Journal of The Korean Astronomical Society
38: 365 ~ 370, 2005

A MULTI-WAVELENGTH STUDY OF 30 DORADUS COMPLEX IN THE LARGE MAGELLANIC CLOUD

Sungeun Kim
Astronomy and Space Science, Sejong University, 98 Gunjadong, Kwangjin-ku, Seoul, 143-747, Korea
E-mail: sek@sejong.ac.kr
(Received September 21, 2005; Accepted September 28, 2005)

ABSTRACT

We have made a multi-wavelength study of the X-ray bright giant shell complex 30 Doradus in the Large Magellanic Cloud (LMC). This is the one of the largest H II complexes in the Local Group. The Australia Telescope Compact Array (ATCA) and the Parkes 64-m single dish observations reveal that the distribution and internal motions of H I gas show the effects of fast stellar winds and supernova blasts. The hot emitting gas within the 30 Doradus complex and the entire giant H II complex are encompassed by an expanding H I shell. We investigate the dynamical age of this H I shell and compare to the age of starbursts occurred in the 30 Doradus nebula using the radiative transfer model and the infrared properties.

Key words : galaxy: Large Magellanic Cloud — ISM: atom — ISM: infrared

I. INTRODUCTION

The Magellanic Clouds (MCs) present us with a unique opportunity to investigate the interaction of massive stars on their interstellar environment. The Magellanic Cloud stars are at a common distance and are close enough that individual stars and their stellar ejecta can be studied in great detail. While the studies of the Milky Way are difficult due to their uncertain distances, this is not a problem in the Magellanic Clouds. Especially, the Large Magellanic Cloud (LMC) is inclined at only 27 degrees to the line of sight and has small foreground and internal extinctions, so that the gas and dust of the interstellar medium (ISM) in the LMC can be mapped without problems of confusion along the line-of-sight. Therefore, the LMC provides an excellent opportunity to study the effects of different UV radiation from stars on their environments in the multi-phase ISM.

The giant H II complex, 30 Doradus complex itself in the LMC, extends for more than 100 pc and has revealed a very complicated velocity structure in nature (Chu and Kennicutt 1994). *ROSAT HRI* (Wang 1999) and recent studies by Chandra observations (Lazendic et al. 2003) have proven that there are hot gas associated with this entire giant H II complex in the LMC. Here we report that H I aperture synthesis observations with the Australia Telescope Compact Array (ATCA) and the Parkes single dish combined observations (Kim et al. 2003) have revealed that the hot emitting gas near the 30 Doradus complex and the entire giant H II complex is surrounded by an expanding H I shell. Recent studies of Kim et al. (2005) show the detection of a high-velocity CO $J = 4 \rightarrow 3$ emitting cloud in this H II shell complex. The physical nature of the neutral hydrogen gas of 30 Doradus complex demonstrates the dynamical interaction between massive stars and their ISM.

II. OBSERVATIONAL DATA

H I observations were taken with the Australia Telescope Compact Array (ATCA) to survey a region $10° \times 12°$ covering the LMC, and at an angular resolution of 1.′0, corresponding to a spatial resolution of 10 pc in the LMC. The detailed observations, data reductions, and imaging processes are described in Kim et al. (1998). The ATCA map has been combined with a single dish Parkes observations (Kim et al. 2003). The data cube of 30 Doradus complex was extracted from the full mosaic of the LMC, which consisted of 1344 separate pointing centers. Approximately five pointing centers were included in the data cube of 30 Doradus complex. The phase and amplitude calibrators were PKS B0407−658 for some fields and PKS B0454−810 for the others. The primary calibrator, PKS B1934−638 (assumed flux density 14.9 Jy at 1.419 GHz), was observed at the start and end of each observing day. These observations served both for bandpass calibration and flux density calibration. The data were edited, calibrated, mosaicked, and combined with the 64-m single dish observations in MIRIAD. The pixel size is 20″ and the size of the 30 Doradus cube is $23 \times 23 \times 120$ pixels. Superuniform weighting (Sramek and Schwab 1989) was applied to the *uv* data with an additional gaussian taper. The resulting data were then Fourier transformed, mosaicked, and combined with the Parkes single dish data in the image plane. The maximum entropy method was used to deconvolve this cube. The final cube was constructed by convolving the maximum entropy model with a gaussian of FWHM 50″×″50.

