XMM-Newton Observations of the N 206 Superbubble in the Large Magellanic Cloud

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Abstract

We present a study of the diffuse X-ray emission detected in the N206 superbubble in the Large Magellanic Cloud by *XMM-Newton*. Comparing the X-ray morphology to the Hα emission of N 206 indicates that the brightest region of X-ray emission is confined by a Hα structure that extends as an approximately spherical shell around the larger superbubble region. However, there is also evidence for a blowout region from the superbubble where the X-ray emitting gas extends beyond the Hα shell. We use the derived spectral parameters of the superbubble and blowout emission to estimate their mass and thermal energy content. Based on the input from the known high mass stellar population in the bubble, we find that the mass of the gas in the bubble is larger than expected whereas the thermal energy stored in gas is lower than input by the stellar population. The additional mass is likely due to mass loading by evaporation of entrained interstellar clouds and/or turbulent mixing of material form the cold shell. The missing energy is likely driving the expansion of the bubble, however, as observed in many other superbubbles, the kinetic energy of the shell and surroundings may be insufficient to account for the energy difference. Further analysis is underway to assess these possibilities.

Introduction

Massive stars, via stellar winds and later supernovae, are responsible for the energizing and enriching of the interstellar medium (ISM). Given that these massive stars usually form and evolve in clusters, the combined mechanical output of these stars create so-called 'superbubbles'. Superbubbles are 100-1000 pc diameter shells of interstellar material surrounding one or more OB associations swept-up by the stellar winds and supernovae shock waves. The shell interior contains the hot (10^6 K) shocked stellar winds and ejecta which are best observed in X-rays. These superbubbles are crucial for the creation and regulation of the multi-phase ISM and governs future star formation in star-forming galaxies. N 206 (Henize, 1956, also known as DEM L221) is a HII region located in the southeast of the Large Magellanic Cloud (LMC) which is excited by the winds of the massive stars in the young NGC 2018 cluster, the LH 66 and LH 69 OB associations (Lucke & Hodge 1970), and contains an X-ray superbubble and a supernova remnant (SNR), see Figure 1.

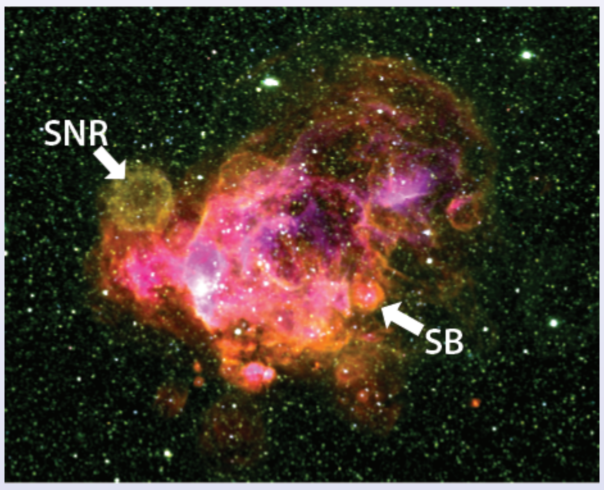

Figure 1: MCELS[1] colour image of N 206 with red corresponding to Hα, green to SII and blue to OIII. The supernova remnant (SNR) and superbubble (SB) are indicated.

Observations and Data Reduction

XMM-Newton has observed the N 206 region on two occasions. We reduced each of the datasets using SAS 10.0.0, filtering for periods of high particle background resulting in a combined effective exposure of 31 ks. We created exposure corrected images in the 0.3-1 keV, 1-2 keV and 2-8 keV to produce the false colour X-ray image of the region shown in Figure 2, which has been smoothed using a Gaussian filter. Source detection was performed using the SAS task `emosaicproc` to achieve the maximum possible detection sensitivity in the overlapping exposures. Detected sources located in the regions of diffuse emission were masked based on the optimum regions determined using the SAS task `eregionanalyse`.

