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Non-Thermal Emission from an X-Ray Shell near 30 Dor C

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1. Introduction

Shell SNRs had been a strong candidate for the site of cosmic ray acceleration up to $10^{15.5}$ eV. By the discoveries of the synchrotron X-rays and the TeV gamma-rays from SN1006 (Koyama et al. 1995, Tanimori et al. 1997), RX J1713.7-3946 (Koyama et al. 1997, Enomoto et al. 2002), and G266.2-1.2 (Slane et al. 2001), high energy particles are now known to exist in the shells of SNRs.

Next, we have to study what amount of energy is going to the acceleration in one SNR. That depends on the environment and properties of the SNR which is to be called "the condition of the acceleration".

For such study, the Large Magellanic Cloud (LMC) is a good place, because

1. the distance is rather accurately known and is rather small (~50 kpc).
2. the interstellar absorption is small.
3. it is nearly face-on.
4. many observations have been done in many wavelengths.

We here report the discovery of the non-thermal X-rays from the shell SNR in LMC, 30 Dor C, which is the first discovery from SNRs outside of the Galaxy.

30 Dor C was suggested to be an SNR or multiple SNRs by Mathewson et al. (1985). Dennerl et al. (2000) identified 30 Dor C as an SNR with XMM-Newton and by Itoh et al. (2001) the existence of hard X-rays was reported.

2. Observation

30 Dor C is covered by the observations of SN1987A with Chandra several times. From them, we chose those by ACIS, without grating and in which 30 Dor C is near the nominal point.

Table 1: Observation Log

ObsID	On axis position (RA, DEC)	Date (yyyy/mm/dd)	Exposure (ksec)
1044	($05^h35^m22^s$, $-69^d16^m33^s$)	2001/04/25	18
1967	($05^h35^m22^s$, $-69^d16^m33^s$)	2000/12/12	99

3. Image and Spectra

We made a two-color image (below) by superposing two observations and correcting for the exposure. We see a clear shell with radius of ~3 arcmin corresponding ~40 pc at the distance of 50 kpc. The western side is harder than the eastern side.

We extracted spectra from regions A-D shown in the image. We here excluded

emissions can't be realized by one temperature and one ionization-degree plasma. So, we fitted it with a two-temperature NEI model, and found this model is acceptable with χ^2/degree of freedom (d.o.f) = 77/80 and the best-fit parameters are shown in table 2. These high and low temperature components can be attributed to forward and reverse shocks, respectively.

Spectra of B-D were fitted with this thermal model with normalizations of each NEI

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We extracted spectra from regions A-D shown in the image. We here excluded point sources from the spectral regions. Spectra of B-D is rather featureless and hard, indicating non-thermal emission, while the spectrum of A shows many line structures and is soft, indicating thermal origin.

To determine the thermal property of this shell first, we fitted spectrum A with a thin-thermal plasma model. He-like and H-like K-lines of Ne and Mg are seen and these

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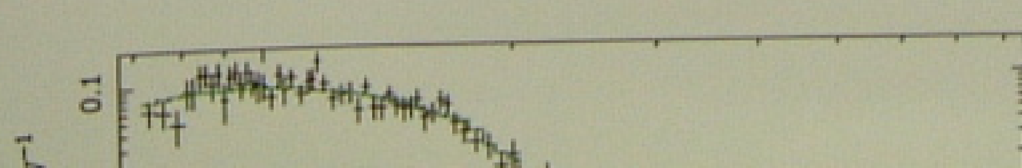