Hα 6563 Å observations of the 30 Doradus complex have been undertaken with a CCD camera mounted at the Newtonian focus of the Curtis Schmidt telescope

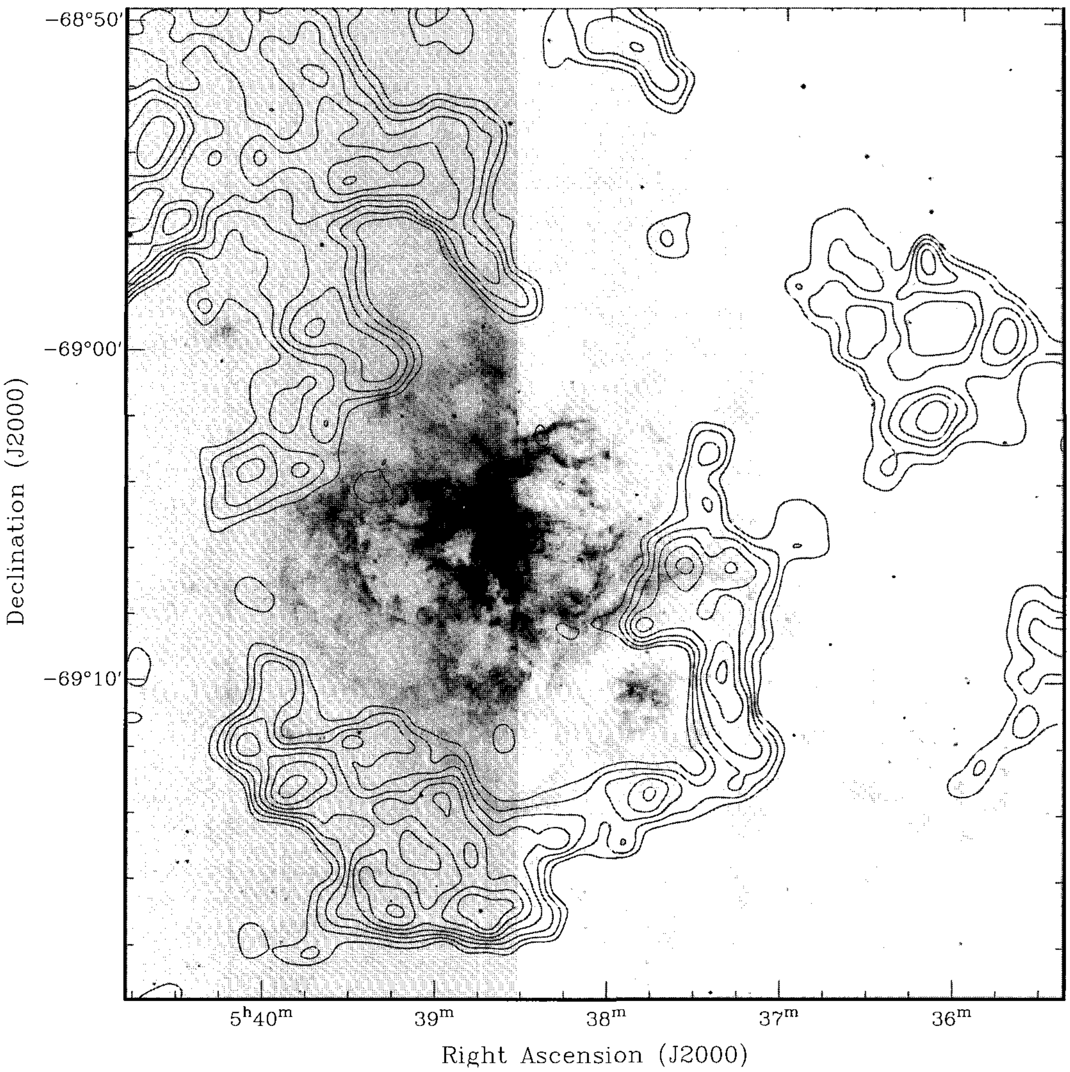

Fig. 1.— The Hα image of 30 Doradus complex (gray scale image) taken with CTIO 4-m telescope overlaid with the H I peak intensity map contours. The contour levels are 400, 450, 500, 550, 600, 650, 700 mJy/beam.

