Discovery of Non-Thermal X-Rays from the Shells of SNR 30 Dor C with Chandra

Aya Bamba[1], Masaru Ueno[1], Katsuji Koyama[1], Masayuki Itoh[2]

([1]: Kyoto Univ., Japan [2]: Kobe Univ., Japan: bamba@cr.scphys.kyoto-u.ac.jp)

1. Introduction

Since the discovery of cosmic rays (Hess 1912), the origin and the acceleration mechanism up to $10^{15.5}$ eV have been long-standing problems. A breakthrough is the discovery of synchrotron X-rays from the shell of SN1006, which supports the presence of extremely high energy electrons near the knee energy (Koyama et al. 1995).

Now, our knowledge about SN1006-like SNRs is still limited in our Galaxy and search for samples in other galaxies is essential issue. Therefore, we search for SN1006-like SNRs in star forming regions of the nearest galaxy, LMC. This paper reports on the discovery of non-thermal X-rays from the shells of 30 Dor C. This is the complex structure in the star forming region 30 Dor and have been suggested as an SNR or multiple SNRs (Mathewson et al. 1985). Dennerl et al. (2000) identified as an SNR with XMM-Newton Itoh et al. (2001) reported the existence of hard X-rays with ASCA observations.

2. Observation

We used the Chandra archival data of the observation around SN1987A (obsID=1044) with ACIS-S array. The on-axis position, observation date, and total exposure is shown in Table 1.

Table 1: The Observation Log

On axis position (RA, DEC)	Date (yyyy/mm/dd)	Exposure (ksec)
($05^h35^m22^s$, $-69^d16^m33^s$)	2001/04/25	18

3. Images

Figure 1 is the true-color image around SN 1987A and 30 Dor C. We can see clear clumpy shell-like structure centered at ($5^h36^m2.^s2$, $-69°11'44''$) with the radius = 40 pc at 50 kpc distance. We also see another SNR, the honeycomb nebula, on the south of 30 Dor C.

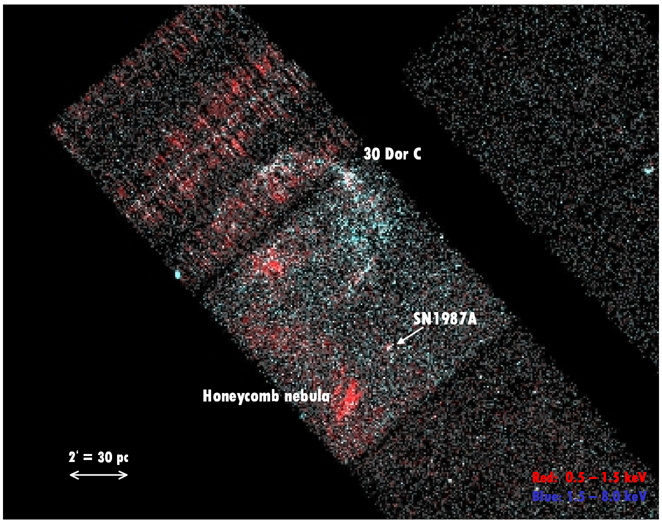

Figure 1: The true-color image around SN 1987A and 30 Dor C (red: 0.5 – 1.5 keV; blue: 1.5 – 8.0 keV). The scale is logarithmic. The red stripes on the CCD is artificial noises.

4. Spectra

The shell is clumpy and the clumps show different hardness ratio from each other. Then we made spectra with the source regions shown in Figure 2. The background regions were selected source-free and the same noise-level regions as the source regions.

We fitted the background-subtracted spectra shown in Figure 3 with a thin thermal plasma model (Mewe et al. 1985) or a power-law function. The absorption column was calculated by Morrison et al. (1983) with the solar abundance (Anders et al. 1989). The best-fit parameters are shown in Table 2.

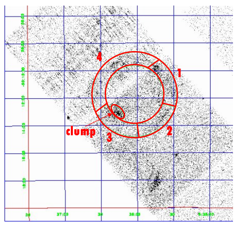

Figure 2: The 0.5 – 10.0 keV image with J2000 coordinates. The red lines are the regions for spectral analyses.

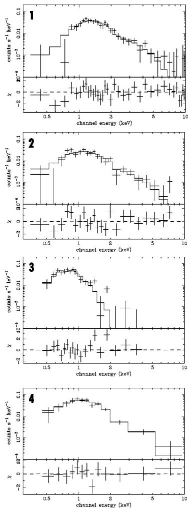

Table 2: The best-fit parameters of spectral fittings†.

