

Feedback of massive stars on the ISM: a *XMM-Newton* view of the LMC superbubble N 51D

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Abstract. N 51D (= DEM L 192) appears at first glance as a nearly circular, 120 pc diameter bubble of ionized gas around the LMC OB association LH 54. A deeper look reveals a complex web of filaments and deviations from radial expansion. Using a deep *XMM-Newton* pointing centered on N 51D we find that diffuse soft X-ray emitting gas fills the whole superbubble as delineated by the H α filaments. Contrary to recent findings for galactic winds, the correlation between H α and X-ray surface brightness is not good. The X-ray spectrum of this diffuse gas cannot be fitted with the LMC abundance pattern, but implies an overabundance of at least oxygen and neon, consistent with recent enrichment from supernovae Type II. Some indications for enhanced mixing at the brightest region of the H α shell and for a beginning outflow of the hot gas were also detected.

1. Introduction

Feedback of massive stars on the interstellar medium (ISM) comes in the form of ionizing radiation and mechanical energy input from stellar winds and the supernova Type II (and Ib and Ic) explosions at the end of the stellar lifespan. Importantly, massive stars occur very rarely in isolation but form stellar associations and even dense clusters.

To understand the impact of large aggregations of massive stars on their host galaxies, especially during the phase of galaxy formation, a sound understanding of the involved processes is needed. One especially favourable laboratory is the Large Magellanic Cloud. Located at high (southern) galactic latitude it offers low foreground extinction and HI absorption, nearly face-on view, low intrinsic depth, and therefore small line-of-sight confusion. With a distance of 50 kpc it is nearby enough to use normal ground-based telescopes for detailed star-by-star analysis of its stellar content and a high resolution view of its ISM.

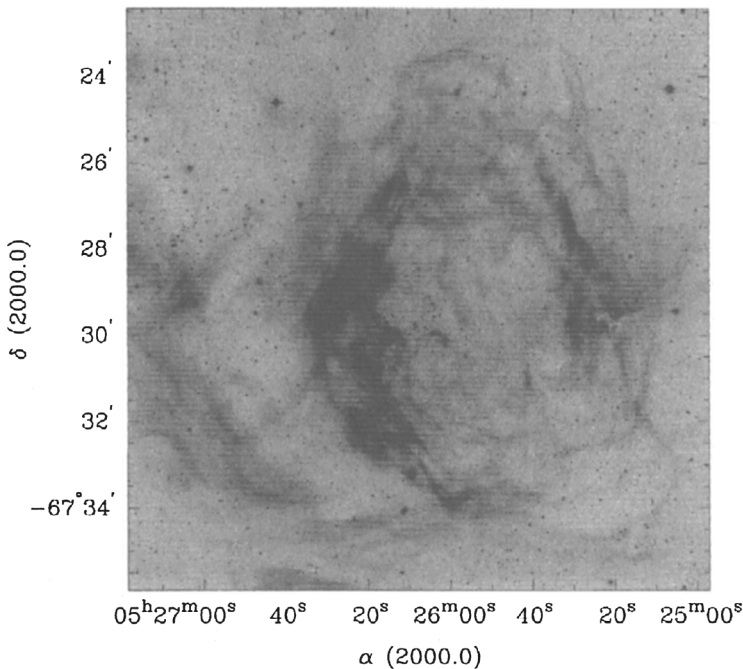


Figure 1. $H\alpha$ image of the LMC superbubble N 51D at sub-arcsecond seeing taken with the CTIO 0.9m telescope.

2. The laboratory N 51D

The superbubble N 51D (Henize 1956) (= DEML 192; Davies, Elliot & Meaburn 1976) is a nearly spherical shell with an diameter of about 120 pc (see Figure 1). The superbubble is located in the southeast corner of the supergiant shell LMC 4, which encircles Shapley constellation III, a super-association in the north of the LMC. N 51D contains two young associations (LH 51 and LH 54) for which a good amount of spectral classification and good photometry is available (*e.g.*, Oey & Smedley 1998).

The expansion of the superbubble was studied by Lasker (1980) and Meaburn & Terrett (1980), who derived an expansion velocity of 35 km s^{-1} with some indications of different expansion velocity of front- and back-side of the superbubble. N 51D is a source of diffuse X-ray emission (Chu & Mac Low 1990), who also found that the eastern side is of higher surface brightness. They interpreted this enhanced X-ray surface brightness, compared to model predictions for a windblown bubble (Weaver *et al.* 1977), as a recent supernova blast wave, hitting the eastern side of the shell. More recently, *ROSAT* data of N 51D were presented by Bomans (2001) and Dunne, Points & Chu (2001).