at CTIO by Chris Schmidt (Smith et al. 1999). The detector was a front-illuminated Thomson 1024 × 1028 CCD with 19 μm pixels, giving a scale of 1″.835 pixel^{-1} and a field of view of 31.′3. A narrow-bandpass Hα filter (λ_c = 6561 Å , $\Delta\lambda$ = 26 Å) was used to isolate the emission, and a red continuum filter (λ_c = 6840 Å , $\Delta\lambda$ = 95 Å) was used to obtain images of the continuum background (images in other emission lines were also obtained, but those will be discussed in another paper). Multiple frames were obtained through each filter, amounting to total integration times of 1200s in Hα and 600s in the continuum. The data were reduced with IRAF and multiple frames were shifted and combined to obtain the images shown in Figure 1.

III. INTERACTION BETWEEN H I, H II, AND X-RAY COMPONENTS OF 30 DORADUS COMPLEX

The peak intensity H I map of 30 Doradus complex shows clear depression that correspond to the entire H II complex revealed by the Hα image (Figure 1). The ATCA+Parkes channel maps of H I kinematically resolve the distribution of H I along the line of sight, and allow more precise identification of physical structures in the H I distribution (Figure 2). The H I channel maps at V_{HEL} = 258 − 281 km s^{-1} show a clear hole corresponding to the H II holes and shells in the 30 Doradus complex. The entire 30 Doradus nebula complex is encompassed by an expanding H I shell. Projected within the H I hole are high-velocity H I clumps (∼30 pc diameter) at 5^{h}39^{m}00^s, −69°00′00″ (J2000) at the velocity range of V_{HEL} ∼ 239 − 257 km s^{-1} (see Figure 2).