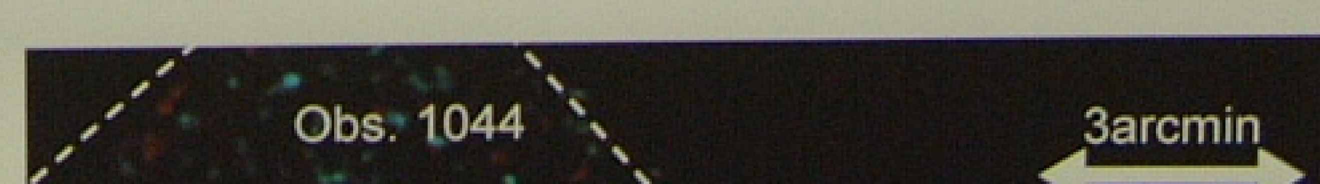

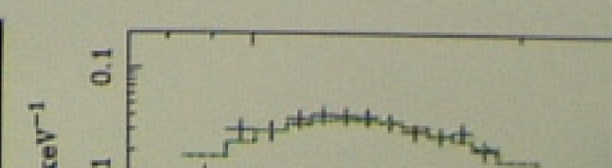

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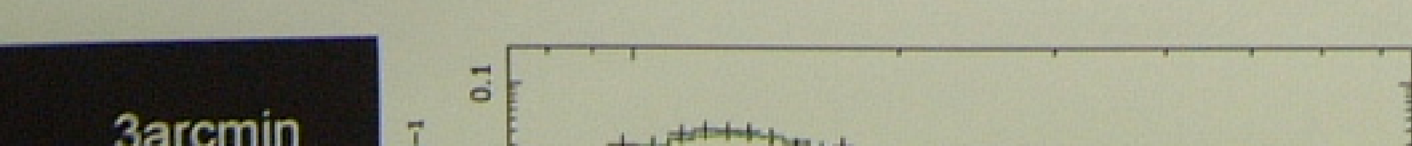
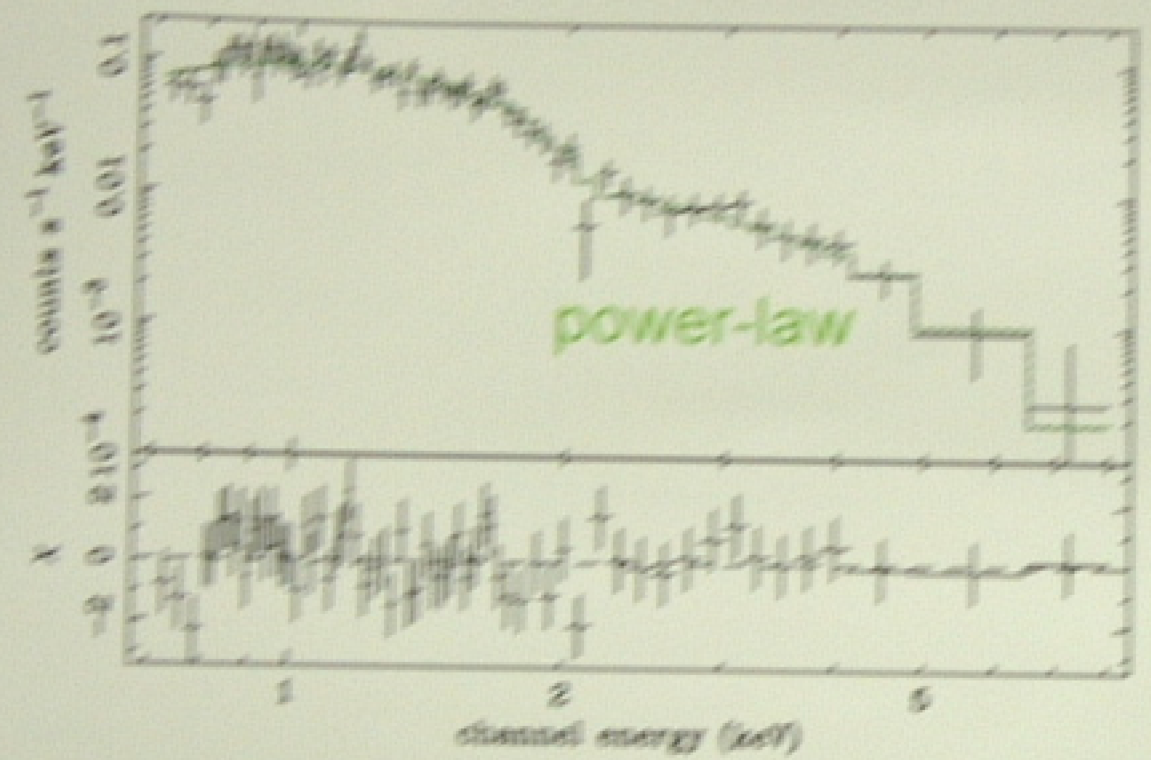
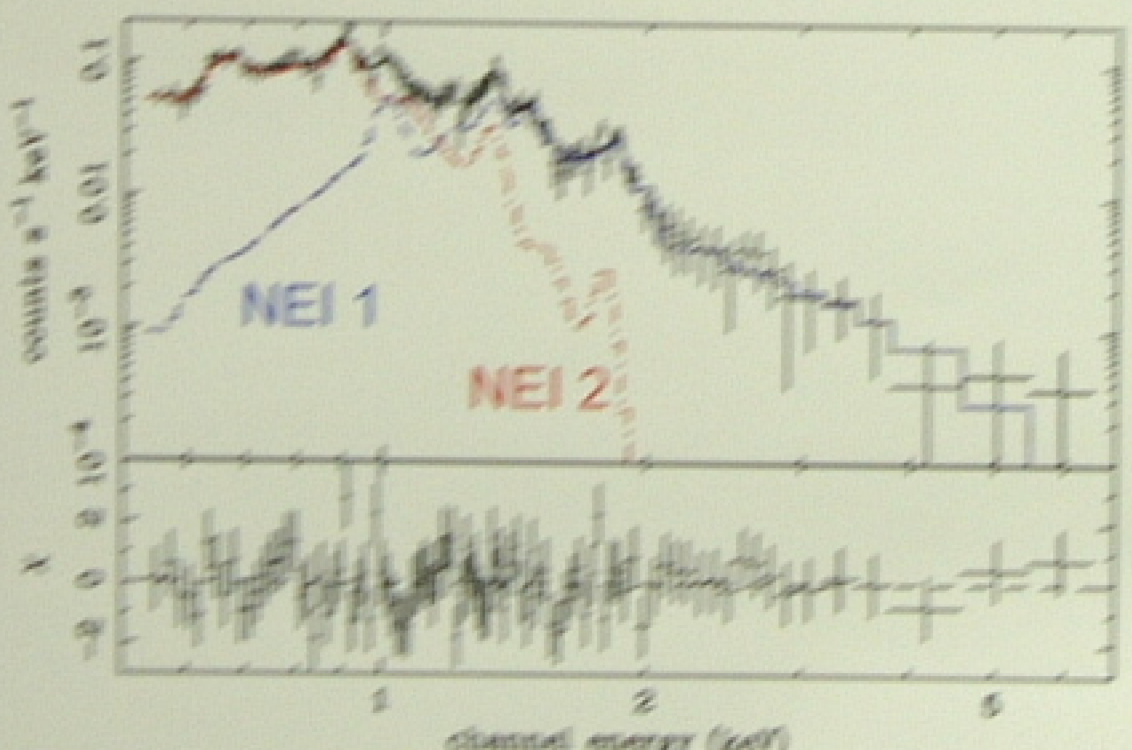
Spectra of B-D were fitted with this thermal model with normalizations of each NEI component free and with a power-law model. We got an acceptable model with best-fit parameters shown in table 3. These spectra are explained mainly by the power-law components which would originate synchrotron emission by high energy (>1TeV) electrons like SN1006.

