The high accuracy model of the 19 July 2012 solar flare: kinetic description, calculations of X-Ray and microwave emission

European Geosciences Union
General Assembly 2016

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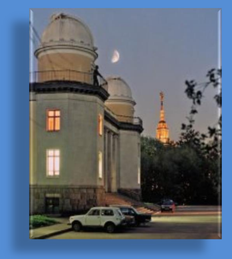


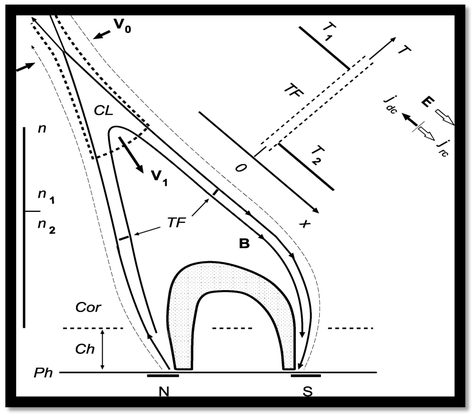
Introduction

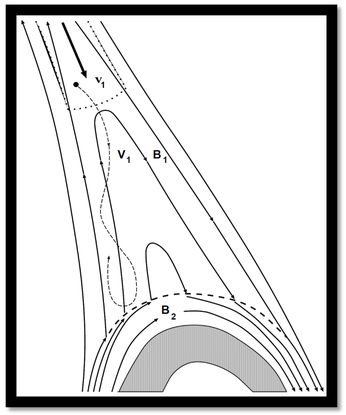
The limb white-light solar flare M7.7 class was observed at the 19 July 2012 at 05:58UT by RHESSI, GOES and SDO with high spectral, spatial and temporal resolution. These new data make possible to test modern models of solar flares. The flare, which considered here, locates in the picture plane, so we well see two different hard X-ray sources: footpoint and above-the-loop-top. The loop was observed in whit-light and microwave wavelengths. The key part of the present work is high accuracy kinetic model, which describe behavior of electrons in the target – solar flare loop. We interpret the footpoint source in approximation of the thick target model with reverse current and above-the-loop-top source – in the thin target approximation.

The exact analytical solution for the appropriate kinetic equation with Landau collision integral was found. Using derived distribution function of electrons we've calculated evolution of their energy spectrum and plasma heating, microwave emission and characteristics of hard x-ray emission in the corona and in the chromosphere for the 19 July 2012 solar flare. To fit observations of the coronal X-Ray source we also had to take into account electrons acceleration in the coronal magnetic trap.

We think that in this flare is present first observation of the Fermi and the betatron accelerations in solar flares!!!

Problem formulation





Methods

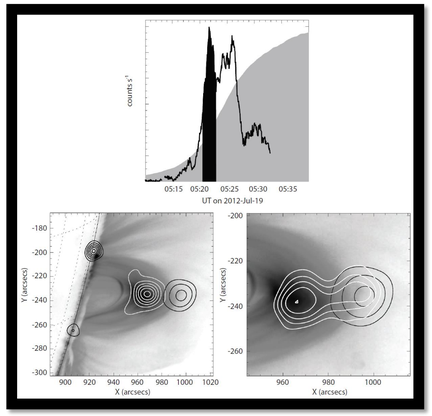
The fast electrons distribution function was found from the Boltzman kinetic equation with Landau collision integral:

$$\frac{\partial f}{\partial t} + v_\alpha \frac{\partial f}{\partial r_\alpha} + \frac{q}{m}\left\{E_\alpha + \frac{1}{c}\left[\mathbf{v}\times(\mathbf{B}+\mathbf{B}_0)\right]_\alpha\right\}\frac{\partial f}{\partial v_\alpha} = -\frac{\partial}{\partial v_\alpha} J_\alpha$$

