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How surface density of galaxy disks affects metallicity? Outflow and Accretion

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Abstract. In this study, we examine the effect of surface density of disks on chemical evolution of galaxies. We find that, higher surface brightness galaxies on average possess higher gas-phase metallicity compared to lower surface brightness galaxies with the same stellar and gas mass. The surface brightness effect is more significant for low-mass galaxies. Using an analytical model of chemical evolution involving gas outflow and accretion, we find that the surface brightness dependence can be attributed to the strength of inflowing pristine gas. Galaxies with lower surface brightness experience stronger inflow than galaxies with a higher surface brightness of a similar mass.

Keywords. galaxies: abundances galaxies: formation galaxies: spiral

1. The Surface Brightness Dependence on Metallicity

The surface brightness of disk galaxies have been considered as a second parameter affecting the evolution of disk galaxies other than mass. For chemical evolution, Ellison *et al.*(2008) found that, at given stellar mass, the gas-phase metallicity is correlated with the size of galaxy, where more compact galaxies on average have higher metallicities.

We first examine whether this effect in inherited from the different gas content in galaxies of different surface densities. We select from Pilyugin *et al.*(2014) 118 nearby disk galaxies with homogenized and resolved gas-phase metallicity determined from HII regions and available HI flux as our sample. We measure their surface brightness profile and stellar masses from the *Wide-field Infrared Explorer* (*WISE*) survey (Wright *et al.*2010).

Figure 1a compares the gas-phase metallicity of galaxies with similar stellar and gas masses, but different surface brightnesses. To make such a comparison, we pick out pairs of galaxies with $\Delta M_\star < 0.3$ dex and $\Delta M_g < 0.3$ dex from the sample and compute the differences in surface brightness ($\Delta\mu_0$) and metallicity (Δ[O/H]) between the two galaxies.

The difference, Δ[O/H], starts from 0 at $\Delta\mu_0 = 0$, and gradually becomes more negative as $\Delta\mu_0$ increases (lower surface brightness). This result indicates that, at the same stellar and gas mass, the metallicity still depends on surface brightness of galaxies. Moreover, the effect is more prominent for low mass galaxies (blue line).

2. Theoretical Consideration

We apply the chemical evolution model of Kudritzki *et al.*(2015), which addresses the relation among inflow, outflow, metallicity, and stellar-to-mass ratio in the spatially resolved case. The inflow and outflow of a galaxy are parameterized by two factors:

$$\Lambda = \frac{\dot{M}_{accr}}{\psi}, \quad \eta = \frac{\dot{M}_{loss}}{\psi} \tag{2.1}$$

where $\dot{M}_{accr}$ and $\dot{M}_{loss}$ are the mass accretion and mass loss rate, and ψ is the star formation rate. Here we assume (1) the Λ and η are constant in time, (2) the inflow gas is free of metals,

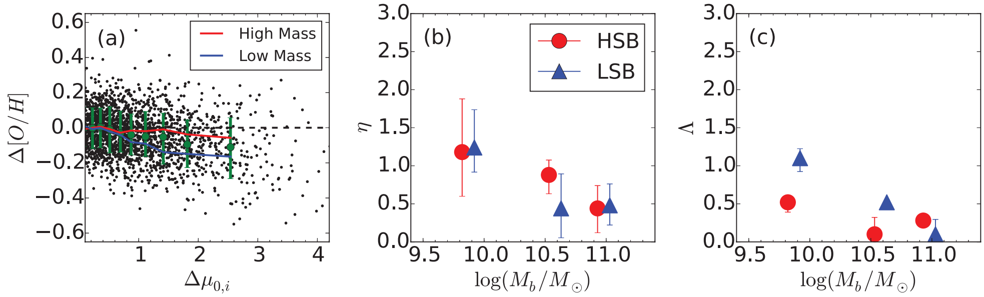

Figure 1. (a) The influence of surface brightness of the disk on metallicity. Each point comes from two galaxies with the same stellar mass and gas mass, but different μ_0. Lower surface brightness galaxies (larger μ_0) on average have lower metallicity (green error bars). The surface brightness effect is stronger in low mass galaxies (median of distribution in the blue line). (b) The median η in different mass-μ_0 bins. (c) The median Λ in different mass-μ_0 bins. Low surface brightness galaxies (blue triangles) at low mass have stronger inflow.

and the outflow gas has the same metallicity as the ISM, and (3) the nucleosynthetic yield (y) and the stellar mass return fraction (R) are both constant. Under these assumptions, the metallicity can be analytically expressed as

$$Z(t) = \frac{y}{\Lambda}\left\{1 - \left[1 + (1 + \frac{\eta - \Lambda}{1 - R})\frac{M_\star(t)}{M_g(t)}\right]^{-\frac{\Lambda}{(1-R)(1+\frac{\eta-\Lambda}{1-R})}}\right\} = f(\frac{M_\star}{M_g}, \eta, \Lambda). \tag{2.2}$$

We assume that the radial gas mass profile scales with the optical radius of galaxies (Bigiel & Blitz 2012). Therefore, we have Z and $M_\star/M_g$ as a function of radius. The multiple measurements in a galaxy can be used to constrain their η and Λ.

Figure 1(b) and (c) shows the median value of best-fit η and Λ in each baryonic mass bin. We further sort galaxies by their surface brightness in each mass bin. The model does not put strong constraint on η. On the contrary, low surface brightness galaxies on average have larger Λ at the two lower mass bins.

From the chemical evolution model, we can conclude that, the lower gas-phase metallicity in low surface brightness galaxies is, at least, partly due to stronger inflow of pristine gas that dilutes the ISM.

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