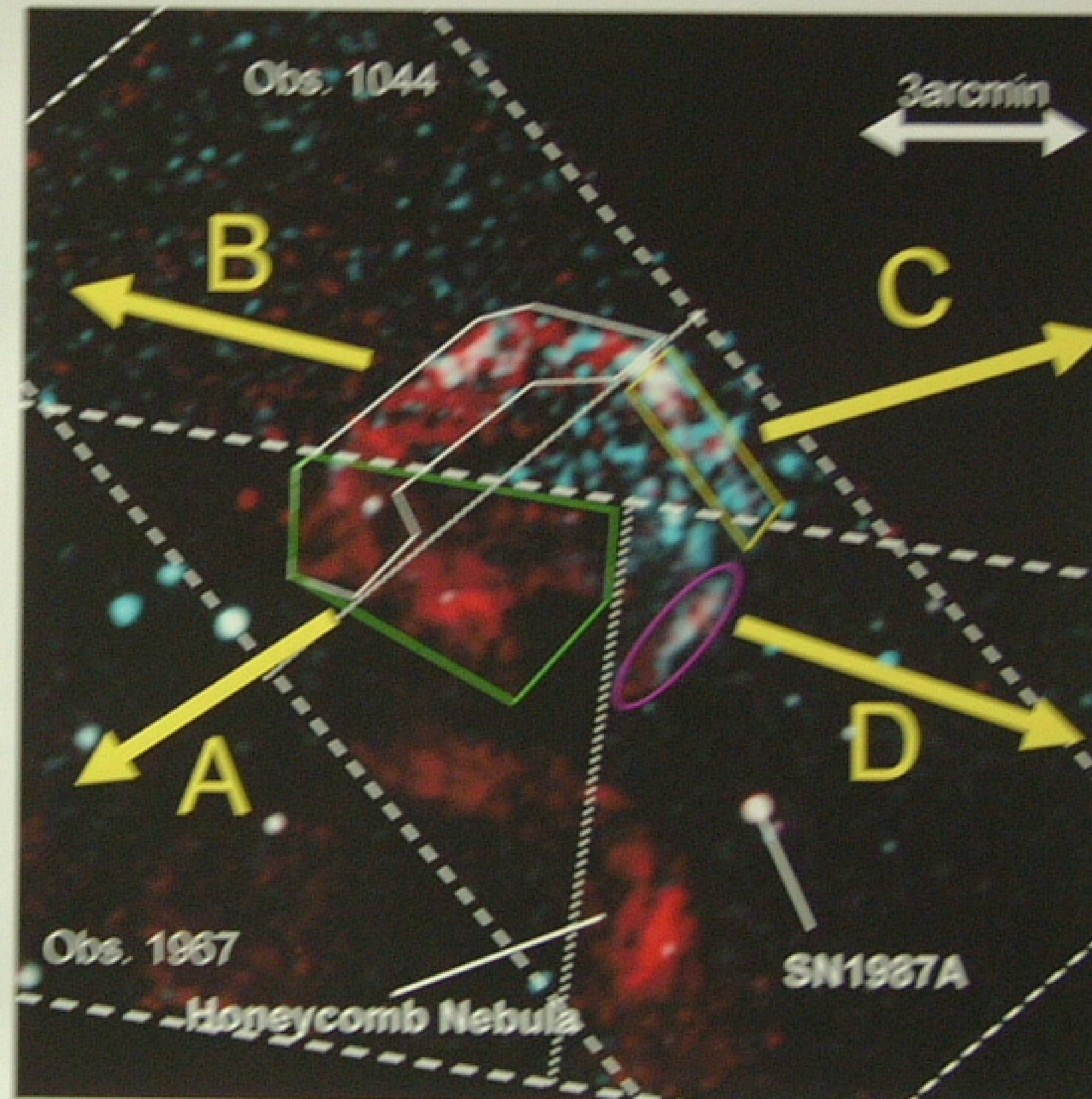
Table 2: The best-fit parameters for the region A

parameter	NEI 1	NEI 2
kT [keV]	1.4 (1.0-2.1)	0.14 (0.11-0.12)
Log (τ) [$cm^{-3}s$]	11.2 (10.8-11.9)	> 13.3
$EM^{\dagger}$ [10^{58} cm^{-3}]	1.7	680
N_H [$\times10^{21}$ cm^{-2}]	5.8 (5.2-7.3)	fixed to the same as left