It is interesting to note here, that absorption of N V from the front-side of the superbubble was reported by de Boer & Nash (1982) using *IUE* high-dispersion spectra.

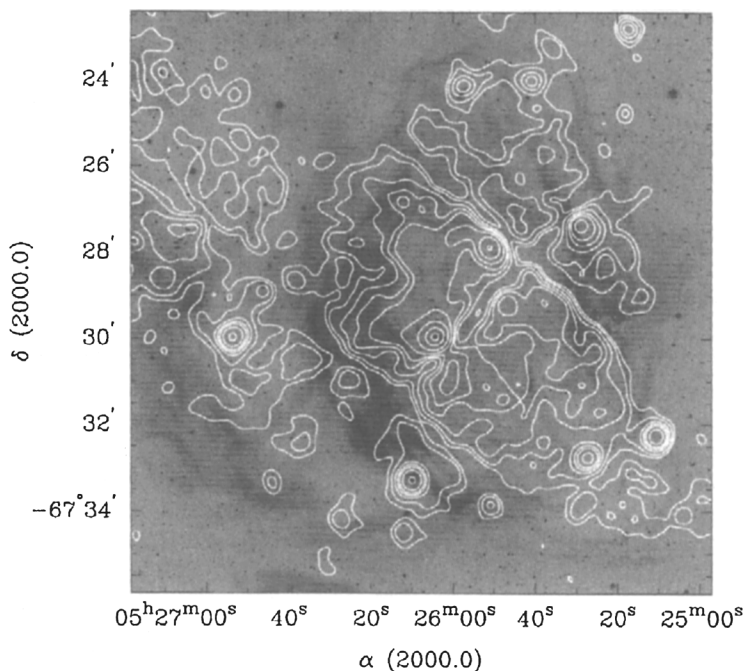


Figure 2. Same $H\alpha$ image of the superbubble N 51D as in Figure 1, overlaid with contours of the 0.3–2 keV X-ray emission from a subregion of the XMM-EPIC-PN image. The rectangular contour structures (bisectors) are of instrumental origin (borders of the individual CCDs).

3. The hot gas as seen by XMM-Newton

We chose N 51D as a target for a detailed study on the feedback of massive stars on the interstellar medium using the XMM-Newton X-ray observatory. N 51D was observed for a total of 32 ksec. Data reduction was performed using SAS-5.2 and XSPEC-11.1. We present here first results using the XMM-EPIC-PN CCDs. Results from the XMM-EPIC-MOS CCDs and the UV and optical imaging using the optical monitor of XMM-Newton will be presented elsewhere.

The relation of the soft X-ray photons (0.3–2 keV) from the XMM-EPIC-PN data with N 51D is shown in Figure 2. Besides several point sources, diffuse X-ray emission is present all over the optical shape of the superbubble. Only the eastern rim of N 51D shows enhanced surface brightness in X-ray. Apparently we detected the emission of hot gas filling the superbubble and not solely the interface between the hot interior and the cold shell wall, as recently argued for in the case of hot outflows of galaxies (*e.g.*, Strickland, these Proceedings).

We fitted the X-ray spectrum extracted inside the optical boundaries of N 51D with a Mewe-Kaastra-Liedahl (MEKAL, Mewe *et al.* 1995) equilibrium plasma model (plus a powerlaw to account for the point sources inside N 51D). The foreground HI was first fitted and later fixed to $\log N_{\text{H}} = 20.5$, roughly consistent with results from the ROSAT studies and HI emission profiles in this direction. The plasma temperature is well constrained at $T = 0.27 \pm 0.05$ keV,

