Diffusive shock acceleration of Fe XXVI ions in galaxy clusters

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Summary

Ion injection and diffusive shock acceleration (DSA) in collisionless shocks in hot multispecies plasma is studied by means of kinetic hybrid code "Maximus". The postshock energy distributions of hydrogen, helium and Fe XXVI are compared for different initial sound Mach numbers M_s and plasma compositions. It is shown that prominent non-thermal population of all ions sorts appears in quasi-parallel shocks with $M_s = 3$, while for the case $M_s = 2$ the injection is much weaker, especially for the admixture ions. Plasma composition also affects the shape of the distributions and the downstream temperature. The observational perspective is discussed.

Internal shocks in galaxy clusters

- High temperature $10^7 - 10^8 K$
- Moderate sound Mach numbers. Bulk of kinetic energy in the cosmic volume gets dissipated by $2 \le M \le 4$ shocks [1]
- Low magnetization $\beta = 8\pi n k_B(T_e + T_i)/B^2 \sim 100$

Are galaxy clusters merger shocks sources of non-thermal particles?

Electrons

- Observations: Clear radio synchrotron signatures of non-thermal electrons [2]
- Simulations: some hints on electrons pre-acceleration, but no clear evidence for injection into the DSA [3,4]

Hadrons

- Observations: Only upper limits on high-energy γ-rays production by cosmic ray-induced pions decay [5]
- Simulations: The protons injection efficiency drops for sound Mach numbers less than about 2.25 [6]

Any other possibility to detect injected ions?

Another observational approach?

- Metal emission lines are observed in galaxy clusters with the XMM RGS and EPIC [7]
- The observations show 1.5-2.5 times metal enrichment
- The non-thermal tails of ions distributions may affect the spectral lines shape
- The downstream ions temperature depends on the injection efficiency
- Plasma composition may affect the injection process
- Fine X-Ray spectroscopy might be capable to detect the presence of accelerated heavy ions
- The properties of high energy tails could be used to constrain the shock parameters and plasma composition
- The XMM spectral resolution and sensitivity seems to be insufficient for such studies. Meanwhile, the future ATHENA fine spectroscopy is quite promising for in-situ searching of the ions injection signatures.

The main goals of the current work:

- Kinetic simulation of collisionless shocks structure in multicomponent plasma of galaxy clusters
- Investigation of various ions injection dependence on the shock Mach number and plasma chemical composition

Shock parameters

For all runs:
- $\beta = 100$
- $\theta = 13^o$
- $T_e = T_i = 10^8 K$

(the same as in [6])

Run	M_a	M_s	Plasma composition
S2	10	2	75% HII, 25% HeII, ~ 0% FeXXVI (Solar)
S3	20	3	75% HII, 25% HeII, ~ 0% FeXXVI (Solar)
D2	10	2	50% HII, 50% HeII, ~ 0% FeXXVI
D3	20	3	50% HII, 50% HeII, ~ 0% FeXXVI

Hybrid code *Maximus*

- Cartesian mesh with constant fields in cells
- Ions as particles
- Electrons as massless fluid
- Non-relativity
- Godunov-based TVD scheme
- Quadratic interpolation
- $div\vec{B} = 0$

Equations:

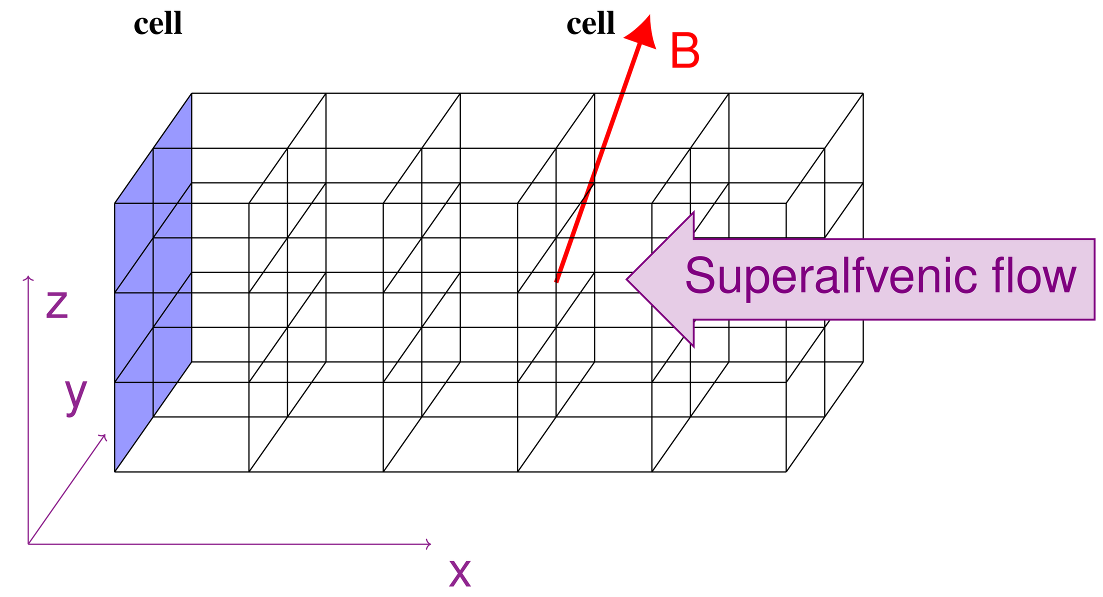
$$\frac{d\vec{r}_k}{dt} = \vec{V}_k \quad (1)$$