	1	2	3	4
Thermal				
kT (keV)……….	1.8 (1.2 – 2.9)	2.5 (1.5 – 4.6)	0.2 (0.1 – 0.2)	2.1 (1.4 – 3.5)
Abundance……..	0.1 (<0.6)	0.3 (<1.6)	1.0 (>0.02)	0.1 (<0.9)
N_H (10^{21}cm^{-2})…….	7.0 (5.3 – 9.1)	2.9 (2.0 – 4.1)	7.6 (6.2 – 8.8)	0.8 (<2.0)
Flux‡ (erg/s/cm²)..	3.3×10^{-13}	2.0×10^{-13}	7.3×10^{-14}	4.8×10^{-13}
Non-thermal				
Photon index…..	3.0 (2.5 – 3.6)	2.6 (2.2 – 3.3)	6.7 (4.7 – 9.7)	2.7 (2.2 – 3.2)
N_H (10^{21}cm^{-2})…….	9.3 (7.3 – 12)	4.6 (3.3 – 6.2)	7.4 (4.4 – 12)	2.5 (1.3 – 4.1)
Flux ‡ (erg/s/cm²)..	3.6×10^{-13}	2.1×10^{-13}	8.1×10^{-14}	5.1×10^{-13}

†: Parentheses show 90% error region.
‡: In the 0.3 – 10.0 keV band.

Figure 3: The background-subtracted spectra of the regions. The solid lines show the power-law best-fit models in Table 2.

5. Thermal or Non-Thermal?

The emission from 30 Dor C is, except for that of region 3, too hard for ordinary thermal SNRs which emits thermal X-rays with kT < 1 keV even in their young phase. On the other hand, the photon indices in non-thermal fittings remind us of SN1006 (photon index ~2.5; Koyama et al. 1995). Therefore, we conclude that the emission from region 1,2, and 4 are non-thermal, whereas that from region 3 is thermal.

30 Dor C is the first extra-Galactic sample of the SNR with synchrotron X-rays, and moreover, the most large, and perhaps the oldest among them.

6. Multiple or Single?

30 Dor C has been in a controversy, whether it is a "superbubble" by multiple SN or a single SNR. From the thermal parameters in region 3, we estimated the total explosion energy with Sedov solutions.

$$R = 39\ \mathrm{pc},\quad kT = 0.2\ \mathrm{keV},\quad n_0 = n_e/4 = 0.15\ \mathrm{cm^{-3}} \;\Rightarrow\; E_{total} = 1.2\times10^{51}\ \mathrm{ergs},\quad \mathrm{Age} = 5.9\times10^{4}\ \mathrm{years}$$

The total energy is consistent with that of ordinary SNRs, suggesting that 30 Dor C is a single SNR with an old age.

7. A clump in the shell

We found a clump in the shell of 30 Dor C (see Figure 2). The spectrum shows strong He-like Mg line (Figure 4). Miyata et al. found similar clump (a "shrapnel") in Vela SNR and concluded it as an ejecta. Assuming the filling factor = 1, the total Mg mass in the clump is 0.3 $M_{\odot}$, which suggests that the progenitor of 30 Dor C is more than 20 $M_{\odot}$.

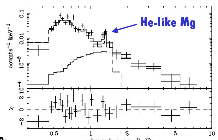

Figure 4: The background-subtracted spectrum of the clump.

8. Conclusion

- We observed the complex star forming region 30 Dor C with Chandra and reconfirmed the shell-like structure.
- The hard spectra of the clumpy shell imply that the emission from region 1,2, and 4 is non-thermal like that of SN1006, whereas that from region 3 is thermal. This is the first discovery of an extra-Galactic SN1006-like SNR.
- The total explosion energy of 30 Dor C is 1.2×10^{51}ergs, suggesting that this is a single SNR.
- We discovered a Mg-enriched clump in the shell of 30 Dor C. It may be a "shrapnel" like the ones of discovered in Vela SNR.
- To explore the nature of the hard emission from 30 Dor C, following observations with deeper exposures are needed.

References

Anders, G.E. et al. 1989, Geochim. Cosmochim. Acta., 53, 197
Dennerl, K. et al. 2001, A&A, 365, L202
Hess, V.F. 1912, Phys. Zeits, 13, 1084
Itoh, M. et al. 2001, PASP Conf. Ser., 251, 250
Koyama, K. et al. 1995, Nature, 378, 255
Mathewson, D.S. et al. 1985, ApJS, 58, 197
Miyata, E. et al. 2001, ApJL, 559, L45
Morrison, R. et al. 1983, ApJ, 270, 119