JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
36: 145 ~ 148, 2003

SINGLY-PEAKED P-CYGNI TYPE LYα FROM STARBURST GALAXIES

SANG-HYEON AHN
Korea Institute for Advanced Study, Seoul 130-722, Korea
E-mail: sha@kias.re.kr

(Received May 08, 2003; Accepted August 17, 2003)

ABSTRACT

P-Cygni type Lyα from starburst galaxies, either nearby galaxies or Lyman Break galaxies, are believed to be formed by galactic outflows such as galactic supershells or galactic superwinds. We develope a Monte Carlo code to calculate the Lyα line transfer in a galactic supershell which is expanding and formed of uniform and dusty neutral hydrogen gas. The escape of Lyα photons from the system is achieved by a number of back-scatterings. A series of emission peaks are formed by back-scatterings. When we observe P-Cygni type Lyα emissions of starforming galaxies, we can usually see merely singly-peaked emission. Hence the secondary and the tertiary emission humps should be destroyed. In order to do this, dust should be spatially more extended into the inner cavity than neutral supershell. We find that the kinematic information of the expanding supershell is conserved even in dusty media. We discuss the astrophysical applications of our results.

Key words : cosmology: radiative transfer – galaxies: starburst

I. INTRODUCTION

Lyα has been the most prominent line feature in the rest-frame ultraviolet spectra of starburst galaxies, and so Lyα is ofetn used as a redshift indicator. Recently a large number of star-forming galaxies are spectroscopically observed, either by using the Lyman break method (Steidel et al. 1996, 1999) or by using gravitational lensing (Franx et al. 1997; Frye et al. 1998, 2002). The rest-frame UV spectra of those galaxies often show unique emission, and sometimes even the continua can not be seen. In these cases we believe that they be Lyα emission lines, and use them as a redshift indicator. However, this unique feature can be more sources of astrophysical information of those star-forming galaxies as well.

Lyα profiles of starburst galaxies can be classified into two major types: P-Cygni type emission and broad absorption. The two types are nearly equally populated. Kunth et al. (1998) proved that the kinematic motion of ambient material is crucial to determine whether emergent Lyα has either broad absorption or P-Cygni type emission. P-Cygni type Lyα emission can be seen only in those galaxies whose interstellar absorption lines are blueshifted with respect to the Lyα emission. In other words, when we define $\Delta v \equiv c(z_{ISM} - z_{Ly\alpha})$, the galaxies with $\Delta v < -100$ km s^{-1} show P-Cygni type Lyα, while those galaxies with -100 km s$^{-1} < \Delta$v < 0 km s^{-1} show broad absorption.

It seems to be a general concensus that these outflowing motion is caused by either galactic superwind or galactic supershell (Lee & Ahn 1998; Heckman et al. 1998; Taniguchi & Shioya 2001; Ahn et al. 2002). No matter what the cause is, it is evident that in these physical situation, the Lyα radiative transfer is mainly achieved by back-scattering processes. We have studied the role of back-scattering process in the formation of Lyα line profile (Ahn et al. 2002). For the case of dustless supershell, we find that a series of peaks appear in the red wing of Lyα. In that paper we emphasized that the kinematic motion is imprinted on the width of each peaks and the velocity difference between peaks. However, nearly all the observed Lyα show merely single emission peak. Naturally we can attribute this discrepancy to the previously neglected dust extinction in the radiative transfer. This is the main topic of this paper.

II. MODEL

Galactic supershells are very well-known structures in the nearby starbust galaxies (Marlowe et al. 1995, Martin 1998), and their origin is believed to be multiple explosions of the supernovae in active star-forming region. In this paper we adopt a model for the starburst galaxies at high redshifts in which Lyα sources are presumed to be located at the center of the galaxy and surrounded by the galactic supershell. The supershell is assumed to be uniform medium of neutral hydrogen and expanding in a bulk manner. We assume that the interior of the supershell is an HII bubble, which seems to be vacuum in the sense of Lyα scattering. The model and the Monte Carlo method was described in detail in our previous papers (Ahn et al. 2000, 2001, 2002). We have several assumptions in this work.

