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Galactic outflows and the pollution of the galactic environment by supernovae

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Abstract

We here explore the effects of the SN explosions into the halo of star-forming galaxies like the Milky Way. Successive randomly distributed and clustered SNe explosions cause the formation of hot superbubbles that drive either fountains or galactic winds above the galactic disk, depending on the amount and concentration of energy that is injected by the SNe. In a galactic fountain, the ejected gas is re-captured by the gravitational potential and falls back onto the disk. From 3D non-equilibrium radiative cooling hydrodynamical simulations of these fountains, we find that they may reach altitudes up to about 5 kpc in the halo and thus allow for the formation of the so called intermediate-velocity-clouds (IVCs) which are often observed in the halos of disk galaxies. The high-velocity-clouds that are also observed but at higher altitudes (of up to 12 kpc) require another mechanism to explain their production. We argue that they could be formed either by the capture of gas from the intergalactic medium and/or by the action of magnetic fields that are carried to the halo with the gas in the fountains. Due to angular momentum losses to the halo, we find that the fountain material falls back to smaller radii and is not largely spread over the galactic disk. Instead, the SNe ejecta fall nearby the region where the fountain was produced, a result which is consistent with recent chemical models of the galaxy. The fall back material leads to the formation of new generations of molecular clouds and to supersonic turbulence feedback in the disk.

Keywords: Galactic outflows; Galactic environment; Supernovae; Astrophysics

1. Introduction: a brief overview

Edge-on star-forming disk galaxies often exhibit hot halos of ionized gas that may extend up to several kpc of height over the regular HI galactic disk. They seem to be fed by ascending gas from the disk in structures that resemble fountains (Shapiro and Field, 1976) and chimneys (Tomisaka and Ikeuchi, 1988). These are thought to be generated by supernovae (SNe) explosions which blow superbubbles that expand and carve holes in the disk injecting high speed, metal enriched gas (e.g., Tenorio-Tagle and Bodenheimer, 1988). Analytical and numerical modeling (see below) indicate that this gas forces its way out through relatively narrow channels (chimneys) with widths of 100–150 pc. They establish a connection between the thin disk and the halo feeding it with the hot disk gas that expands through the halo under buoyancy forces up to a maximum height and then returns to the disk bent by the disk gravity. The whole cycle is like a fountain – hence the name galactic fountain. Close-up evidence for chimneys is scant, but evidence for large chimneys is clear in external galaxies in the form of holes in the distribution of HI, often with some evidence for flows (for a review of the observations see, e.g.,

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Melioli et al., 2008 and references therein). In the Milky Way (MW), the evidence has mainly been in the form of fragments and vertical structures in the large scale maps of the interstellar medium. A multi-wavelength survey of the halos of several star-forming galaxies (e.g., Dettmar, 2005; Dettmar and Soida, 2006) have revealed a correlation of these halos with the rates of star formation and the energy input rates by SNe suggesting that gaseous halos are associated to star formation processes in the disk.

Other observed features that seem to be correlated to gas circulation in chimneys and galactic fountains are the so called intermediate and high-velocity-clouds (IVCs and HVCs, respectively). These are mainly neutral hydrogen (HI) clouds that can be as large as 100 pc, with masses of up to 10^4 solar masses which are observed in the halo of the MW and other star-forming galaxies at altitudes typically between 300 pc and 2.5 kpc and which are falling on the disk with velocities between -20 km/s and -90 km/s. The HVCs can be observed in even higher altitudes of up to 12 kpc and velocities up to -140 km/s. Fig. 1 provides a mosaic of the matter distribution in the halo of the MW. It indicates that the galactic disk is surrounded by a very *cloudy* environment. It is generally believed that at least the IVCs have been formed from the condensation of the gas that arises in the chimneys triggered by SN explosions and numerical simulations suggest that this seems to be indeed the case (e.g., de Avillez, 2000; de Avillez and Berry, 2001; Melioli et al., 2008, 2009, see below). However, the origin of the HVCs is still controversial. The difficulty at producing fountains in the hydrodynamical simulations reaching altitudes higher than 5 kpc (Melioli et al., 2009) and the very small metallicity contents observed in these HVCs suggest that they may have been originated from gas raining into the galaxy that is accreted from the intergalactic medium (IGM) or from satellite galaxies (e.g., Fraternali and Binney, 2006).

