A Study of Superwind Galaxies(Abstracts of Doctoral Dissertations,Annual Report (form April 1998 to March 1999))

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journal or publication title	The science reports of the Tohoku University. Ser. 8, Physics and astronomy
volume	20
number	1
page range	189-190
year	1999-07-30
URL	http://hdl.handle.net/10097/26027

A Study of Superwind Galaxies

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In starburst galaxies, a large number of massive stars (e.g., $\sim 10^{4-5}$) are formed within a short duration. Therefore, a burst of supernova explosions occurs inevitably $\sim 10^7$ years after the onset of the starburst. Since these numerous supernovae release a huge amount of kinetic energy into the circumnuclear space, the circumnuclear gas is thermalized and a "superbubble" forms. This blows out often into the directions perpendicular to the galactic disk as a bipolar "superwind". A superwind is a natural consequence of luminous starbursts and thus is a basic physical process in the formation and the evolution of galaxies as well as the chemical evolution of the intergalactic space. Thus, the investigation of their basic nature is very important.

Chapter I AN OPTICAL INVESTIGATION OF SUPERWINDS FROM STARBURST NUCLEI Because physical conditions and the velocity field of the ionized gas are expected to be related closely with each other, it is very important to investigate their mutual relationships. I have conducted the systematic spectroscopic program for a sample of 18 starburst galaxies and obtained their spectra around [NII]$\lambda\lambda$6548, 6583 and Hα emission lines with a very high velocity resolution ($\simeq$ 20 km s^{-1}). Based on detailed investigations of the line profiles, I find the blue- and red-shifted high-velocity components (BHVC and RHVC, respectively) in both Hα and [NII] emission lines. Their properties are used for the correlation analyses with other various basic properties of galaxies.

Our main results are; (1) most galaxies show blue-asymmetric line profiles, (2) the line width (the full width at half maximum; FWHM) is larger in more inclined and more far-infrared (FIR) luminous galaxies, (3) relative contribution of the high velocity component becomes more enhanced in face-on galaxies, (4) enhancement of blue-shifted [NII] emission becomes larger in FIR luminous edge-on galaxies, and (5) the [NII]/Hα ratio in BHVC becomes more enhanced with respect to that in RHVC in galaxies with larger dust extinction. In order to explain these correlations, I attribute the ionized gas to the following three components; (I) the disk component following the galactic disk rotation, (II) the fast superwind component flowing into the direction perpendicular to the disk, and (III) the expanding ring-like component within the disk. In the third component, the [NII] emission is enhanced by the strong shock heating at the interface between the expanding superbubble and the dense ambient gas in the disk. With the effect of the dust extinction, the red-shifted part of this component is expected to be hidden and, thus, the blue-shifted [NII] emission would be apparently enhanced.

I find that the [NII]/Hα ratio in both BHVC and RHVC shows correlations with mid-infrared (MIR) and FIR properties, suggesting that physical conditions of the ionized gas are closely related with both the star-formation and the superwind activities. I construct a new model in which a starburst model of Mouri & Taniguchi (The Astrophysical Journal, Vol. 386, P. 681) is combined with a dynamical model of the superbubble and a physical model of the shock heating. The model can explain the observed correlations in terms of the relative contribution of the shock heating in the superwind with respect to the photoionization by massive stars.

Chapter II OBSERVATIONAL PROPERTIES OF THE SUPERWIND FROM THE FACE-ON WOLF-RAYET STARBURST GALAXY MRK 1259 A bubble of the ionized gas sweeps up the circumnuclear gas, leading to an outflow of cold gas as well as the ionized-gas one. Thus, in order to understand the whole physical processes of superwinds, investigation of both hot and cold gas is important. In Chapter II, I present results of a comprehensive study of both ionized gas and molecular gas in one of the nearby starburst galaxy Mrk 1259.

First, an optical discovery of the superwind in this galaxy is reported and results of the analyses of its basic properties are presented. While the nuclear emission-line region is photoionized by usual massive stars, the circumnuclear emission-line regions show anomalous line ratios that can be due to cooling shocks. Since the host galaxy seems to be a face-on disk galaxy and the excitation conditions of the circumnuclear emission-line regions show the spatial symmetry, I consider that we are seeing the superwind of this galaxy nearly from a pole-on view.

Next, a discovery of the molecular-gas superwind in this galaxy is reported and results of the analyses of its basic properties are presented. We have conducted ^{12}CO (J = 1-0) mapping observations of this galaxy. With a single-dish telescope, the CO emission is detected in the central 4 kpc region and shows single-peaked broad ($\sim$ 100 km s^{-1} in FWHM) profiles in both nuclear and off-nuclear regions. The off-nuclear CO profiles may be explained if we introduce a CO gas disk extending up to a few kpc in radius with a velocity dispersion of $\sim$ 100 km s^{-1}. Alternatively, we may attribute the off-nuclear CO emission to the gas associated with the superwind. In order to discriminate the two possibilities, I have also conducted aperture synthesis observations in ^{12}CO (J=1–0) of this galaxy with higher spatial resolution. As a result, the following three ^{12}CO emission components are found. (1) The nuclear component, which is compact ($r \lesssim$ 650 pc) and is spatially associated with the starburst nucleus. The line width is relatively narrow ($\simeq$ 100 km s^{-1} in FWHM). I attribute this component to the molecular gas associated with the nuclear starburst region. (2) The outer disk component, which is found at the systemic velocity and is spatially extended ($r \simeq$ 650–2600 pc) around the nucleus. The line width ($\simeq$ 20 km s^{-1} in FWHM) is typical for the vertical velocity dispersion of gas in the disk. I attribute this component to the molecular gas associated with the galactic disk seen from nearly a face-on view. And, (3) the high-velocity component, which is spatially extended around the nucleus ($r \simeq$ 650–2600 pc) and shows symmetric double profiles with respect to the systemic velocity. I attribute this component to the molecular gas associated with the superwind seen from nearly a pole-on view., i.e., the molecular gas flowing toward us and away from us are responsible for the blue- and red-shifted components, respectively.

With the detailed knowledge of both ionized gas and molecular gas superwind, a comprehensive picture of the superwind activities of this galaxy are finally made.