1. The starburst occurs in the central nuclear region of the galaxy. This assumption is based on the fact

---

Proceedings of the APCTP Workshop on *Formation and Interaction of Galaxies*

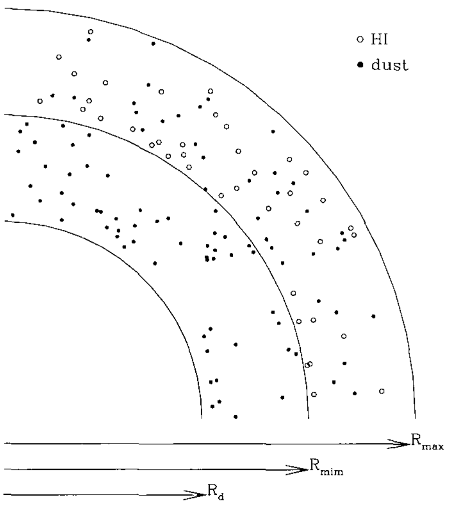

Fig. 1.— A model presumed in this paper. We assume that the dust cavity exist at the center, and the dust is distributed inside the hydrogen shell, as well as in the hydrogen shell. Hydrogen gas and dust are assumed to be homogeneous, and so dots are randomly located in this figure.

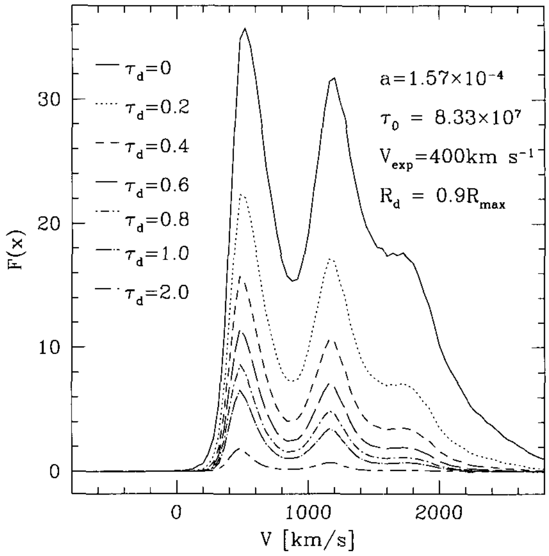

Fig. 2.— Emergent Lyα profiles for several cases with different dust opacity and same R_d. We assume that dust is only distributed with the supershell or that $R_d = R_{min}$. We regard the left peak as a primary peak, the central peak as a secondary peak, and the right peak as a tertiary peak.

that almost all the observed Lyα emission lines are asymmetric, as well as the HST images of the Lyman Break Galaxies (Calzetti 2001).

2. The galactic scale supershell at least fully covers the starburst regions, and its thickness is $R_{min} = 0.9R_{max}$, where R_{max} is the outer radius of the supershell and R_{min} is the inner radius of the supershell.
3. The supershell is made of uniformly distributed neutral hydrogen. This assumption is not so wrong and inevitable to make the radiative transfer problem solvable.
4. We assume that the supershell is expanding with a expansion velocity of 100 – 500 km s^{-1} and the column density around 10^{20}cm^{-2}, which are based on the observations (e.g. Kunth et al. 1998).
5. Dust is also uniformly distributed, but its spatial distribution can be different from that of neutral hydrogen. In this paper R_d is the inner radius of the dust shell, and the outer radius of dust shell is assumed to be equal to R_{max}.

III. RESULTS

We first assume that dust is uniformly distributed only within the supershell. Our results for this case is seen in Figure 1. We can see that there are several peaks for each case, which is similar to our previous study (Ahn et al. 2002). We see that the secondary and the tertiary peaks are not so much decreased as we expected for the results to reconcile with observation of singly-peaked Lyα emission. Secondary peaks survive even when $\tau_d = 2$. This fact means that the emergent Lyα photons, forming the peaks, have experienced almost the same amount of dust extinction. This can be explained as follows. Every back-scattering causes redshift of the photon. Since the column density of the supershell is very high, Lyα photons are back-scattered at the shallow part of the inner wall of the supershell. Hence, the opacity contribution by dust within the supershell during back-scatterings is not so high, but that of the final escape dominates the total dust opacity. Hence, the total dust opacity for most of Lyα emergent photons are similar.

