The influence of Galactic wind upon the star formation histories of Local Group galaxies

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Abstract

We examine the possibility that ram pressure exerted by the galactic wind from the Galaxy could have stripped gas from the Local Group dwarf galaxies, thereby affecting their star formation histories. Whether gas stripping occurs or not depends on the relative magnitudes of two counteracting forces acting on gas in a dwarf galaxy: ram pressure force by the wind and the gravitational binding force by the dwarf galaxy itself. We suggest that the galactic wind could have stripped gas in a dwarf galaxy located within the distance of \( R_c \simeq 120 (r_s/1 \text{ kpc})^{3/2} (E_b/10^{50} \text{ erg})^{-1/2} \text{ kpc} \) (where \( r_s \) is the surface radius and \( E_b \) is the total binding energy of the dwarf galaxy, respectively) from the Galaxy within a timescale of Gyr, thereby preventing star formation there. Our result based on this Galactic wind model explains the recent observation that dwarfs located close to the Galaxy experienced star formation only in the early phase of their lifetimes, whereas distant dwarfs are still undergoing star formation. The present star formation in the Large Magellanic Cloud can also be explained through our Galactic wind model.

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1 INTRODUCTION

It is widely accepted that the hot interstellar gas, mainly originating from supernova explosions, will eventually escape from the galactic disk as galactic wind (Shapiro & Field 1976; Habe & Ikeuchi 1980; Tenorio-Tagle & Bodenheimer 1988; Norman & Ikeuchi 1989). Such a wind can have various effects on the disk-halo system. For example, it can supply energy and gas to the halo (Chevalier & Oegerle 1979; Habe & Ikeuchi 1980; Li & Ikeuchi 1992).

We, here, consider if ram pressure exerted by the galactic wind from the Galaxy could have stripped gas from the Local Group dwarf galaxies. Such ram pressure stripping may influence star formation histories of the dwarfs. The effects of ram pressure are extensively discussed by Portnoy, Pistinner, & Shaviv (1993).

We summarize various properties of Local Group dwarf galaxies in Table 1, where \( R \) is the distance from the Galaxy (the galactocentric distance), and \( r_s \) and \( E_b \) are the surface radius and the binding energy calculated from the observations of velocity dispersions, respectively. In the fifth column of SF (star formation), we distinguish the following two categories:

A: Dwarf galaxies in which the stellar population is dominated by the initial bursts of star formation;

B: Dwarf galaxies which experienced recent star formation, as well.

Van den Bergh (1994) has asserted that the star formation histories of Local Group dwarf galaxies correlate with the distance from the Galaxy (\( R \)): Dwarf galaxies near the Galaxy, such as Ursa Minor and Draco, only experienced star formation in the early phase of their lifetimes (\( \sim 12 \) Gyr), while there is observational evidence for more recent (or present) star formation in distant dwarfs (see van den Bergh 1994 and references therein). He also implied that star formation in dwarfs suffers great difficulty in the existence of mass flow from the Galaxy.

The plan of this Letter is as follows. First of all, in the next section, we define the critical radius (\( R_c \)) in such a way that a dwarf galaxy within \( R_c \) from the Galaxy suffers ram pressure stripping of the wind, and derive the general expression for \( R_c \). We then discuss in §3 the interpretation of the observations by van den Bergh (1994) and one exceptional case, the Large Magellanic Cloud, whose star formation histories are also explained with our galactic wind model. In the final section, we shall conclude.
that our hypothesis can qualitatively account for the observation.

## 2 THE CRITICAL RADIUS FOR GAS STRIPPING

In this section we compare ram pressure force by the wind and gravitational binding force by a dwarf galaxy itself. We shall then evaluate the critical radius, $R_c$, within which the ram pressure exceeds the gravitational force.

First we evaluate the mass loss rate of the Galaxy. The hot gas component of the Galaxy typically has a density of $10^{-2.5}\text{cm}^{-3}$ and a temperature of $10^{5.7}\text{K}$ (McKee & Ostriker 1977). The hot gas will flow out of the Galaxy (Shapiro & Field 1976), because its thermal energy is larger than the gravitational binding energy of the Galaxy (Cox & Smith 1974). Using the calculation by Habe & Ikeuchi (1980), we estimate the mass ejection (escaping) rate as $\dot{M} \sim 1 M_\odot \text{yr}^{-1}$. Assuming a steady, spherically symmetric flow, we can write approximately

$$\dot{M} \sim 4\pi R^2 \rho v_{\text{esc}},$$

where $R$ is the galactocentric distance, and $\rho$ and $v_{\text{esc}}$ are the density and the velocity of the escaping wind at distance $R$, respectively (see also Wang 1995). From equation (1), $\rho$ is expressed as follows:

$$\rho \simeq \frac{\dot{M}}{4\pi R^2 v_{\text{esc}}}. \quad (2)$$
Next we consider a dwarf galaxy which is located at the distance $R$ from the Galaxy. Ram pressure by the wind is $\sim \rho v_{\text{esc}}^2$. For the ram pressure to remove the gas from the dwarf, we require
\[ \rho v_{\text{esc}}^2 \pi r_s^2 \gtrsim \mathcal{E}_b / r_s, \tag{3} \]
where $r_s$ and $\mathcal{E}_b$ are the surface radius and the binding energy of the dwarfs, respectively. $r_s$ and $\mathcal{E}_b$ are calculated from observations of velocity dispersions (Saito 1979a; see also Table 1). Approximately the left-hand side of (3) represents the total ram pressure force on the dwarf, while the right-hand side represents the total gravitational force. Combining (2) and (3), we find the following condition,
\[ R^2 \lesssim \frac{\dot{M} r_s^3 v_{\text{esc}}}{4 \mathcal{E}_b} \equiv R_c^2. \tag{4} \]
Here, $R_c$ is the critical radius. If $R < R_c$, ram pressure exceeds binding force so that the wind can strip the gas from the dwarf. The velocity of the wind escaping from the Galaxy is $v_{\text{esc}} \simeq 300 \text{ km s}^{-1}$ (Habe & Ikeuchi 1980). We finally derive
\[ R_c \simeq 120 \left( \frac{\dot{M}}{1 M_\odot \text{ yr}^{-1}} \right)^{1/2} \left( \frac{r_s}{1 \text{ kpc}} \right)^{3/2} \left( \frac{v_{\text{esc}}}{300 \text{ km s}^{-1}} \right)^{1/2} \left( \frac{\mathcal{E}_b}{10^{50} \text{ erg}} \right)^{-1/2} \text{ kpc.} \tag{5} \]

The calculated critical radii are listed in Table 1. Moreover, we calculate and list the crossing time, $t_{\text{cross}} \equiv R / v_{\text{esc}}$, which is typically
\[ t_{\text{cross}} \simeq 0.3 \left( \frac{R}{100 \text{ kpc}} \right) \left( \frac{v_{\text{esc}}}{300 \text{ km s}^{-1}} \right)^{-1} \text{ Gyr.} \tag{6} \]

3 DISCUSSIONS

3.1 Star formation histories

Observationally, Ursa Minor, Draco and Sextans are classified as A in Table 1, in which the stellar population is dominated by early bursts of star formation. For Ursa Minor and Draco, we find $R < R_c$. Thus it seems highly probable that the galactic wind has stripped the gas from these dwarfs within $\sim 1$ Gyr after the wind formation in the Galaxy.

The other dwarf galaxies in Table 1 belong to the category B. Indeed they satisfy the condition $R > R_c$, and the ram pressure by the wind has little influence on them.
In two most distant dwarfs, particularly, Phoenix and DDO 210, star formation is still going on (van den Bergh 1994). This is because they practically feel no ram pressure by the wind.

We also comment that as for dwarf galaxies in the category A, a radial ‘pumping’ mode, in which mass flows quasi-periodically into the core of the galaxies (Balsara, Livio, & O’Dea 1994), is not permitted, because of their shallow gravitational potential, although this mode may exist for more distant dwarfs in the category B (Comins 1984).

3.2 The Large Magellanic Cloud

Though the Galactic wind should have a considerable influence on the Large Magellanic Cloud (LMC), the nearest galaxies from the Galaxy, there are some evidences of recent star formation in the LMC (e.g., Massey 1990). Someone might think that the LMC breaks our model. But, throughout our discussions, we have only discussed the steady galactic wind. In the realistic situations, however, supernova rate (star formation rate) decreases as time goes on. According to Larson & Tinsley (1978), its decaying timescale may be about \( \sim 1 \) Gyr. In recent epochs, OB-star formation rate also decreases and then the Galactic wind becomes weaker. In other words, the Galactic halo is now bound and cooled type (Habe & Ikeuchi 1980), because OB-star heating in the Galactic disk becomes insignificant [galactic fountain picture like Shapiro & Field (1976)]. This makes possible the recent star formation in the LMC, since the LMC is free from the Galactic wind. Indeed, the LMC has a bimodal age distribution of stellar populations, with almost all of the star clusters in the LMC being either younger than 3 Gyr or older than 12 Gyr (Da Costa 1991). First star formation is stopped by the Galactic wind, and second star formation becomes possible after the Galactic wind has stopped. We should note that the LMC is much larger gravitational potential than galaxies listed in Table1, which makes the second star formation easier.

Thus, through our galactic wind model, we can understand proximity effect on star formation rate in nearby galaxies.

3.3 The importance of Galactic wind

In the previous two subsections, we have verified the importance of galactic wind in the following three points:
[1] Gas in dwarf galaxies located within $R_c$ from the Galaxy ($R_c$ is defined in Eq. 5) can be stripped by ram pressure by the Galactic wind.

[2] The process of ram pressure stripping by the Galactic wind must be considered in studying star formation histories of Local Group dwarf galaxies.

[3] The star formation histories of the LMC can be explained consistently by adopting a Galactic wind model (see §3.2). Thus, our Galactic wind model is successful in understanding the star formation histories of Local Group galaxies.

4 CONCLUSION

On the basis of the observational results in van den Bergh (1994), we suggest that star formation histories of Local Group dwarf galaxies depend on the distance from the Galaxy. If the distance from the Galaxy is less than the critical radius $R_c$, which is given in equation (5), the gas of the dwarf galaxy is stripped by ram pressure exerted by the Galactic wind, since the ram pressure force by the wind exceeds the gravitational binding force by the dwarf itself.

Thus we can conclude that galactic wind from a giant galaxy generally has considerable influence on star formation histories of nearby dwarf galaxies.

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