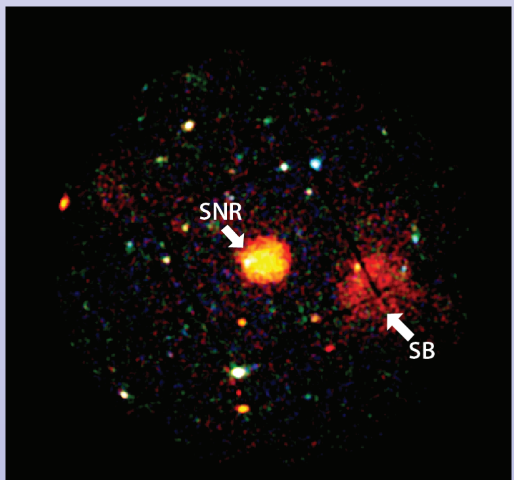

Figure 2: Combined exposure corrected false colour *XMM-Newton* image of N 206. The locations of the N 206 SNR and superbubbles are indicated. Red corresponds to the 0.3-1 keV energy range, green to 1-2 keV and blue to 2-8 keV. The supernova remnant (SNR) and superbubble emission (SB) are indicated.

Analysis

We compared the MCELS[1] Hα image to the soft 0.3-1 keV *XMM-Newton* image and determined that the brightest region of X-ray emission (labelled as region A) is confined by a Hα structure, as found by Dunne et al. (2001), shown in Figure 3a and 3b. The Hα structure confining Region A extends as an approximately spherical shell around the N206 which we define as Region SB (see Figure 3c). X-ray emission is also detected outside of the Hα shell near Region A. This is indicative of a blowout where the hot gas in the interior of the superbubble is escaping into the surrounding ISM. We label this blowout region as Region B (see Figure 3c).

Rather unusually, we detect no X-ray emission from the majority of the region contained in the Hα shell. Based on spectral fitting of the sources in the N 206 region we find that there is likely strong variation absorption across the face of N 206. To investigate this we obtained ATCA-Parkes 21 cm emission image in the direction of N 206 from the HI Magellanic Cloud Survey (available at http://www.atnf.csiro.au/research/HI/mc/). Figure 3d shows the HI emission toward N 206 at the heliocentric velocity (~241 km s^{-1}) of the HI cloud containing N 206, as determined by Kim et al. (2007). Figure 3d clearly shows the variation in absorbing material toward N 206. Thus, we suspect that the seemingly absent X-ray emission from Region SB is absorbed by the line-of-sight material.

Spectral Fitting

We fit the spectra from each region with a variety of absorbed thermal models in XSPEC 12.7.0 and found that Region A is best fit with a 2T thermal plasma model, whereas Region B is best fit with a 1T model. After comparing the best fit model parameters form each region we found that the cooler component in Region A is almost identical to the thermal component of Region B. Thus we assume that the emission described by these components is from the same source, i.e, the hot gas in the blowout. We find that the bubble emission is best described by a non-equilibrium thermal plasma (NEI model in XSPEC, Borkowski 2000) with $kT \sim 1$ keV, with the blowout emission described by a the same model except with $kT \sim 0.7$ keV. In each case ionisation timescale is ~ 2 x 10^{10} s cm^{-3}. The reduction in temperature is consistent with a blowout scenario as the gas expands adiabatically into the lower density ISM.