$$\mu z^2 \frac{\partial f}{\partial s} - 2\varepsilon\mu z^2 \frac{\partial f}{\partial z} - \varepsilon z(1-\mu^2)\frac{\partial f}{\partial \mu} = z\frac{\partial f}{\partial z} + \tau z \frac{\partial^2 f}{\partial z^2} + \frac{1}{2}\frac{\partial}{\partial \mu}\left[(1-\mu^2)\frac{\partial f}{\partial \mu}\right]$$

$$\mu = \cos\theta \qquad \varepsilon = \frac{kT_0 E}{2\pi n_1 e^3 \ln\Lambda}$$

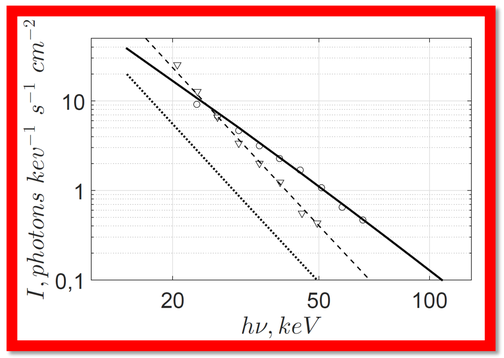
$$z = mv^2/2kT_0 \qquad s = \frac{\pi e^4 \ln\Lambda}{(kT_0)^2}\int_0^l n_1(l')dl'$$



Observations (M7.7 flare, 19.07.2012)

Super-hot plasma temperature: 10^8 K
Cold background plasma temperature: 2.1×10^7 K
Hard X-Ray spectral index (chromosphere source): 3.0
Hard X-Ray spectral index (coronal source): 4.6
Electrons energy range: from 15 keV to 1.2 MeV
Background plasma density: 3×10^9 cm^{-3}
Magnetic field value: 100 G

Results of Simulations
X-Ray spectra for the 19 July 2012 solar flare

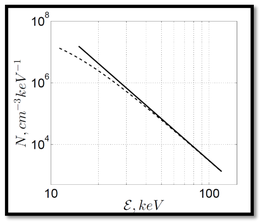


Solid line – Chromosphere source (observations were drawn as circles)
Dotted line – Coronal source (observations were drawn as triangles)
Dashed line – Coronal source spectrum, which was calculated with effect of the magnetic trap acceleration! The model works!

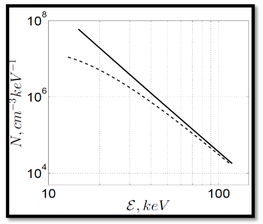
Results consist with known theory predictions: the power-law spectra don't change the power-law index if we take into account acceleration in the magnetic trap

Results of Simulations
Energy spectra of accelerated electrons

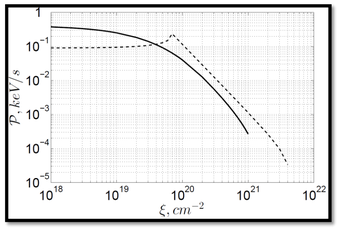
A). In the classical thick-target model



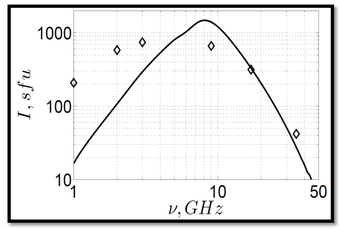
B). In the model with reverse current



Cold plasma heating



Microwave spectra in the corona



Conclusions

✓ in case of the classical thick target model is impossible to describe correctly both hard x-ray sources (coronal and chromosphere); but it's possible in our model **with reverse current** and **with acceleration in the magnetic trap**;

✓the reverse current electric field significantly changes particles propagation in solar flares. It decelerates part of the electrons in the beam and turns back other part of them without significant energy losses;

✓too many electrons in the corona (versus the classical thick target model) generate more intensive microwave emission; our results don't fit low frequency part of the spectra, because we consider simple model of the isotropic distribution of the flare loop;

✓ many runaway electrons also penetrate into the footpoints, where generate bremsstrahlung hard x-ray emission with more softer spectrum than in case of the classical model.

References

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