$$\frac{d\vec{V}_k}{dt} = \frac{Z_k}{m_k}\left(\vec{E} + \vec{V}_k \times \vec{B}\right) \quad (2)$$

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E} \quad (3)$$

$$\vec{E} = \frac{1}{\rho_c}\left(\nabla \times \vec{B}\right) \times \vec{B} - \frac{1}{\rho_c}\left(\vec{j}_{\rm ions} \times \vec{B}\right) - \nabla P_e/\rho_c \quad (4)$$

$$\vec{j}_{\rm ions} = \sum_{\rm cell} S(\vec{r}_k) Z_k V_k \rho_c = \sum_{\rm cell} S(\vec{r}_k) Z_k \quad (5)$$

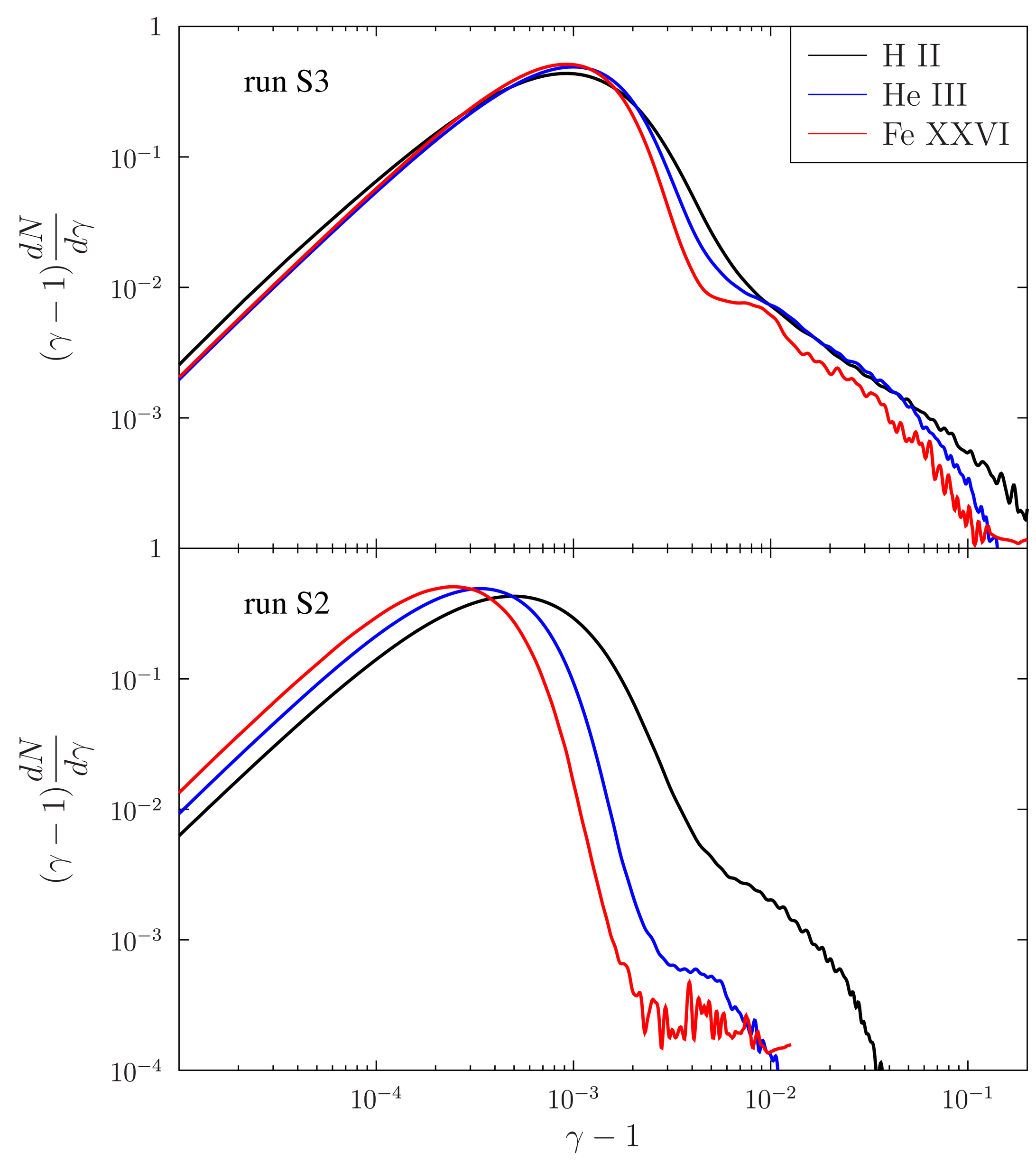


How to treat P_e:

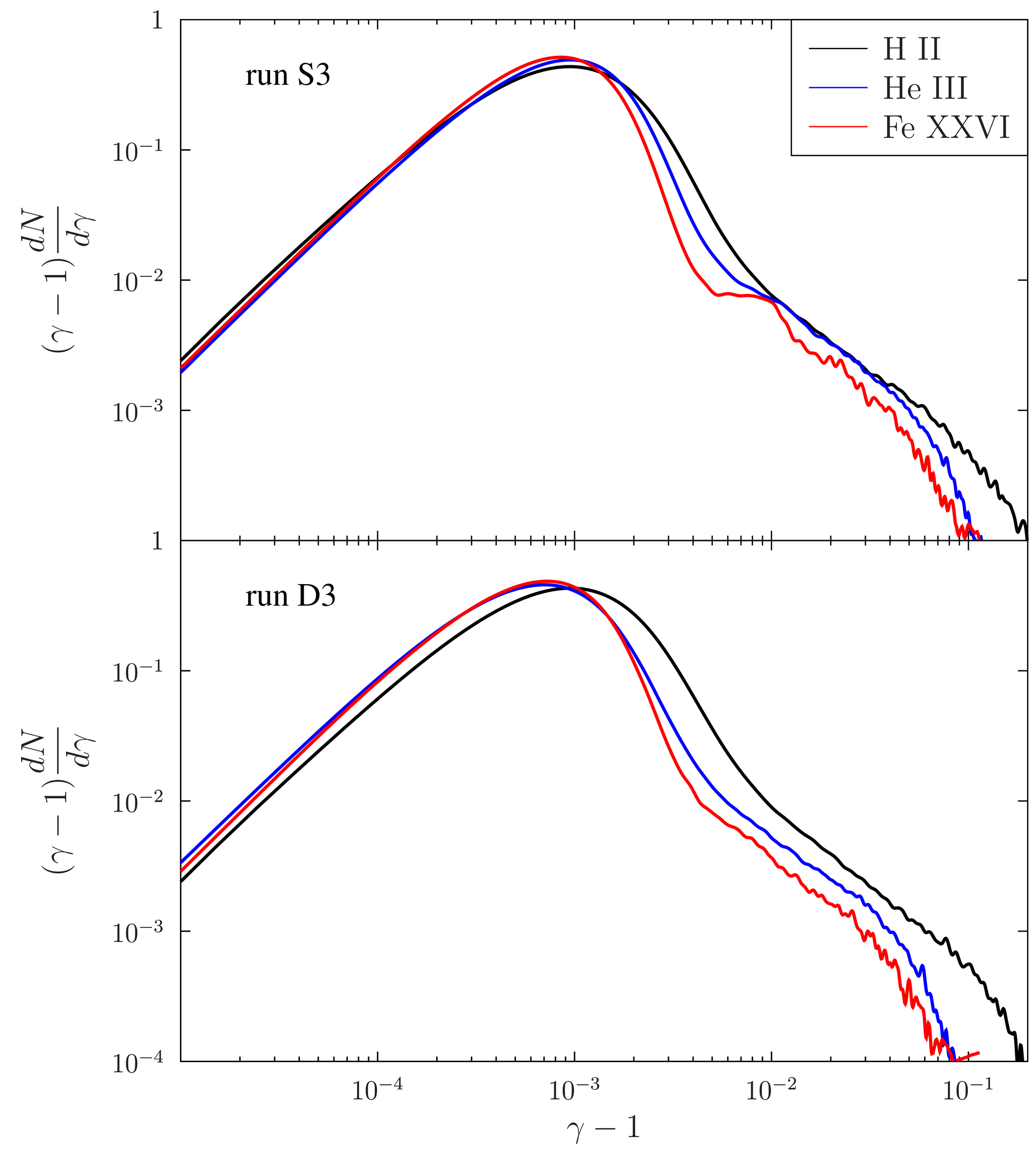
- $n_e = n_i$ (quasineutrality)
- downstream $T_e = 0.7 T_i$ for $M_s = 3$
- downstream $T_e = T_i$ for $M_s = 2$