Then we study the cases $R_d < R_{max}$, i.e. dust is distributed in the ionized bubble, as well as within the supershell. In this case dust extinction is dependent on the number of back-scatterings, and we expect the secondary and the tertiary peaks can be more extinct. Figure 2 show the results when $R_d = 0.4R_{max}$. We can see that the secondary and the tertiary peaks are reduced much more sensitively than those in Figure 1. It is very interesting that the width of primary peak is insensitive to the dust opacity. We have shown that the kinematics of outflowing material is imprinted on both the velocity width of the peaks and the velocity differences between peaks (Ahn et al. 2002). Therefore this results open a possibility that we can estimate the expansion velocity of the supershell even in dusty interstellar media without loss of kinetic information.

Figure 3 shows the effects of R_d on the emergent

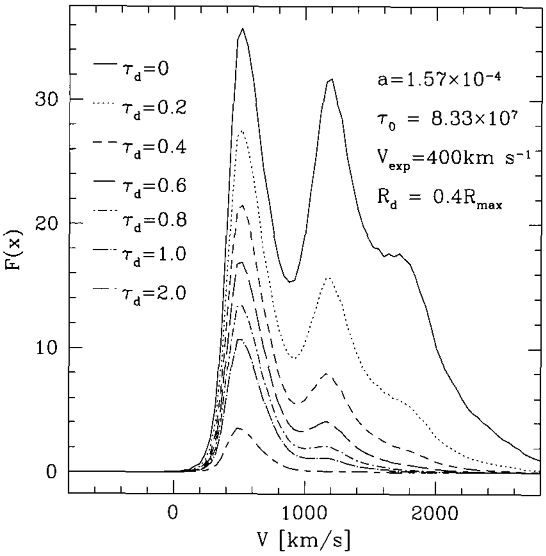

Fig. 3.— Emergent Lyα profiles for several cases with different dust opacity. We assume that dust is more extended to the center than the neutral hydrogen supershell or that $R_d < R_{min}$.

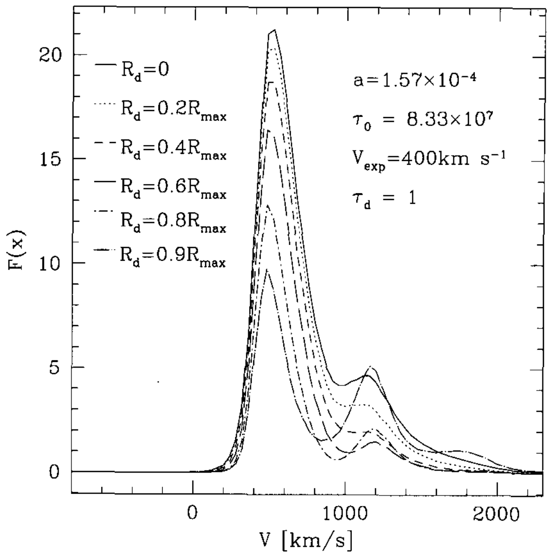

Fig. 4.— Emergent profiles for the several cases with different dust distribution. R_d is the inner radius of dust shell. All other parameters are fixed as shown in the figure.

profiles with $\tau_d = 1$ fixed, where τ_d is total dust opacity in the line of sight to the center. We define the dust opacity in this way, because we usually estimate the dust opacity by analysing the extinction of the UV continuum from central stars. In the figure we can see that the secondary peaks nearly disappear only when $R_d < R_{min}$. It is noticeable that the effective dust opacity for unit path length becomes small as $R_d \to 0$, which explains the fact that the secondary peak does not completely disappear when $R_d = 0$.

IV. DISCUSSION

In this paper we emphasize that the spatial distribution of dust grains in the supershell are as important in forming the Lyα emission profiles as the kinematics of the supershell. The usual observations of single peak in the Lyα emission of remote starburst galaxies can be nicely explained by our study. We also emphasize that the kinematic information of outflowing media surrounding Lyα sources is imprinted on the Lyα profiles and conserved even though the medium is dusty.

