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The role of SN-driven turbulence on the formation of outflows, inflows and cooling flows: from Galaxies to Clusters of Galaxies

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Abstract. Star forming galaxies often exhibit hot halos with structures that resemble chimneys and fountains extending for several kpc above the galaxy. Observations indicate that they are probably produced by supernovae (SNe) which blow superbubbles that carve holes in the disk. Through these holes, high speed material is injected and expands buoyantly up to a maximum height and then returns to the disk pulled by the galaxy gravity. This circulating gas in a fountain tends to condense out forming high-velocity clouds and filaments. Starburst galaxies also show evidence that the spectacular winds that arise from their disk are fed by SNe explosions. Similarly, at galaxy cluster scales, most massive clusters exhibit rich filamentary structure of ionized gas which is distributed all around the central galaxy. We discuss here the role that SNe bubbles play in driving outflows and filamentary structures both at galaxy and galaxy-cluster scales. With the help of HD and MHD numerical simulations, we show in particular that SN-driven turbulence may play a key role at helping a central AGN halting and "isotropize" the cooling flow in the central regions of a galaxy cluster.

Keywords. supernovae, outflows, galaxies, galaxy clusters.

The role of SNe at Galactic Scales: The ejection of gas out of the disc in late-type galaxies is related to star formation and is due mainly to Type II SNe. We have recently explored the development of fountains in the Milky Way in order to understand their dynamical evolution and their influence on the redistribution of the freshly delivered metals over the disc (Melioli *et al.* 2008, 2008). We performed 3D hydrodynamical, non-equilibrium radiative cooling simulations where the whole Galaxy structure, the differential rotation and the supernova explosions generated either by a single or by multiple generations of fountains were considered. A typical fountain powered by 100 Type II SNe may eject material up to ~ 2 kpc which then collapses back mostly in the form of dense, cold clouds and filaments. To investigate the dynamical evolution of multiple generations of fountains (fueled by SNe from ~ 100 OB associations), we have considered the observed size-frequency distribution of young stellar clusters of the Galaxy. As in the case of a single fountain, multiple fountains are able to form only intermediate-velocity clouds above the disc. This indicates that the high-velocity clouds (HVCs) which are detected at galactic altitudes higher than ~ 5 kpc are probably formed by material that has been captured from the surrounding intergalactic medium (IGM) (e.g., de Gouveia Dal Pino *et al.* 2009 and references therein). Another possibility is that they have been accelerated to higher latitudes by a cosmic-ray driven wind (e.g., Hanasz *et al.* 2009). The simulations also reveal that most of the lifted gas falls back on the disc within a radial distance $\Delta R \simeq 0.5$ kpc from the place where the fountain flow originated. This implies that the fountains do not change significantly the radial profile of the disc chemical abundance or metallicity. The simulations also allowed us to consistently calculate the feedback of the star formation on the halo gas. We found that the hot gas gains about 10% of all the SN II energy produced in the disc which suggests that the SN feedback more than compensates for the halo radiative losses. Besides, it allows a quasi steady-state disc-halo circulation after about 150 million years. We have also considered the possibility of mass infall from the IGM and its interaction with the clouds that are formed by the fountains. Though the simulations are not suitable to reproduce the slow rotational pattern that is typically observed in the haloes around disc galaxies, they indicate that the presence of an external gas infall may help to slow down the rotation of the gas in the clouds and thus the amount of angular momentum that they transfer to the coronal gas, as previously suggested in the literature.

The role of the SNe at galaxy clusters scales: Perseus (Abell 426) is commonly regarded as a prototype of the cooling core clusters of galaxies. NGC 1275, the central galaxy in the Perseus cluster, is the host of gigantic hot bipolar bubbles inflated by AGN jets observed in the radio as Perseus A. It presents a spectacular H_α-emitting nebulosity surrounding NGC 1275, with loops and filaments of gas extending to over 50 kpc. The origin of the filaments is still unknown, but probably correlates with the mechanism responsible for the giant buoyant bubbles. Motivated by the findings described in the previous session, we have performed 2.5 and 3-dimensional MHD simulations of the central regions of this cluster in which turbulent energy triggered by star formation and SNe explosions is introduced (Falceta-Gonçalves *et al.* 2009). The simulations reveal that the turbulence injected by massive stars could be responsible for the nearly isotropic distribution of filaments and loops that drag magnetic fields upward as indicated by recent observations. Weak shell-like shock fronts propagating into the ICM with velocities of 100-500 km/s are found, also resembling the observations. The isotropic outflow momentum of the turbulence slows the infall of the intracluster medium, thus limiting further starburst activity in NGC 1275. As the turbulence is subsonic over most of the simulated volume, the turbulent kinetic energy is not efficiently converted into heat and additional heating is required to suppress the cooling flow at the core of the cluster, and simulations combining the MHD turbulence with the AGN outflow can reproduce the temperature radial profile observed around NGC 1275. We conclude, therefore that, while the AGN mechanism is the main heating source, the SNe are crucial to *isotropize* the energy distribution.

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