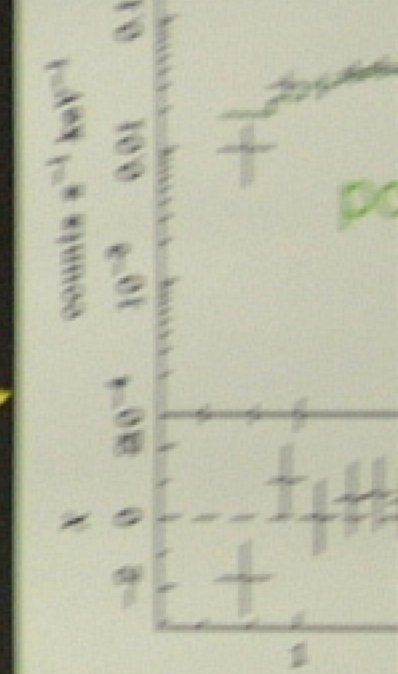


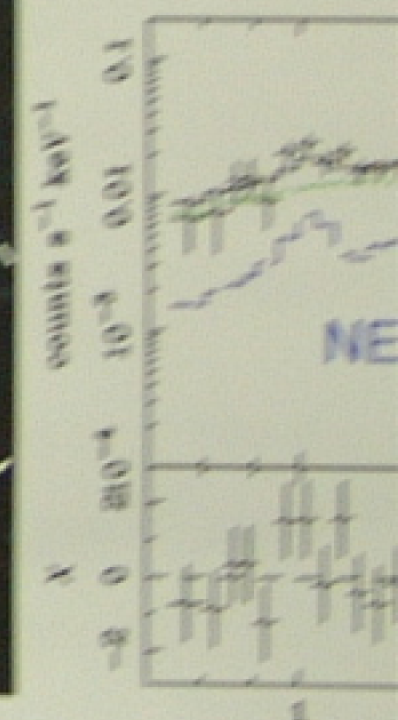




red: 0.7-2.0keV
blue: 2.0-7.0 keV

both of them in log scale

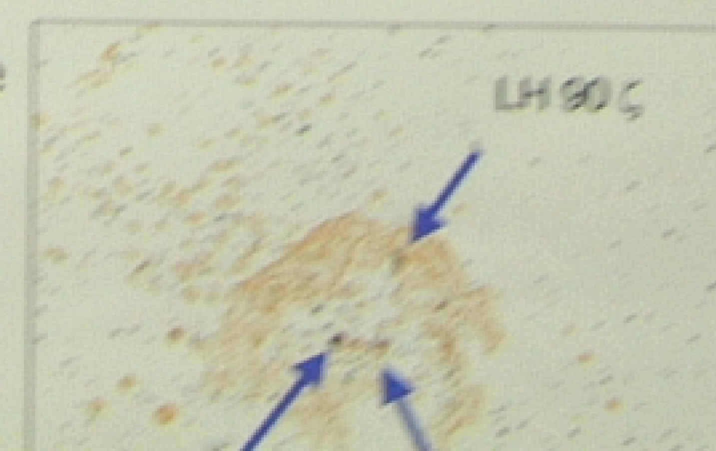




4. The information from other wavelengths

Many observations with other wavelengths have been done.