The geometrical distribution of the dust associated with the massive stars in starbursts has been studied for many years, which is well reviewed in Calzetti (2001). Recently Inoue (2002) showed that central dust cavity exists in the Galactic HII regions from the ratio of the infrared and radio fluxes by using a simple radiative transfer model of Lyman continuum photons. They reported that the mean radius of the dust cavity of the Galactic compact HII regions is about 0.4 times the Strömgren radius. He attribute the formation of dust cavity to the radiation pressure and stellar wind in HII regions. Ferland (2001) also investigated on the spatial distribution of dust and gas in the Orion HII region, and found that radiation pressure is more important than winds in controlling the overall geometry. We think that the same physics can be applied to the case of starburst galaxies at high redshifts.

The author thanks the financial support of APCTP and KOSEF.

REFERENCES

Ahn, S. -H., Lee, H. -W., & Lee, H. M. 2000, Lyα Transfer in a Thick, Dusty, and Static Medium, JKAS, 33, 29

Ahn, S. -H., Lee, H. -W., & Lee, H. M. 2001, Lyα Line Formation in Starbursting Galaxies. I. Moderately Thick, Dustless, and Static H I Media, ApJ, 554, 1

Ahn, S. -H., Lee, H. -W., & Lee, H. M. 2002, Lyα Line Formation in Starbursting Galaxies. II. Extremely Thick, Dustless, and Static H I Media, ApJ, 567, 922

Calzetti, D. 2001, The Dust Opacity of Star-forming Galaxies, PASP, 113, 1449

Ferland, G. J. 2001, Physical Conditions in the Orion H II Region, PASP, 113, 41

Franx, M., Illingworth, G. D., Kelson, D. D., van Dokkum, P. G. & Tran, K. 1997, A Pair of Lensed Galaxies at $z = 4.92$ in the Field of CL 1358+62, ApJ, 486, 75

Frye, B., Broadhurst, T., & Benítez N. 2002, Spectral Evidence for Widespread Galaxy Outflows at $z > 4$, ApJ, 568, 558

Heckman, T. M., Robert, C., Leitherer, C., Garnett, D., & van der Rydt, F. 1998, The Ultraviolet Spectroscopic

Properties of Local Starbursts: Implications at High Redshift, ApJ, 503, 646

Inoue, A. K. 2002, Spatial Distribution of Dust Grains within H II Regions, ApJ, 570, 688

Kunth, D., Mas-Hesse, J. M., Terlevich, E., Terlevich, R., Lequeux, J., & Fall, S. M. 1998, HST study of Lyman-alpha emission in star-forming galaxies: the effect of neutral gas flows, A&A, 334, 11

Lee, H. -W. & Ahn, S. -H. 1998, Polarization of the Ly alpha from an Anisotrophy Expanding H I Shell in Primeval Galaxies, ApJ, 504, L61

Marlowe, A. T., Heckman, T. M., Wyse, R. F. G., Schommer, R. 1995, Observations of the impact of starbursts on the interstellar medium in dwarf galaxies, ApJ, 438, 563

Martin, C. 1998, The Impact of Star Formation on the Interstellar Medium in Dwarf Galaxies. II. The Formation of Galactic Winds, ApJ, 506, 222

Steidel, C. C., Giavalisco, M., Pettini, M., Dickinson, M., & Adelberger, K. L. 1996, Spectroscopic Confirmation of a Population of Normal Star-forming Galaxies at Redshifts $z > 3$, ApJ, 462, 17

Steidel, C. C., Adelberger, K. L., Giavalisco, M., Dickinson, M., & Pettini, M. 1999, Lyman-Break Galaxies at $z > 4$ and the Evolution of the Ultraviolet Luminosity Density at High Redshift, ApJ, 519, 1

Taniguchi, Y. & Shioya, Y. 2001, A New Interpretation of Chain Galaxies at High Redshift, ApJ, 547, 146