Pecularities of rare ions acceleration by helical turbulence in solar flares

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Solar flare energy stores originally in magnetic field. Rapid transition of magnetic energy in other forms by break of current layer leads to throw away of plasma clouds, particle acceleration, emission of electromagnetic radiation from radio to gamma range. The perturbation of plasma and magnetic field cause the generation of stochastic turbulent modes.

In bottom of solar corona near magnetic spots kinetic pressure Is small in comparison to magnetic pressure.

$$rotB = \alpha_{FFF} B,$$

$$\alpha_{FFF} = const \neq 0,$$

$$\alpha_{FFF} \sim 10^{-10} cm$$

We suppose that in this regions magnetic field is **nonpotential and force-free.**

(observ. estimation)

A perturbation of force-free magnetic field leads to generation of turbulent helicity; helicity parameter may be calculated:

$$\alpha = \frac{\tau_c}{3}\langle u \bullet rot u \rangle \approx \alpha_{FFF} \tau_c {v_A}^2 \frac{\langle b^2 \rangle}{3B^2}$$

B --- force-free field; b --- turbulent field;
u --- turbulent velocity;
\tau_c --- correlation time.

Large-scale electric field, created by turbulence with helicity:

$$E = \frac{\alpha}{c} B + \frac{\alpha_{FFF}}{c} B = \frac{\alpha_{ef}}{c} B,$$

$$\alpha_{ef} = \frac{5\tau_c}{12} \alpha_{FFF} v_A{}^2 \frac{\langle b^2 \rangle}{B^2}.$$

$$v_A{}^2 = B^2 / 4\pi\rho$$

Particle acceleration by gyrotropic turbulence

I. Stage of pre-acceleration by electric field.

1. Purely hydrogen plasma, p + e.

Drift velocities:

$$u_p = -\frac{m_e}{m_p} u_e << u_e$$

The force of Coulomb braking decrease, if drift electron's velocity exceed the mean thermal velocity.

Critical (Dreiser) field E(D):

$$E(D) = 0.2\frac{e\lambda}{D^2}, D^2 = \frac{T}{4\pi n_e e^2}, \lambda \approx 20.$$

If E>E(D), the electronic flow accelerated unrestricted (runaway electrons). In solar corona E<E(D) (apparently, slightly subdreiser).

2. Rare ions, composition e + p + i. Z --- charge number of ions. From equations of motion for e, p, I we have

$$u_i \approx -u_p \left[\frac{Z-1}{Z} \left(\frac{m_p}{m_e} \right)^{1/2} - 1 \right],$$

$$n_i << n_e, n_p; \left(\frac{m_p}{m_e} \right)^{1/2} \approx 43.$$

Collisions with electrons drive rare ions against the electric force ZeE with relatively high drift velocity (Gurevich A.V., 1961)

3. Solar corona, composition e, p, helium-4 and helium-3,

$$\left(\frac{n_4}{n_p}\right)_{sun} \approx 0.1, \left(\frac{n_3}{n_4}\right)_{sun} \approx 10^{-4}.$$

Drift velocities (from calculation)

$$u_4 \approx -0.07u_e, u_3 \approx +0.45u_e, u_3 / u_4 \approx 6.4.$$

Rare isotope helium-3 has sixmultiple preference against the main isotope helium-4 on the stage of injection into stochastic acceleration regime.

All helium-3 nuclei and only small part of helium-4 isotopes injected into stochastic acceleration regime. This effect of pre-acceleration by large-scale electric field may explain helium-3 rich events. In such events is observed very high density number of helium-3 isotopes in comparison with its presence at the Sun:

$$\left(\frac{n_3}{n_4}\right)_{acc} \simeq 1, \left(\frac{n_3}{n_4}\right)_{acc\max} \approx 10^4 \left(\frac{n_3}{n_4}\right)_{sun}.$$

Preceding explanations of helium-3- rich events use specific plasma modes, which accelerated mainly this isotope by resonant interactions (ion acoustic waves, electrostatic ion cyclotron waves and other; see Kocharov and Kocharov (1984) as a review).

For deuterium nuclei Z-1=0, and no enrichment is predicted by our model, although deuterium and helium-3 are comparable rare. Observations of deuterium-rich events are absent.

The enrichment of helium-3-rich events in addition also with ultra-heavy ions is widely observed (Mason 2007).

Typical for helium-3-rich events is spatial displacement between high-energy X-rays emission (from electrons) and gamma-rays emission (from nucleus).

II. Stage of stochastic acceleration by gyrotropic turbulence.
Main equation for homogeneous medium and isotropic distribution function is diffusion equation:

$$\frac{\partial F}{\partial t} = \frac{1}{p^2}\frac{\partial}{\partial p}\left(D_F + D_h\right)\frac{\partial F}{\partial p} + Q(p,t),$$

$$D_F = \frac{\langle u^2 \rangle p^2}{3v\Lambda}$$

Fermi acceleration

$$D_h = \frac{\alpha^2 \Lambda p \wedge 2}{3vR^2{}_0}$$

Electric field stochastic acceleration (Kichatinov, 1983)

$$Q(p,t)$$

Source of particles injected into acceleration.

$$\frac{D_h}{D_F} = \frac{\alpha^2}{\langle u^2 \rangle} \left(\frac{\Lambda}{R_0} \right)^2$$

Λ --- free path;

$R_0 = cp / eB$ --- particle gyroradius.

Gyrotropic term predominate in stochastic acceleration at low energies of particles.

Conclusions and main results

1. We find the relation between global property of solar convective turbulence (helicity) and its particular effect (particle acceleration).

2. An alternative model of helium-3 and heavy isotope-rich solar events is proposed.

3. Observed spatial displacement between sources of HXR (produced by electrons) and gamma-rays (produced by ions) is explained (electric field move electrons and main positive ions in different directions).

4. Observed correlation between the type III radiobursts and Helium-3 rich events is explained by presence of directed electron beam. The last is characteristic feature of type III radiobursts.

Thank you very much
for
your attention and
patience