Evidence of ion Foreshock in 2-D PIC Simulations of a Curved Collisionless Shock: statistical and individual trajectory approach

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Abstract

2-D full particle simulations are used to investigate the so-called foreshock region which is filled with energized backstreaming particles. Two populations are observed for $90° \geq \Theta_{Bn} \geq 45°$: (i) field-aligned ion beams collimated along the IMF and having a gyrotropic distribution and (ii) gyro-phase bunch ions having a global gyration around the magnetic field. Our analysis evidences that these two populations are reflected by the shock itself and can have different origins both in term of interaction time, drift along the shock front and distance of penetration ("leaked" ions are observed).

Electron and ion foreshocks have been clearly identified by different space missions as regions magnetically connected to the shock front and characterized by populations backstreaming from the shock front and by an important wave activity. Present results are based on the use of two dimensional PIC (Particle In Cell) simulations of a curved shock, where full curvature effects, time of flight effects, and both electrons and ions dynamics are fully described by a self consistent approach. The analysis is restricted to a quasi-perpendicular shock with $90° > \theta_{Bn} > 45°$, where θ_{Bn} is the angle between the shock normal and the upstream magnetostatic field. For the first time to our knowledge, the formation of both electron and ion foreshocks is evidenced within a full self-consistent approach. Herein, we focuss our attention only on the ion foreshock and more particularly, on the different populations of backstreaming ions observed in the upstream region. In agreement with experimental data, two distinct populations are observed : (a) field-aligned ion beams characterized by a gyrotropic distribution (hereafter named "G" population), and (b) gyro-phase bunched ions (characterized by a NON gyrotropic distribution, hereafter named "NG" population) which exhibit a non-vanishing perpendicular bulk velocity and a global gyration around the magnetic field. A deeper analysis of our simulation results shows that:

(i) each population is identified in different spatial region. The "G" population is observed at the edge of the foreshock and at very short distance from the shock front, whereas "NG" population is observed more deeply in the foreshock and at larger distance from the curved shock front.

(ii) Although some wave activity (dB / B = 0.02) is evidenced in the upstream region, our simulations show that both backstreaming populations are formed at the shock front and do not result from local ion beam instabilities.

(iii) each class of backstreaming ions can be clearly identified according to the interaction time range (DT_inter) of individual ions with the shock front: the "NG" population corresponds to a short interaction time of ions (DT_inter= 1 to 2 T-ci), while the "G" population corresponds to a much larger time range (from 1 T_ci to 10 T_ci), where T_ci is the upstream ion gyroperiod.

(iv) A statistical study shows that the "G" population can have different origins: it is formed with ions coming both from the shock front itself ("reflected" ions) and from a deeper downstream region of the shock ("leaked" ions).

978-1-4244-6051-9/11/$26.00 ©2011 IEEE