1. Optical to infrared
   - High-mass star clusters (LH 90) are known to exist inside. (cf. Testor et al. 1993)



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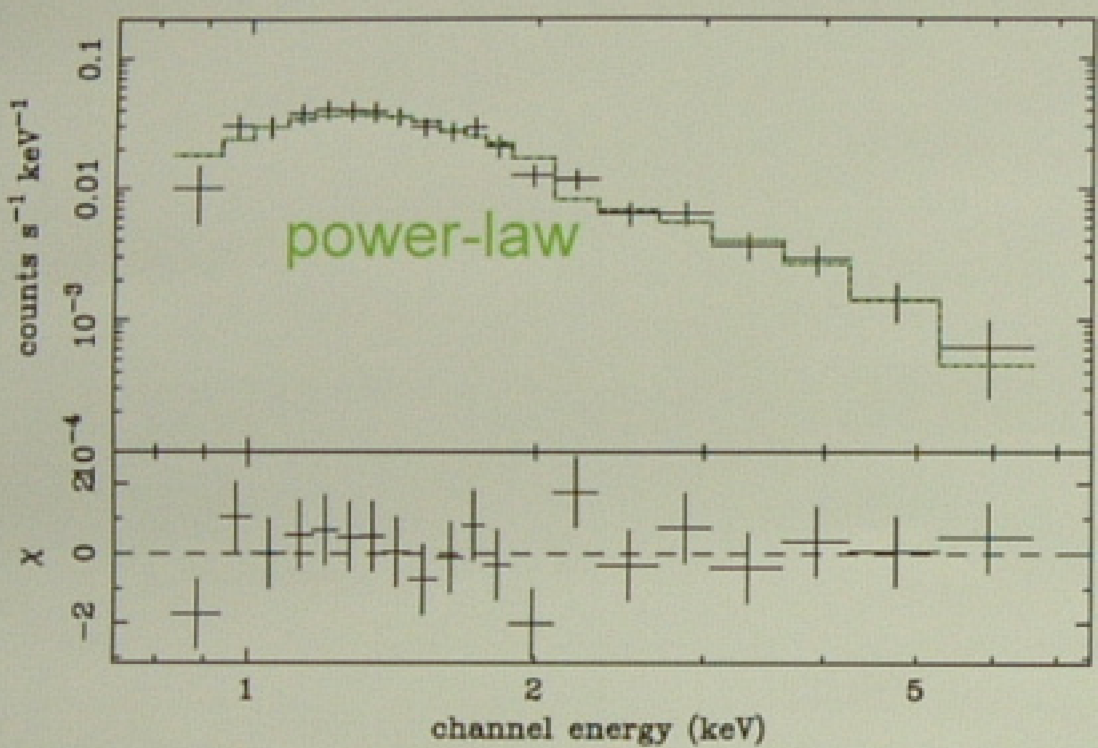

