Synopsis

Galactic outflows play an important role in the formation and evolution of galaxies by regulating the star formation rate (SFR) within them and by throwing out metals into the intergalactic medium (IGM). They are key to understand the relation between the stellar and the dark matter halo mass, mass-metallicity relation of galaxies, intergalactic metal enrichment, formation of high velocity clouds and much more. Galactic outflows have been observed to be present in galaxies at all redshifts either in emission or in absorption of the stellar continuum. Outflows have been also detected in the immediate vicinity of galaxies by probing absorption lines in the spectrum of background Active Galactic Nuclei. In this thesis we explore the interactions between supernovae (SNe) driven outflows and the circumvallate medium (CGM), an extended hot gas atmosphere believed to be present in the haloes of massive (stellar mass, M? & 1010 M_) galaxies. Given the complexity of geometry and multiphase nature of outflows, we use numerical simulations to study gas interactions. Our results shine light on many interesting aspects of the galactic outflows, such as, i) the effect of the circumgalactic medium on the mass outflow rate and velocity of the outflowing gas on large scales, ii) origin of high velocity cold (_ 104 K) gas in outflows iii) origin of X-ray emission in different scenarios. We connect our numerical and analytical work with the X-ray data. We also use our numerical set up to understand the origin and nature of two giant -ray bubbles, called the Fermi Bubbles, at the centre of our Galaxy. We compare our synthetic emission models to the observed -rays, X-rays, radio and UV absorption data and constrain the energetics and age of these bubbles. Below we outline the investigations undertaken in this thesis and point out our main results.

Interaction of circumgalactic medium and outflows

In a standard SNe driven outflow scenario, SNe ejected gas is a continuous outflow that expands freely with or without the gravity of the galaxy (Chevalier & Clegg 1985; Sharma & Nath 2013). The multiphase nature of the outflowing gas and the resistance provided by the CGM is often neglected while estimating the total mass outflow rate from galaxies (Arribas et al. 2014; Heckman et al. 2015). In the presence of a CGM, this scenario can change completely as the wind does not remain in a steady state anymore and involves far more complexities than typically considered, such as mixing with the hot CGM. The dynamics of the cold gas is expected to be different in such a non-steady state compared to the calculations in which the cold clumps move under the effect of a steady state wind. To study these effects, we perform hydrodynamical simulations of SNe driven outflows in a Milky-Way type galaxy that includes a CGM. We assess the effects of the CGM on the outflow by varying the star formation rate. We find that the total mass outflow rate is divided almost equally in two phases that peak at _ 105 K (warm) and at _ 3_106 K (hot). This means that observations in optical/UV or X-ray only probe a fraction of the outflowing mass. We also find that the mass loading factor (_), defined as the ratio between mass outflow rate to the star formation rate, at outer radii (_ 100 kpc) of a galaxy can be much higher than the rate observed in warm gas (_ _ 0:3-0:5). We present simple scaling relations between the mass loading factor in warm gas and the total mass loading factor at the virial radius (_v) that can be used to estimate the total mass outflow rate from such galaxies. We also find that warm gas can be entrained by _ 1000 km s⍰1 free wind to reach velocities as large as _ 700 km s⍰1. Cold clouds also form at the interaction zone between the outflow and the CGM. Some of these clouds keep moving outwards while some of them fall back to the stellar disc due to gravity. This galactic fountain gas which falls back can lead to further star formation in the disc.

X-rays from galaxies

Diffuse X-ray emission in case of a standard SNe driven outflow is dominated by the central part of the wind where temperature is _ 107 K and density is & 0:1 MP cm�3 . Since density at the centre of a standard SNe driven outflow is simply proportional to the star formation rate (SFR), the X-ray luminosity (LX) is expected to be proportional to the SFR2. Observations, however, indicate a linear, or even a sub linear relation between LX and SFR (Mineo et al. 2012b; Wang et al. 2016). We used analytical results and numerical simulations to understand the origin of the X-ray emission from the star forming galaxies. We find that for highly star forming galaxies with no CGM, the diffuse X-ray mainly comes from the centre of the SNe wind as expected. However, for massive galaxies with low star formation rate (. 1 M_ yr�1), the emission is dominated by the contribution from the CGM. This contamination results in a flatter LX-SFR relation than typically expected from a pure SNe driven outflow. Even after we increased the contribution from the outflowing wind by enhancing the mass loading factor to its maximum value, the CGM contamination could not be ignored. We further argue that these high LX values of low star forming, massive galaxies could be inverted to study the properties of the CGM itself

Multi-wavelength properties of outflow and Fermi Bubbles in our Galaxy

Observations reveal two giant (_ 50_) gamma-ray bubbles, called the Fermi Bubbles (FBs) toward the centre of our Galaxy (Su et al., 2010; Ackermann et al., 2014) the origin of which is still a mystery. Observations in other wavebands such as X-ray, radio and UV (absorption lines) also revealed many other interesting features associated with the FBs. There have been a number of attempts to explain the gamma-ray brightness and spectrum by considering feedback from the Galactic centre black hole (GCBH) and cosmic ray diffusion (Guo et al., 2012; Yang et al., 2012; Zubovas & Nayakshin, 2012). The required mechanical luminosity in these models exceeds the value that is achievable with the current accretion rate by a few orders of magnitude. Star formation driven wind models have been, however, under-investigated so far with much less attention to explain the multi-wavelength features related to the FBs.

To understand the origin and nature of these bubbles, we simulate SNe driven wind scenario appropriate for the Milky-Way. By using the information about morphology and X-ray emission, we find that the required star formation rate at the centre of our Galaxy is _ 0:5 M_ yr�1. After comparing the synthetic microwave surface brightness from our simulation with the observed data, we constrain the magnetic field inside the bubbles to be _ 4_G. We also find that the gamma-ray morphology and spectral signatures in our simulated bubbles closely resemble the observed ones. The cold gas (< 105 K) kinematics in our simulations also have a similar behaviour, to some extent, as observed in UV absorption lines through the northern bubbles.

O viii and O vii line ratio through Fermi Bubbles

Most of the models of the Fermi Bubbles focus on getting a reasonable gamma-ray morphology and spectrum by varying the mechanical luminosity of the central source. Other ways to determine the origin of the FBs include probing the bubbles in X-rays to obtain information about the strength of the explosion at the Galactic centre. X-ray spectral analysis by Kataoka et al. (2013) suggests that the shock velocity is _ 300 km s�1 with an age of _ 20 Myr for the bubble, whereas, by analysing the O viii and O vii line ratio Miller & Bregman (2016) obtained a shock speed of _ 500 km s�1 , indicating an age of _ 4 Myr. We simulate

both star formation driven and GCBH driven wind scenarios in our Galaxy with varying strength of star formation and accretion rate. We consider a self consistent gas distribution for the Milky-Way CGM that is close to the observations. We compare the synthetic O viii and O vii lines from our simulations with the observations of Miller & Bregman (2016) and find that the data indicates a shock velocity of _ 300 km s^{-1} and a corresponding age of the bubbles to be 15-25 Myr. After considering possible electron-proton non-equilibrium in the shocked gas that can affect the observability of the X-ray lines, we rule out mechanical luminosities & 1041 erg s^{-1} as the possible driver of the Fermi Bubbles.