Studying plasma heating and particle acceleration in collisionless shocks through astrophysical observations

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Supernova remnants (SNRs), the products of stellar explosions, are powerful astrophysical laboratories, which allow us to study the physics of collisionless shocks, thanks to their bright electromagnetic emission. Blast wave shocks generated by supernovae (SNe) provide us with an observational window to study extreme conditions, characterized by high Mach (and Alfvénic Mach) numbers, together with powerful nonthermal processes. Shocks in SNRs are collisionless because they expand in a rarefied medium, where Coulomb collisions cannot provide the viscous dissipation at the shock front. Collective effects, as electromagnetic fluctuations and plasma waves, instead, are responsible of dissipating the shock energy and of heating the interstellar medium. In this framework, temperature equilibration between different species may not be reached. SNRs are also characterized by a broadband nonthermal emission stemming at the shock front as a result of nonthermal populations of leptons and hadrons. These particles, known as cosmic rays, are accelerated up to ultrarelativistic energies via diffusive shock acceleration. If SNRs lose a significant fraction of their ram energy to accelerate cosmic rays, the shock dynamics should be altered with respect to the adiabatic case. This shock modification should result in an increase of the total shock compression ratio with respect to the Rankine-Hugoniot value of 4. The combination of high resolution spectroscopy (to measure ion temperatures) and moderate resolution spectroscopy (for a detailed diagnostic of the post-shock density) can be exploited to study both the heating mechanism and the particle acceleration in collisionless shocks. I review the main results obtained in this field and report on the temperatures measured for different ion species in the remnant of the SN observed in 1987 in the Large Magellanic Cloud (SN 1987A, Miceli et al. 2019, Nature Astronomy 3, 236). We found that the post-shock temperature is proportional to the particle mass, in remarkable agreement with what expected in case of scattering isotropization of the incoming particles by plasma waves. I also present evidence of shock modification in the remnant of SN 1006 a. D. (Giuffrida, Miceli et al. 2021, under review). In this SNR, the shock compression ratio increases significantly as the angle between the shock velocity and the ambient magnetic field is reduced. The quantitative study of the shock modification as a function of the shock obliquity attests to the prominence of parallel acceleration and to the importance of cosmic rays re-acceleration in oblique shocks.