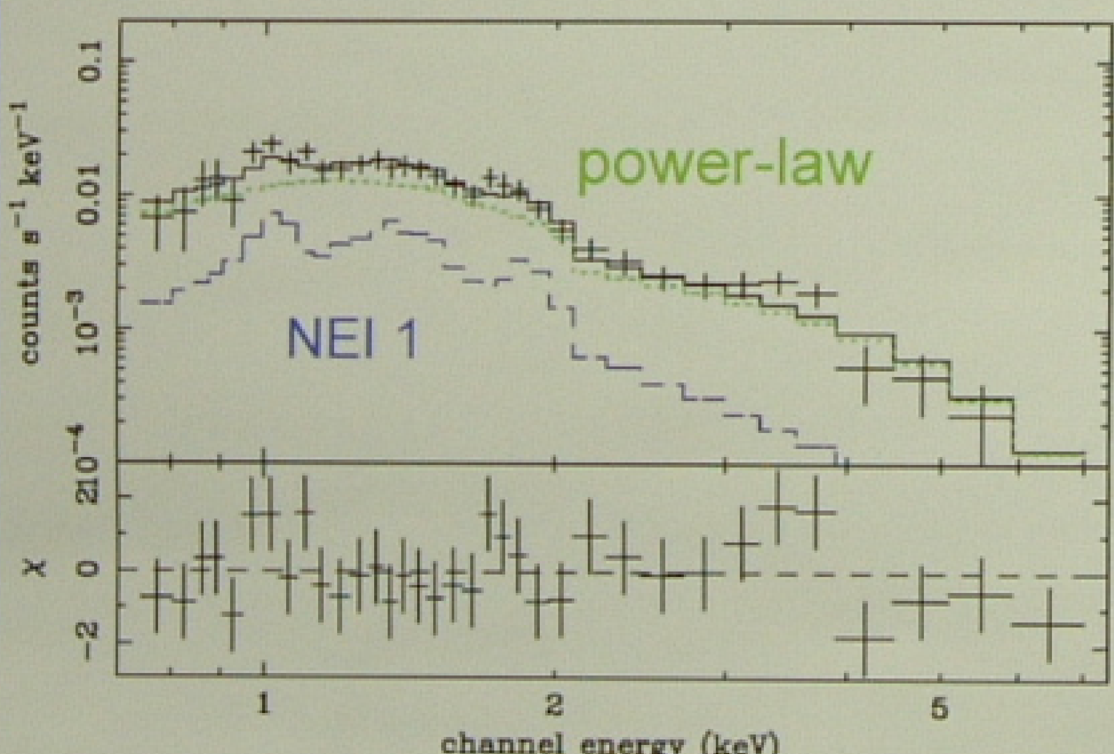

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$EM^{\dagger}$ [10^{58} cm^{-3}]	1.7	680
N_H [x10^{21} cm^{-2}]	5.8 (5.2-7.3)	fixed to the same as left
O abundance‡	0.19 (fixed)	0.02 (0.01-0.05)
Ne	0.65 (0.30-2.68)	0.08 (0.06-0.14)
Mg	0.57 (0.35-0.90)	0.56 (0.06-1.24)
Si	0.37 (0.22-0.58)	0.31 (fixed)
S	0.018 (<0.035)	0.36 (fixed)
Fe	0.00(<0.04)	0.36 (fixed)

†: EM are emission measure $EM = \int n_e n_H dV$ assuming the distance ~50 kpc.
‡: Abundances are relative to solar values. Fixed abundances are at the average values in the LMC (Russell & Dopita 1992; Hughes et al. 1998).

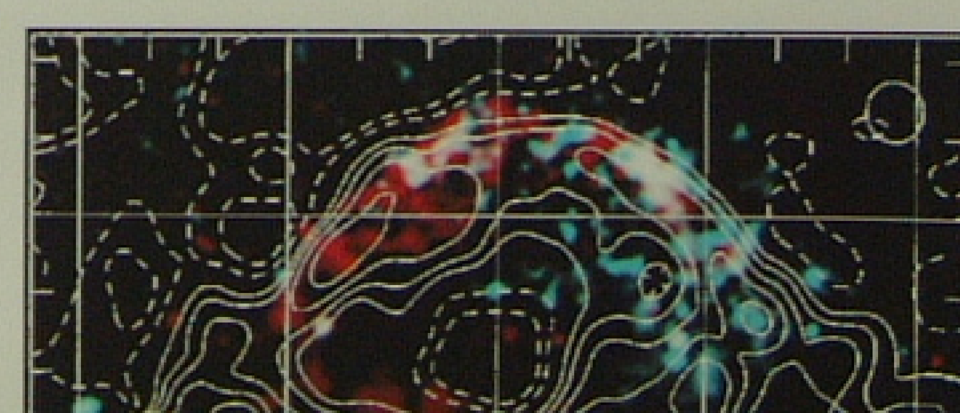
Table 3: The best-fit parameters for the regions B, C and D

parameter	B	C	D
$EM_1{}^{\dagger}$ [10^{58} cm^{-3}]	0.0 (<0.24)	0.0 (<0.54)	0.18 (0.03-0.31)
$EM_2{}^{\dagger}$[10^{61} cm^{-3}]	0.0 (< 1.3)	0.0 (<3.0)	0.0 (<0.033)
Power-law			
photon index	2.5 (2.3-2.8)	2.7 (2.2-3.1)	2.3 (1.9-2.7)
flux‡ [erg s^{-1} cm^{-2}]	1.0x10^{-12}	8.1x10^{-13}	2.0x10^{-13}
N_H [x10^{21} cm^{-2}]	1.8 (1.0-8.0)	8.0 (6.4-18.2)	5.2 (3.9-7.3)
χ^2/d.o.f	55.8/58	15.0/15	31.5/30

†: EMs are emission measure of NEI 1 and NEI 2.
‡: absorption corrected flux in the 0.7-10.0 keV band.