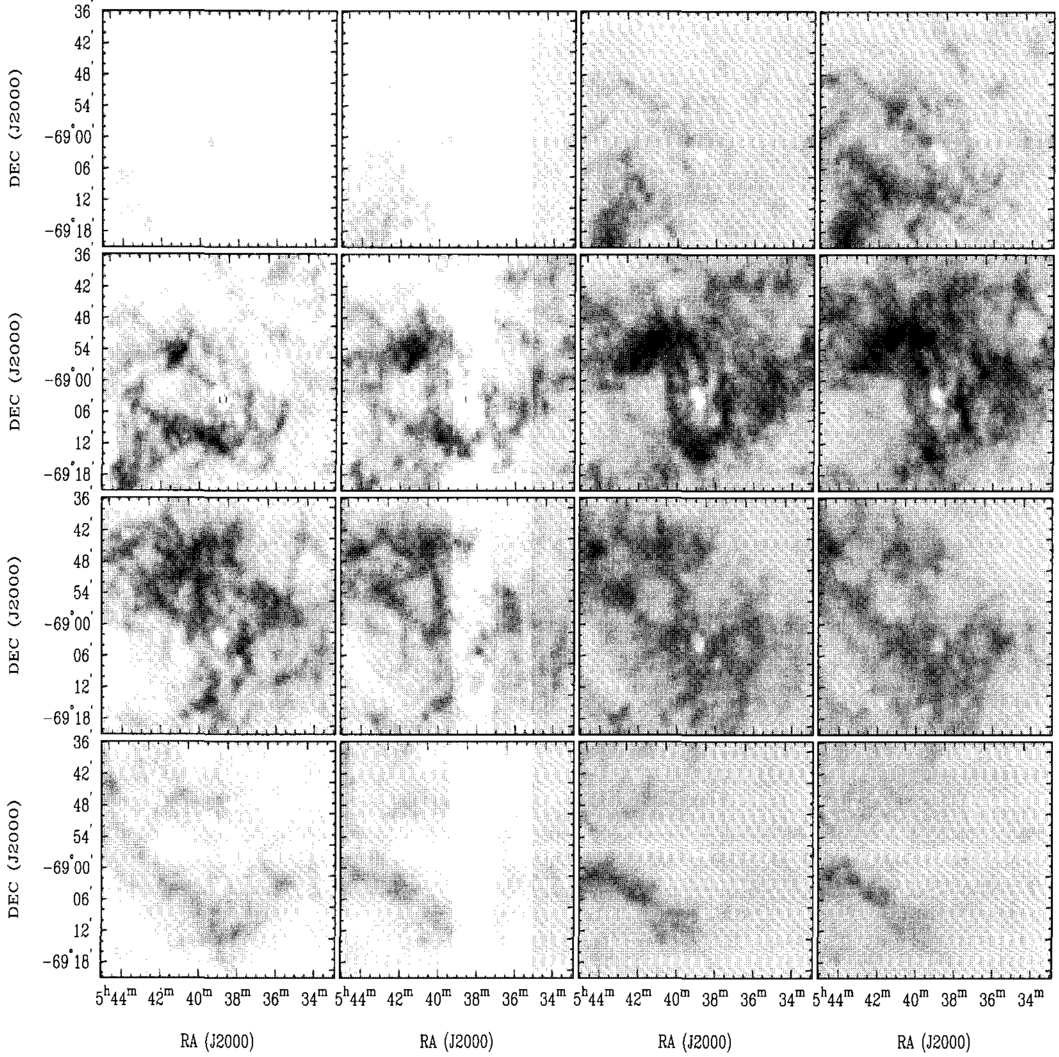

Fig. 2.— The individual channel maps for the H I datacube in the 30 Doradus complex. Each panel is the average of three adjacent channels of width 1.649 km s^{-1} giving a panel spacing of 4.95 km s^{-1}. The heliocentric velocity of the first channel map is 239.5 km s^{-1} and that of the last one is 313.8 km s^{-1}.

The H I shell associated with the 30 Doradus complex shows a typical expansion structure in the position–velocity diagram (Figure 3). The 30 Doradus giant H II region complex has a very complicated structure with a complex kinematic structure on a parallel with its chaotic Hα morphology. The 30 Doradus has several fast expanding H II ionized shells and some of these shells are likely to be associated with SNRs (Chu and Kennicutt 1994). The high-velocity H I clumps are likely to be associated with these fast shells and SNRs. We have used the KARMA routine KPVSLICE (Gooch 1996) to measure the expansion velocity of the shell and find V_{exp} = 18 km s^{-1}. Since both the approaching and receding hemispheres are visible in the $P - V$ diagram, it has been classified as an expanding shell.

If we adopt the standard theory of wind-driven bubbles by Weaver et al. (1997), the kinematic age of this shell, t_s (in units of Myr), can be estimated from $t_s = 3R_s/5V_s$. Here R_s is the shell in units of pc and V_s is the expansion velocity of the shell in units of km s^{-1}. Since the size of this H I shell is about 300 pc at the distance of the LMC (Feast 1991) and less than 350 pc, this shell is likely to be in the energy-conserving phase (Weaver et al. 1977). The dynamical age of this H I shell is approximately 5 Myr. This age estimate will be discussed in §4.

By comparing to the *Chandra* X-ray image of the 30 Doradus H II complex, the relationship between the X-ray emitting ionized gas and the H I gas is shown in Figure 4. As seen in Figure 4, the H I shell encompasses X-ray emitting regions as a whole in the 30 Doradus complex. These observations clearly show a multi-phase ISM model by McKee and Ostriker (1977). In Figure 4, we show the exposure-corrected 0.5–10

