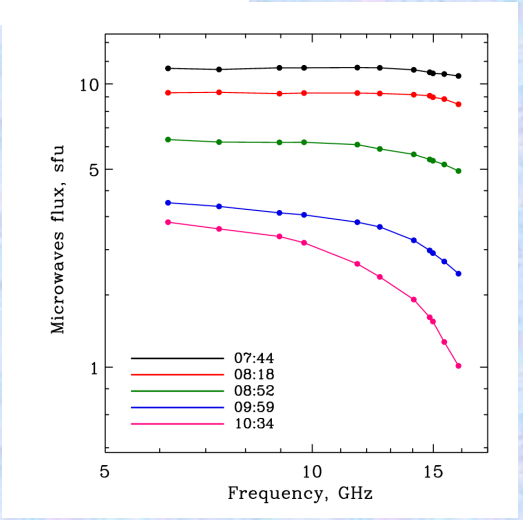




Blue – E wave
Red – O wave
Black is their sum

So, we obtain a shape of the spectrum
of the thermal radiation similar to observed one.

If this simplest model is realized, the circular polarization should be observable. The lower values are registered that is due to in fact the source contains a set of loops that are oriented by different ways. The more complicated model is in progress.

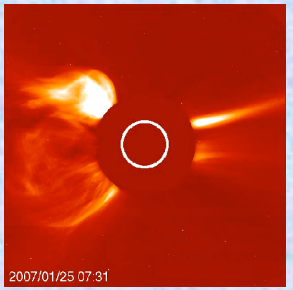


Conclusion

- Thanks to the multi-T analysis we solve contradiction between microwave observations of post-eruptive arch systems and their conventional interpretation.

- We confirm the presence of large amount of the hot plasma in post-eruptive loops.

- Interpretation of real observations requires more complicated models. Now it is clear that the thermal plasma exists at the start of formation of the arch system, but even for weak events, small contribution of accelerated particles is possible.
- During subsequent several hours, microwave radiation arises due to the thermal cyclotron mechanism. It means that in lower part of loops the magnetic field of 700 – 1000 G does exist and decreases up to tens G at loop tops.



Thanks for your attention

Yalta in Winter,time ,Crim

Bayesian Iterative Method (BIM)

$$P^{(n+1)}(T) = P^{(n)}(T) \cdot f\left[P^{(obs)}(l); P^{(n)}(l); T\right]$$

$$P^{(n)}(l) = \int_{\Delta T} P(l \mid T) \cdot P^{(n)}(T) dT$$

This iterative procedure is non-linear and is obtained on basis of Bayes' theorem

$P^{(0)}(T)$ is a priori probability density

χ^2 – criterion and $P(\text{obs})/P(n)$ is used to estimate the rate of the convergence and the number of iterations

Features of the BIM

- The language of the probability theory and mathematical statistics is used (distribution functions, hypothesis, confidence level etc.).
- The BIM is deduced by a regular way on the basis of Bayes' theorem.
- The regularization procedure is not needed.
- The BIM algorithm, being considered as a sequential estimation of a current hypothesis for the DEM distribution, corresponds to the Maximum Likelihood (ML) criterion.
- The BIM provides the ultimate resolution enhancement as compared with other non-parametric methods (Gelfgat et al. 1993).