Another extreme example of gas outflow from the disk of star-forming galaxies are the supersonic winds which are powerful enough to escape from the gravitational potential of the galactic disk to the IGM. There is evidence of a large-scale bipolar wind emerging from the center of the MW (Bland-Hawthorn and Cohen, 2003). Spectacular winds extending for several kpcs above the disk have been observed in galaxies with bursts of star formation, the so called starburst galaxies. These are merging or interacting galaxies that may have star formation rates up to 20 times larger than those of regular galaxies, like the Milky Way, and this could explain the large amount of energy injection by SNe and the resulting production of powerful winds. Indeed, galactic winds are ubiquitous in starburst galaxies (see Veilleux, Cecil & Bland-Hawthorn 2005 and references therein). Recent high resolution observations of the best studied prototype of this class, the starburst galaxy M82, has evidenced that its wind, like in the galactic fountains, is being fed by SNe explosions nestled in several stellar associations around the nuclear region of the galaxy (Konstantopoulos et al., 2008). However, we have recently investigated the real effectiveness of the energizing process by the SNe in starbursts and found that it is sensitive to the amount of gas locked within clouds. If large enough, then the efficient radiative cooling of the shock-heated clouds by the SNe may prevent the gas from escaping as a wind for about half-lifetime of the starburst (Melioli and de Gouveia Dal Pino, 2004). In the present work, we are not going to address these powerful winds, but we refer to some models for their production (see e.g., Tomisaka and Ikeuchi,

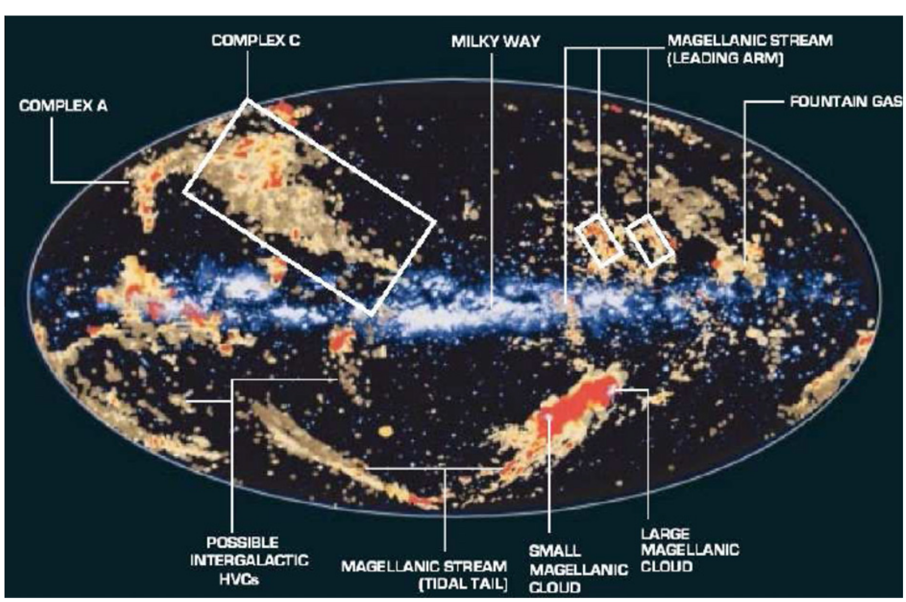

Fig. 1. Map of the galactic gas and its environment: it combines radio observations of neutral hydrogen (HI) of the environment with a visible light image of the MW (the galactic disk in the middle). The high and intermediate-velocity clouds of hydrogen, such as complexes A and C, are located above and below the disk. A galactic fountain is also identified in the map (extracted from P. Richter & B.P. Wakker, Sci. Am., http://www.astro.uni-bonn.de/~webiaef/outreach/posters/milkyway/).