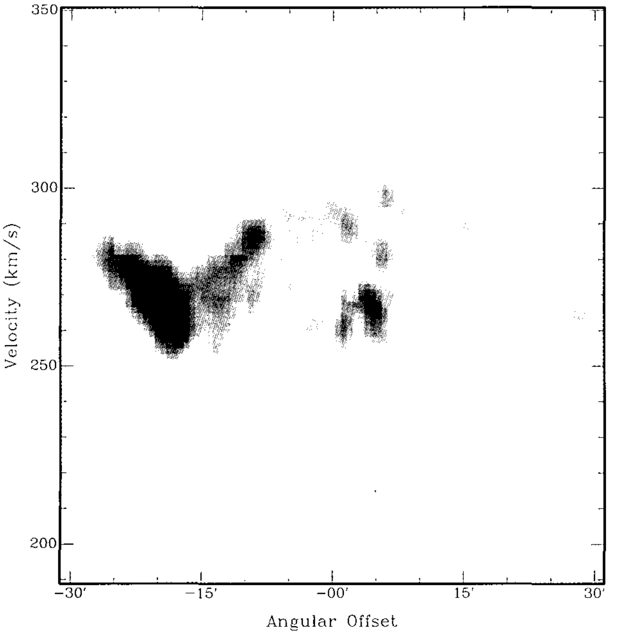

Fig. 3.— Position-velocity diagram of the H I shell. The unit of the H I velocity is in heliocentric velocity (Kim et al. 2005). The center of cuts along the declination with PA of 105° is at 5^h39^m, $-69°07'$ (J2000).

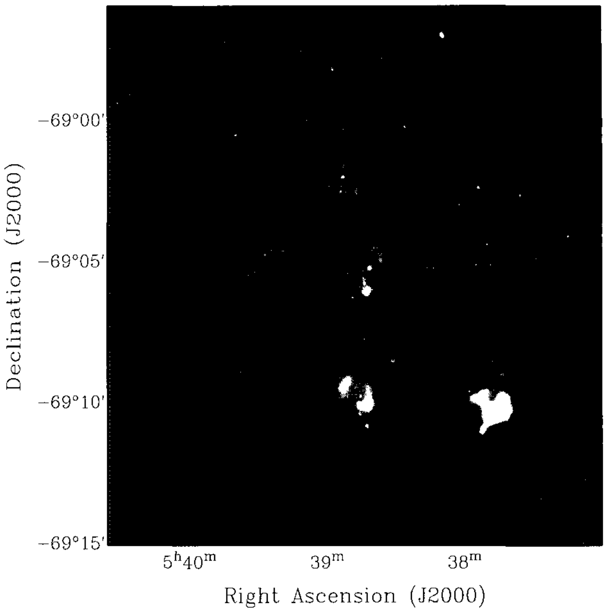

Fig. 4.— The exposure corrected 0.5−10 keV *Chandra* image provided by L. Townsley. Red contours indicate the integrated H I map of 30 Doradus complex.

keV *Chandra* image provided by L. Townsley and overlaid with the H I image contours. We find a strong X-ray emission arising from the Hα and H I cavities in the central region of the nebula. The overall distribution of X-ray emission imaged by *Chandra* is similar to that seen in the previous *ROSAT* image (Wang and Helfand 1991; Wang 1999) except the additional point sources revealed in the image. An extension of diffuse X-ray emission toward the north of 30 Doradus complex shows a clear extension of the H I hole to the north coinciding with the X-ray extension. The Hα echelle observations by Chu and Kennicutt (1994) reported the presence of high-velocity ionized gas in the X-ray extension bounded by Hα ionized gas shell. This extension of the H I hole is likely to be an opening through which the breakout occurs.

IV. DISCUSSION

It has been thought that the 30 Doradus nebula has been formed by the stellar winds and supernova explosions from the central cluster R136 with about 10^{53} ergs of the mechanical energy (Chu and Kennicutt 1994; Wang 1999). Recent studies by Lazendic et al. (2003) report SNR candidates associated with the 30 Doradus nebula. 30 Doradus nebula has been thought as an extraordinarily complex interstellar environment based on the kinematic structure. Another important aspect of this H II complex is the strong far-infrared emission and the mixture of gas and dust therein. In general, about 70 percent of the total infrared radiation between 40 and gas and dust therein. In general, about 70 percent of the total infrared radiation between 40 and 350 μm arises from typical H II regions and their H I surrounding gases. The *IRAS* (InfraRed Astronomy Satellite) All Sky Survey provides fluxes from such regions at 12, 25, 60, and 100 μm in the far-IR emission. The 100 μm *IRAS* HIRES picture in Figure 5 confirms that the dust emission emanates from the 30 Doradus nebula itself and the H I shell surrounding the nebula. At 100 μm and the longer wavelengths, radiation from the cooler grains in H I medium at the dust temperatures of 20 to 30 K would dominate the far-IR emission. Strong 100μm emission in the southern part of 30 Doradus complex would be attributed to emission from grains within the H I shell.