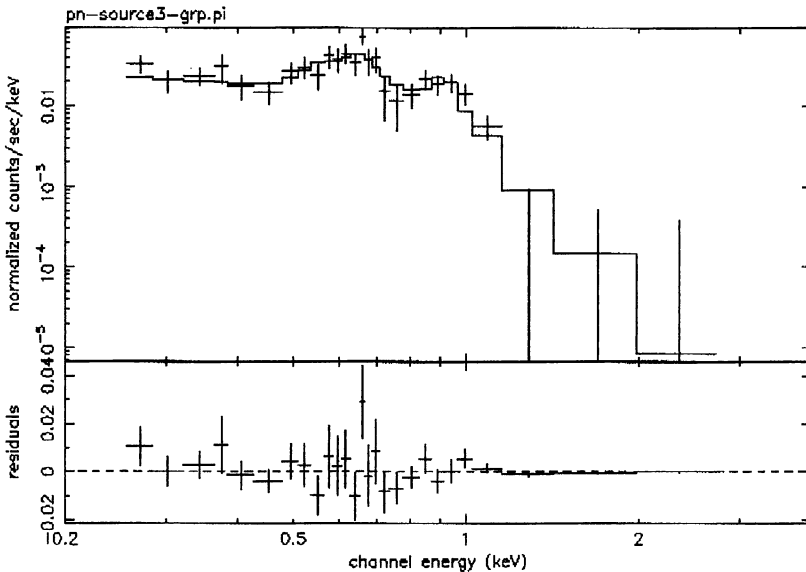


Figure 3. *XMM-EPIC-PN* spectrum of a circular region in the high X-ray surface brightness area inside N 51D. The best fitting *MEKAL* equilibrium plasma model is overplotted.

very similar to the *ROSAT* results (Bomans 2001; Dunne, Points & Chu 2001). Due to the much higher spectral resolution of the *XMM-EPIC-PN* data, coupled with the number of photons detected, it is possible to look into considerable detail of the metal abundance pattern of the gas. Indeed, an acceptable fit is only possible with oxygen and neon abundances enhanced by a factor of two over the metal abundance of the LMC ISM (*e.g.*, Wilcots 1994). The spectrum and the best fitting model is plotted in Figure 3. We also selected smaller regions inside N 51D (a X-ray bright region coinciding with bright $H\alpha$ emission, an X-ray bright region with very faint $H\alpha$ emission, and a region with low diffuse X-ray surface brightness). The spectral fits confirm the results, but also hint a lower metal abundance in the region of the bright north-eastern $H\alpha$ ridge.

The diffuse X-ray emission north-east of N 51D is inside the supergiant shell LMC 4. The spectrum indicates similar metal enhancement of the hot LMC gas as reported by Dennerl *et al.* (2001) for the region near SN 1987A.

4. X-ray point sources

The *XMM-Newton* field centered on N 51D also contains an appreciable number of point sources, partly intrinsic to the LMC, partly background AGN and galactic foreground sources. One X-ray source is especially noteworthy. It coincides exactly with the LMC O8I+WC5 binary Sk-67 104 (= HD 36402). The spectrum can be fitted with a powerlaw, exhibiting a soft spectral index ($\Gamma = 2.6$), while being surprisingly luminous ($L_x = 9 \times 10^{35} \text{ erg s}^{-1}$). The nature of the source is

unclear yet and cannot be explained solely by colliding winds of the two massive stars.

5. Conclusions

Diffuse X-ray emission is present over the whole area of N 51D as defined in $H\alpha$, including the large, faint $H\alpha$ protrusions to the north and south-west, hinting at a beginning outflow of the hot gas out of the bubble.

Preliminary spectral analysis of the data from the XMM-EPIC PN detectors shows a significant overabundance of oxygen and neon over the ISM abundance of the LMC. This is consistent with the hot gas being recently enriched by SN Type II ejecta. Some indications from the spectra also point at enhanced mixing in the region of the bright north-eastern $H\alpha$ ridge.

Clearly, the high signal-to-noise X-ray spectra from the N 51D region show clear signs of metal deposition into the hot phase of the ISM and its interaction with the warm and cold gas surrounding the superbubble. Analysis of the XMM-EPIC-MOS detector data and the UV imaging from the XMM-Newton optical monitor will further improve the situation and will allow a detailed look at the processes at work for the thermal, dynamical, and chemical evolution of this region in the LMC.

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Discussion

CHU: What are the error bars for the plasma temperature? How many counts are detected from N 51?

BOMANS: The errors in temperature are about 0.07 keV in kT , but one has to keep in mind that equilibrium models are used for fitting. We are currently checking the fits with non-equilibrium models too, which can affect the temperature values. There are about 5000 counts from N 51, not including the XMM-EPIC-MOS detectors.