# Spatial evolution of nonresonant instabilities in the precursors of young supernova remnant shocks

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**ABSTRACT**

The nonresonant cosmic-ray-current-driven instability that operates in the precursors of shocks in young supernova remnants may be responsible for magnetic-field amplification, plasma heating, and hydrodynamical turbulence, all of which have impact on the shock properties and particle-acceleration processes. The temporal and spatial development of the instability is investigated here with Particle-In-Cell (PIC) simulations. Earlier PIC simulations used computational boxes with periodic boundary conditions which do not account for mass conservation in decelerating flows. Our current study for the first time uses a more realistic setup with open boundaries that permit inflow of plasma on one side of the simulation box and outflow at the other end. We demonstrate magnetic-field amplification as expected on the grounds of our earlier results. The effects of backreaction on CRs that slow down the initial relative drift velocity, limit further growth of the turbulence and lead to its saturation are also re-confirmed. We discuss a spatio-temporal structure of the shock precursor and the saturation processes. Preliminary results are presented.

## 1. INTRODUCTION

Diffusive shock acceleration process requires turbulent amplified magnetic fields at shocks. Such fields can be generated through nonresonant (Bell) instabilities [1-7] when shock-accelerated cosmic rays (CRs) drift in the shock precursor.

## 2. NEW PIC SIMULATION SETUP

In this work a new ***realistic*** setup with ***open boundaries*** is used, which accounts for mass conservation in decelerating flows and allows us to trace both the temporal and the spatial evolution of the system. Calculations are performed in the CR rest frame, in which e-p beam drifts with a nonrelativistic shock velocity $v_{sh}$=0.4c. Unprecedented large-scale PIC experiment utilizes a 2D grid with 130,000 x 12,000 cells. The beam is injected at one side of the simulation box and removed at the other end. Physical parameter set is similar to that used in [5]: $\gamma_{CR}$=50, $N_i/N_{CR}$=50, $\gamma_{max}/\Omega_i$=0.4, $m_i/m_e$=50.

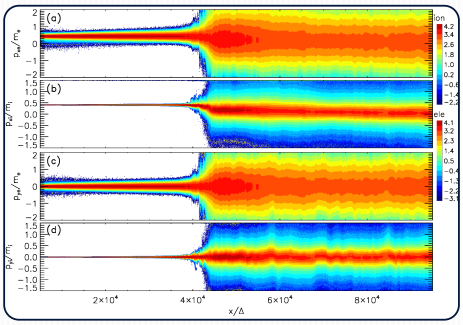

**Fig. 3: Phase-space in x-$p_x$ (a,b) and x-$p_y$ (c,d) for ambient electrons (a, c) and ions (b, d) at t=26.8/$\gamma_{max}$. At x/Δ > 43,000 strong non-resonant turbulence nonlinearly backreacts on CRs and ambient plasma which results in a slow-down of the beam drift from $v_{sh}$=0.4c to ~0.15c.**

**REFERENCES**

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## 3. RESULTS

Our results re-confirm magnetic-field amplification through nonresonant instability, its saturation and backreaction on CRs, as observed in earlier studies with periodic simulation boxes. A detail physics of saturation processes is also studied [8].

- Figs. 1 and 2 display a spatio-temporal structure of the CR-current-driven instability. Nonresonant modes with wave vectors parallel to the plasma drift grow in amplitude while the plasma beam propagates with respect to CRs.
- In the nonlinear phase the EM turbulence is accompanied by strong density and velocity fluctuations [3-7].
- Strongly nonlinear backreaction of CRs cause the bulk deceleration of the plasma drift (Fig. 3) and saturation of the instability [3-6].
- Once the incoming plasma beam collides with the slowed-down plasma, the magnetic modes are compressed forming a shock-like structure in which additional plasma heating occurs.
- Turbulent electric fields inelastically scatter CRs introducing anisotropy and modifying their distribution (Fig. 4).

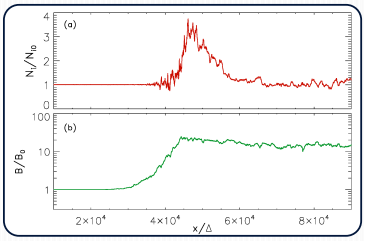

**Fig. 1: Transversaly-averaged profiles of ion density (a) and magnetic field (b) at t=26.8/$\gamma_{max}$, normalized to their unperturbed values.**

**ACKNOWLEDGEMENTS**

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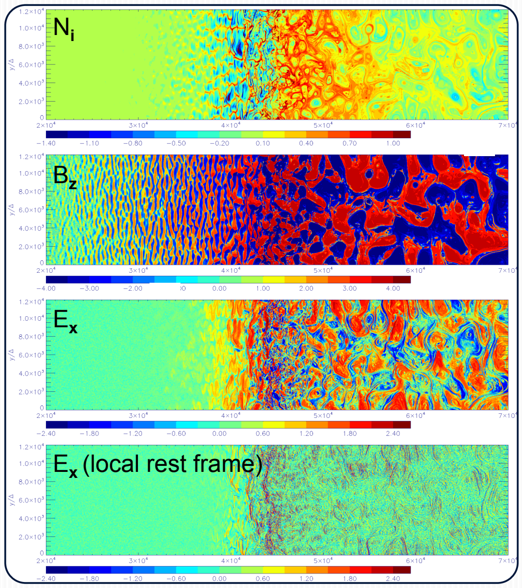


**Fig. 2: (*From top to bottom*) Spatial distributions of ion density, $B_z$ magnetic field, and $E_x$ electric field in the simulation frame at t=26.8/$\gamma_{max}$. Bottom panel shows $E_x$ distribution in the local plasma rest frame, in which contribution from the motional electric fields has been subtracted. Sign-preserving logarithmic scaling is used.**

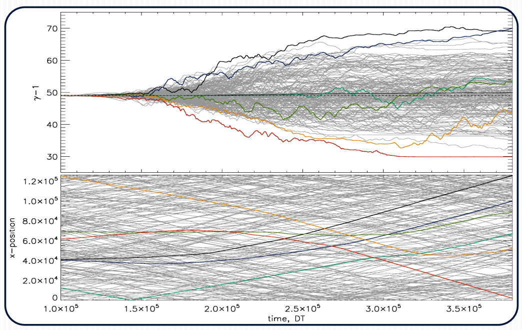

**Fig. 4: Temporal evolution of the energy (*top*) and the position along the simulation box (*bottom*) of sample CR ions. CR distribution is modified due to interaction with EM turbulence. CRs that propagate in the direction of the plasma flow increase their energies; propagation againts the flow leads to CR deceleration (see trajectories marked with colors).**