Comprising ionized shells and H II regions, 30 Doradus H II complex remains trapped inside H I shell which continues to expand at ∼ 18 km s^{-1} as we saw that in § 3. Now we discuss whether the dynamical age of the neutral shell is consistent with the age of the starburst from the *IRAS* colors. The spectral energy distributions (SEDs) of dust enshrouded starbursts model by Efstathiou et al. (2000) are applied for 1.7 Myr, 16 Myr, 26 Myr, 37 Myr, and 45 Myr in Figure 6. Radiative transfer model for the infrared emission of starbursts by Efstathiou et al. (2000) illustrates the evolution of giant molecular clouds (GMCs) illuminated by massive star formation and the evolution of H II regions due to ionization induced expansion. At the later stages of $t \geq 10^7$ yrs it includes the evolution of GMCs by stellar winds and supernova explosions. The dust model for the Magellanic Clouds by Weingartner

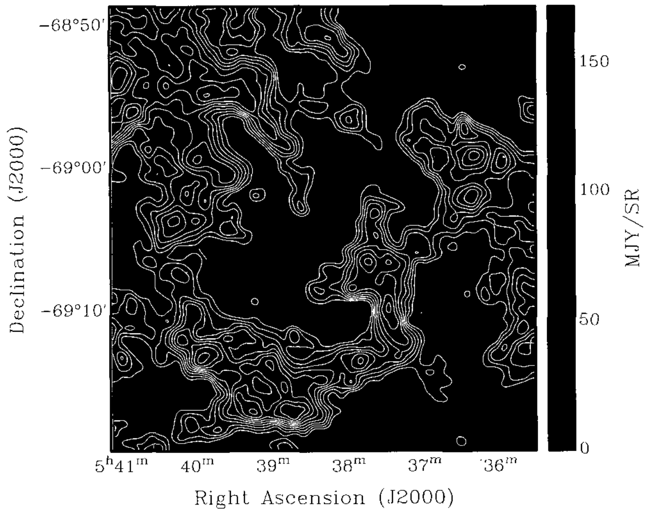

Fig. 5.— *IRAS* 100 μm emission (gray scale image) overlaid with the H I integrated map contours. The contour levels are 17.2, 18.4, 19.6, 20.8, 22.0, 23.2, 24.4, 25.6, 26.8 Jy/beam km s^{-1}

and Draine (2001) is taken into account. However, the *IRAS* data of 30 Doradus complex is not possible to be reprocessed according to the SED with ages of 1.7 – 45 Myrs. Combining the $ASTRO - F$ and SST data with the *IRAS* data of 30 Doradus complex and its immediate surroundings might be able to constrain the infrared properties to its age and star formation history. It will be of much interest to include the submillimeter properties into the SEDs as well in future study and relate to its age and star formation history.

ACKNOWLEDGEMENTS

We thank Leisa Townsley for providing us Chandra X-ray image and Chris Smith for Halpha image. We thank HI project team members. We thank anonymous referee for helpful and critical comments. SK was supported in part by Korea Science & Engineering Foundation (KOSEF) under a cooperative agreement with the Astrophysical Research Center of the Structure and Evolution of the Cosmos (ARCSEC).