Results: injection for Solar abundance

The injection of all sorts is much stronger for $M_s = 3$ (run S3). However, weak high energy tails appear even for $M_s = 2$ at later times than those simulated in [6]:



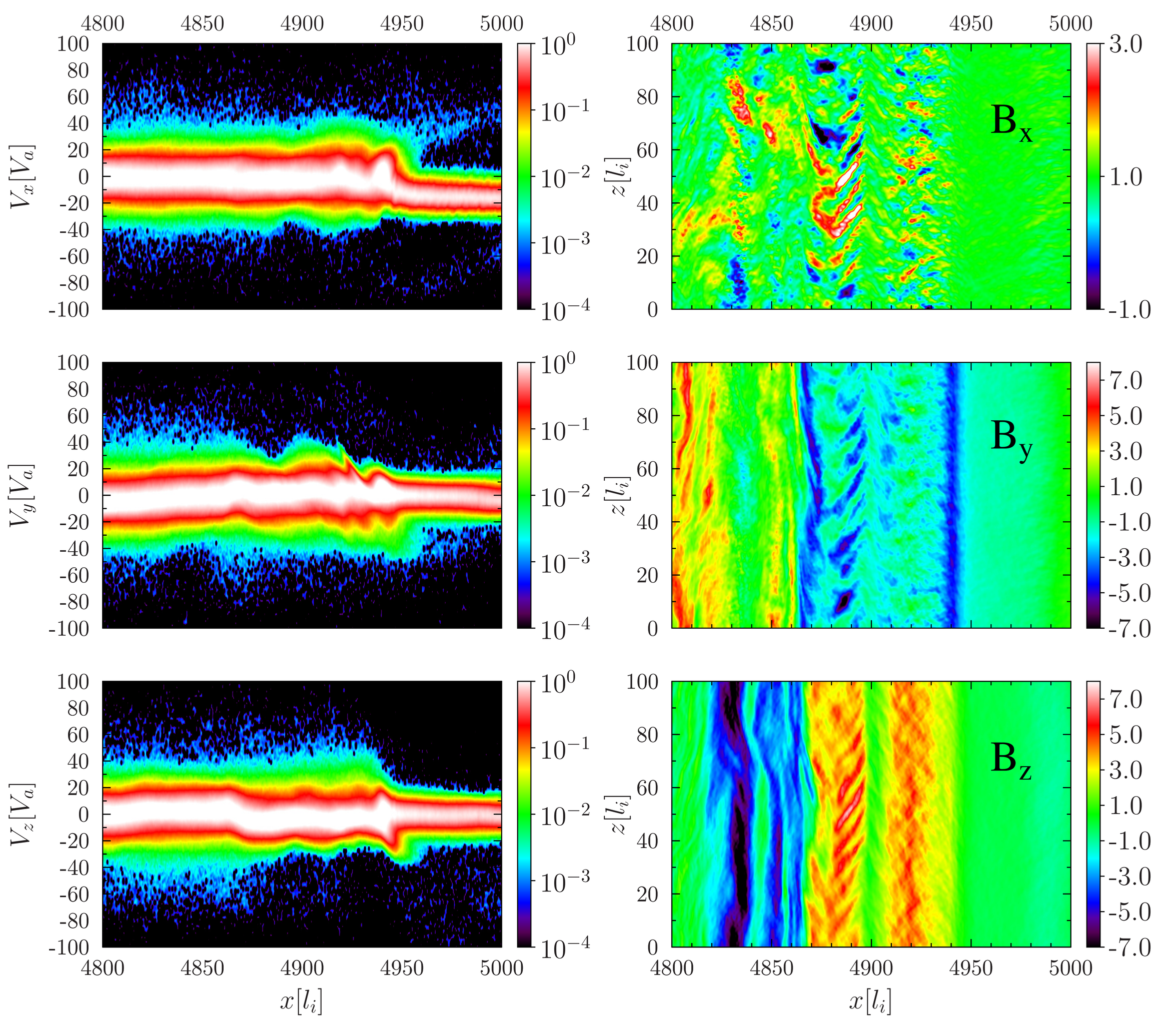
Results: dependence on plasma composition



For enchanced He III abundance:
- Slightly higher H II temperature
- Lower He III and Fe XXVI temperature and injection
- Faster Fe XXVI relaxation

Shock structure

Prominent striped structure, likely generated by the mirror instability



References

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Conclusions

The hybrid code Maximus was used to simulate collisionless shocks in hot hydrogen plasma with the admixture of He(+2) and Fe(+25). The ion injection proceeds for all investigated sound Mach numbers and plasma compositions. However, it is much less effective for low sound Mach numbers. The strongest injection of Fe XXVI ions was found for the case of solar abundance, $M_s = 3$ shock. The normalization of the high energy tail is about 10^{-2} in this case, which leaves a small chance to observe high energy tails in the future ATHENA data.