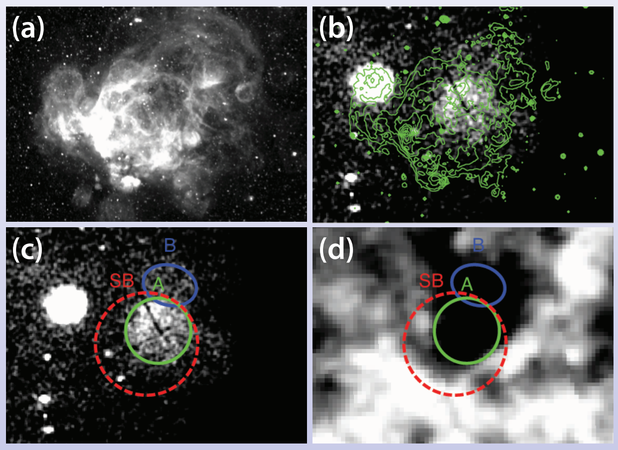

Figure 3: Multiwavelength view of the N206 superbubble: (a) - MCELS Hα image; (b) - smoothed *XMM-Newton* 0.3-1 keV image with Hα contours overlaid; (c) same as (b) with superbubble (SB), superbubble emission region (A) and blowout region (B) indicated; (d) - ATCA-Parkes 21 cm emission image at the heliocentric velocity of ~ 241 km s^{-1} from the HI Magellanic Cloud Survey.

Mass and Energy Estimates

Using results of the spectral analysis we estimated the mass and energy content of the superbubble and blowout regions (as in Cooper et al. 2004, Sasaki et al. 2011, for example) assuming a spherical volume for the bubble and an ellipsoidal volume for the blowout. Additionally, we assume the volume filling factor of both the bubble and blowout to be unity. We find that the hot X-ray emitting gas in the bubble and blowout has a mass of ~ 800 $M_\odot$ with a thermal energy content of ~ 4 x 10^{51} erg.

To determine the mass and energy injected into the bubble by the stellar population we estimated mass loss and wind velocities based on the known spectral types obtained from the SIMBAD database. Additionally, we compared the HR diagrams of the of the 3 stellar associations to theoretical isochrones of Schaerer et al. (1993) to determine their approximate ages. We find that NGC 2018, LH 66 and LH 69 have ages ~ 2 Myr, ~ 4 Myr and ~ 4 Myr, respectively. Integrating the mass and energy input for each of the associations over their ages, we determine a total of ~ 200 $M_\odot$ and ~ 6 x 10^{51} erg have been input by stellar winds.

Additionally we must estimate the contribution of previous supernovae (SNe). Using the masses of the stellar populations and assuming a standard Salpeter (1955) IMF, we determine that 3-5 SN have already occurred in the bubble. This amounts to an additional ~ 200-400 $M_\odot$ and ~ (3-5) x 10^{51} erg contained in the hot gas. Thus, in total, the overall input by the stellar populations is ~ 400-600 $M_\odot$ and ~ (9-11) x 10^{51} erg.

Discussion

Comparing these values to the observed mass and energy stored in the X-ray emitting gas of the bubble and blowout shows an apparent underestimation of mass and overestimation of input energy. The higher than expected observed mass is likely due to mass loading by evaporation of entrained interstellar clouds and/or turbulent mixing of material form the cold shell (Silich et al. 1996). Most if not all of the missing energy is likely driving the expansion of the bubble. To assess this we must determine from observation, the additional energy stored in the bubble, i.e, the kinetic energy of the shell and surrounding material. This analysis is currently underway.

However, we note that in almost all superbubbles, the thermal energy stored in the gas combined with the kinetic energy of the shell and surroundings are insufficient to account for all of the energy input by the stellar population. This effect is manifest by a less than expected expansion velocity for the bubble and is known as the growth rate discrepancy. Only after the analysis of the kinetic energy of the shell and surroundings is complete can determine whether the growth rate discrepancy is evident in N 206, or all of the energy input by the stellar population is present and accounted for.

Conclusions

We have shown the X-ray emission from the N 206 region is not confined to the hot gas in the bubble but rather extends beyond the Hα shell in an apparent blowout. We have determined the mass and thermal energy content of the gas in the bubble and blowout regions, and compared them to the mass and energy input of the known stellar population. The observed energy is less than half of that input by the stellar population, however most or all of the missing energy is likely stored in the kinetic energy of the Hα shell and the surroundings. We are currently assessing whether or not this is the case.

eROSITA

The LMC will be observed during the *eROSITA* survey with a long total exposure due to its location close to the SEP. With the resulting data we will be able to study the entire LMC superbubble population in detail.

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2 - This research has made use of the SIMBAD data base operated at CDS, Strasbourg, France.

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