REFERENCES

Chu, Y.-H., & Kennicutt, R. C., Jr., 1994, Kinematic structure of the 30 Doradus giant H II region, ApJ, 425, 720

Efstathiou, A., Rowan-Robinson, M, & Siebenmorgen, R., 2000, Massive star formation in galaxies: radiative transfer models of the UV to millimetre emission of starburst galaxies, MNRAS, 313, 734

Feast, M. W., 1991, Opening Address the Magellanic Clouds :DISTANCE, Structure, Chemical Composition, in IAU Symposium No.148, Eds., R. Haynes, and D. Milne, Kluwer, 1

Gooch, R., 1996, Australian National University, PhD thesis

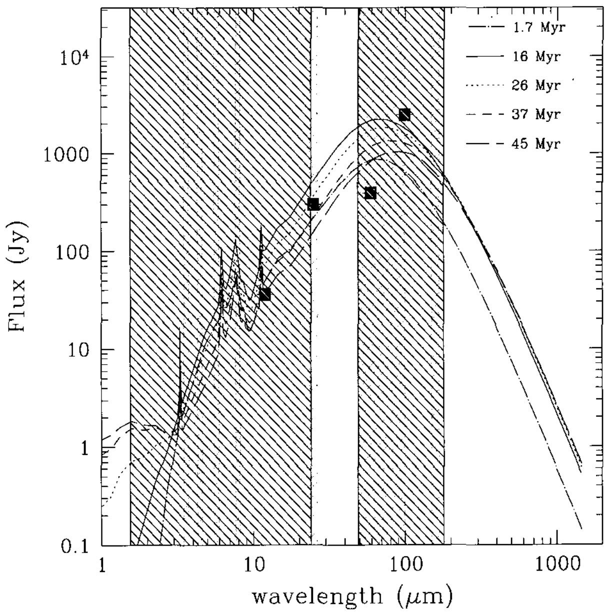

Fig. 6.— Model SEDs of dust enshrouded starbursts by Efstathiou et al. (2000) are applied for starburst ages of 1.7 Myr (dot-dashed line), 16 Myr (solid line), 26 Myr (dotted line), 37 Myr (short-dashed line), and 45 Myr (long-dashed line). Shaded areas represent the wavelength ranges covered by the ASTRO-F observations (red color) and SST observations (cyan color).

Kim, S., Staveley-Smith, L., Dopita, M. A., Freeman, K. C., Sault, R. J., Kesteven, M. J., & McConnell, D., 1998, An HI Aperture Synthesis Mosaic of the Large Magellanic Cloud, ApJ, 503, 674

Kim, S., Staveley-Smith, L., Dopita, M. A., Sault, R. J., Freeman, K. C., Lee, Y., & Chu, Y.-H., 2003, A Neutral Hydrogen Survey of the Large Magellanic Cloud: Aperture Synthesis and Multibeam Data Combined, ApJS, 148, 473

Kim, S., Walsh, W., Xiao, K., & Lane, A., 2005, A ^{12}CO J = 4→3 High-Velocity Cloud in the Large Magellanic Cloud, AJ, 130, 1635

Lazendic, J., Dickel, J., & Jones, P., 2003, Supernova Remnant Candidates in the 30 Doradus Nebula, ApJ, 596, 287

McKee, C. F., & Ostriker, J. P., 1977, A theory of the interstellar medium - Three components regulated by supernova explosions in an inhomogeneous substrate, ApJ, 218, 148

Smith, C. R., 1999, in private communication

Sramek, R. A., & Schwab, F.,R., 1989, in *Synthesis Imaging in Radio Astronomy*, eds., Perley, R. A., Schwab, F. R., & Bridle, A. H. (San Francisco: ASP), 123

Wang, Q., & Helfand, D. H., 1991, The detection of X-ray emission from the OB associations of the Large Magellanic Cloud, ApJ, 373, 497

Wang, Q., 1999, Structure and Evolution of Hot Gas in 30 DOR, ApJ, 510, 139

Weaver, R., McCray, R., Castor, J., Shapiro, P., & Moore, R., 1977, Interstellar bubbles. II - Structure and evolution, ApJ, 218, 377

Weingartner, J. C., & Draine, B. T., 2001, Dust Grain-Size Distributions and Extinction in the Milky Way, Large Magellanic Cloud, and Small Magellanic Cloud, ApJ, 548. 296