3. Radio continuum

Like SN1006, enhancement of radio continuum coincides well with that of non-thermal X-rays. As the spectrum in the radio band



material was detected. (Chu 1997)

2. [SII]/Hα

Flux ratio between them suggests the origin is not only one SN but stellar wind. (Mathewson et al. 1985)

grey scale image: optical (Sloan Digital SkySurvey)
contour: X-ray (0.7-2.0keV)

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5. Discussion

4.1. Explosion energy

By Sedov solution, assuming the distance of 50 kpc and temperature of 1.4 keV,

$$t = 1.8 \times 10^4\ D_{50kpc} T_{1.4keV}^{1/2}\ [yr]$$

$$E/n = 1.0 \times 10^{53}\ D_{50kpc}^{5/2} T_{1.4keV}\ [erg\ cm^{-3}]$$

As the plasma is younger than the SNR itself,

$$t_{plasma} < 1.8 \times 10^4\ [yr] = 5.7 \times 10^{11}\ [s]$$

From NEI model,

$$n_e t_{plasma} = 1.6 \times 10^{11}\ [cm^{-3}\ s]$$

$$n_e > 0.28\ [cm^{-3}]$$

And then, the ambient density and the explosion energy are,

$$n > 0.28 / 4 = 0.070\ [cm^{-3}]$$

$$E > 1.0 \times 10^{53} \times n = 7.0 \times 10^{51}\ [erg]$$

This value can be realized by a Ib or II-type SN which produces a black-hole.
A member of the high-mass star clusters inside 30 Dor C might be the progenitor.

4.2. Produced by a supernova or not?

30 Dor C has been suspected not to be an SNR by optical and radio observations. But the X-ray emitting plasma is demonstrating the existence of high-velocity shock. The X-ray structure must be produced mainly by a SN.

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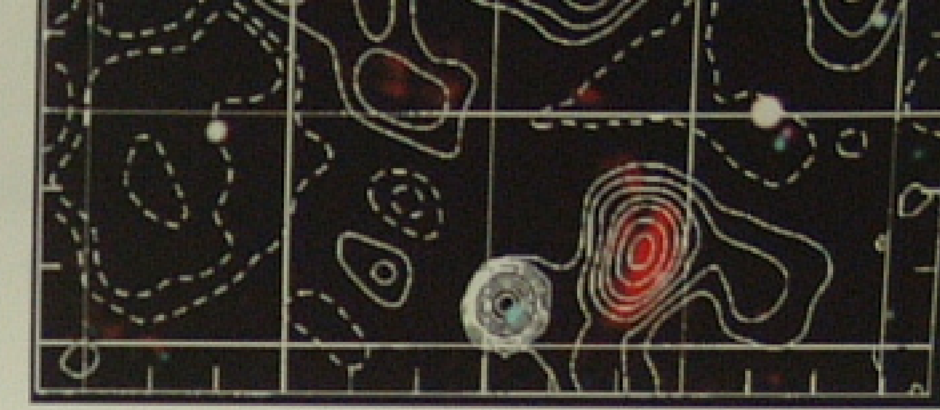
(cf. Mathewson et al. 1985 and references therein.)

4. CO-line

A molecular cloud exist in the south-western part. (Yamaguchi et al. 2001) The existence may explain the difference of absorption column density between regions in the 30 Dor C.



contour: 843MHz radio continuum

4.2. Non-thermal emission

The total luminosity (0.7-10.0 keV) of non-thermal X-ray from 30 Dor C amounts to 6.0×10^{35} erg s^{-1}. This value corresponds to ~ 10 times that of SN1006. This fact indicates many particles are accelerated in 30 Dor C. The large explosion energy (4.1) would be a main reason for the energetic acceleration.

6. Summary

1. Non-thermal X-ray emission from the shell of 30 Dor C was discovered.
2. The explosion energy to produce the X-ray shell is ~ 7×10^{51} erg.
3. The shell is mainly produced by one or multiple SNe.
4. The luminosity of non-thermal X-ray emission amounts to ~ 10 times that of SN1006.

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