CHANDRA OBSERVATION OF RCW 89 AT TWO EPOCHS

Y. Yatsu[1], N. Kawai[1], J. Kataoka[1], T. Tamura[2], and W. Brinkmann[3]

[1]Department of Physics, Tokyo Institute of Technology, 2-12-1 Oookayama Meguro Tokyo 152-8551, Japan,
yatus@hp.phys.titech.ac.jp
[2]Department of Physics, Nagoya University, Chikusa-ku, Nagoya 464-8602, Japan
[3]Max-Planck-Institut für Extraterrestrische Physik, Postfach 1603, 85740 Garching, Germany

ABSTRACT

We presented a *Chandra* observation of the HII region RCW 89 in Dec 2004. RCW 89 is part of the radio shell supernova remnant MSH 15-5*2* which contains a 150 ms young pulsar PSR B1509-58. Comparing with the X-ray image taken by Chandra in Aug 2000, we found that each plasma clouds in RCW 89 have moved outward from the SNR center. The velocity of the radial motion is 5800 $\pm$ 2300 km s^{-1}. This result agrees with the scenario in which the plasma clouds in RCW 89 are the SN ejecta from the progenitor of the pulsar.

Key words: ISM, pulsars, supernova remnants.

1. INTRODUCTION

PSR B1509-58, a 150 ms radio, X-ray, gamma-ray pulsar is one of the youngest pulsars ever known. From the spin parameters, a characteristic age $\tau_c = 1700$ yr, a spin-down luminosity $\dot{E} = 1.8 \times 10^{37}$ ergs s^{-1}, and a surface magnetic field $B_p = 1.5 \times 10^{13}$ G have been obtained (Kaspi et al. 1994). Since the pulsar has a visible crab-like pulsar wind nebula (PWN) containing a torus and jets, this object have been observed many times as a precious sample to study the PWNs.

In radio band, a 30 arcmin diameter radio supernova remnant (SNR) MSH 15-5*2* exists around the pulsar and is believed to associate with the central pulsar (Caswell et al. 1981). HI absorption measurements confirm the distance to the SNR as 5.2 $\pm$ 1.4 kpc (Gaensler et al. 1999). From the distance the kinetic age of the SNR is constrained as 6$\sim$20 kyr assuming standard parameters for the ISM and for the supernova explosion (Seward et al. 1983). But this age is an order of magnitude larger than the characteristic age of the pulsar.

The HII region RCW 89 discovered by Rodgers et al. (1960) is an unique feature of the pulsar-SNR system. In optical the nebula shows complicated filaments lying on the north radio shell. From optical and IR spectroscopic observations, the number density of nebula is measured , $n_e \sim 5 \times 10^3 - 5 \times 10^4$ cm^{-3} (Seward et al. 1983).

Past radio observations showed that the nebula emits non-thermal continuum radio from the clumpy structures in RCW 89 (Gaensler et al. 1999). In X-rays, RCW 89 has a spectrum with several line features and non-thermal continuum (Tamura et al. 1996). The *Chandra* observation revealed that the thermal components are mainly due to the clumps in RCW 89 which coincide well with the non-thermal radio structures (Gaensler et al. 2002).

Since the pulsar has jet which seems to flow into the nebula, one may propose that the thermal plasma nebula is powered by the pulsar jet (Manchester et al. 1987; Tamura et al. 1996; Brazier et al. 1997). Yatsu et al. (2005) reported that the temperature and ionization age ($n_e t$ cm^{-3}s) depend on the position and vary along the horse-shoe shape. Although the plasma seems not to be heated simultaneously, this results are insufficient to conclude that the energy source of RCW 89 is the pulsar jet.

The SNR system MSH 15-5*2* is a visible and precious sample to study the physics of SNRs and pulsars. However there still remain some questions to be resolved. One is the discrepancy in age between the pulsar (1700 yr) and the SNR ($\sim$ 20 kry). Moreover the RCW 89 is still mysterious, we have not understood the energy source, origin of the matter and the process of formation. These problems are important to understand the physics of supernovae, pulsar wind nebulae, and interactions between the pulsar wind and ISM. In this paper we report a *Chandra* observation aiming to RCW 89 and discuss about the dynamics of the RCW 89 by comparing the observation with past data.

2. OBSERVATIONS AND RESULTS

RCW 89 was observed on 2004 Dec 31st with Advanced CCD Imaging Spectrometer (ACIS) aboard *Chandra*. A 30 ks exposure was made in the "time exposure" mode with "VFAINT" data format. We carried out the data processing for VFAINT mode using "acis_event_process" in CIAO version 3.2. The obtained X-ray image (0.4-8.0 keV) is shown in Fig 1. For comparison, we show Hα image observed by *UKST* in Fig 2. The *Chandra* observation revealed filament structures which seem to be

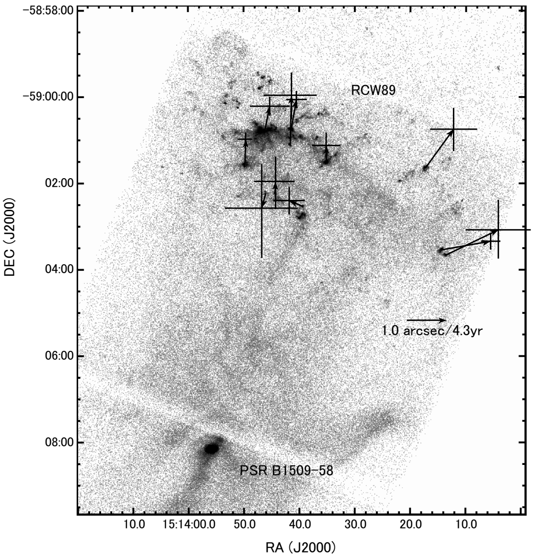

Figure 1. X-ray image by Chandra. The energy range is 0.4-8.0 keV. Arrow labels present the secular motions of the plasma clouds.

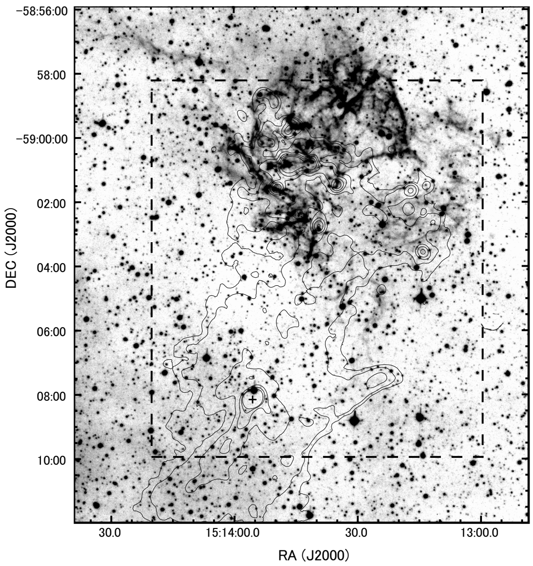

Figure 2. Hα image by Super COSMOS H-alpha Survey (http://www-wfau.roe.ac.uk/sss/halpha). The contour lines represent Chandra data. The central box drawn by dashed line corresponds to the FOV of the X-ray image.

associated with the optical filaments.

In order to study the dynamics of RCW 89, we measured the position of each plasma cloud in RCW 89. The past radio observations show that the proper motion of the pulsar is very small, less than 190 marcsec yr^{-1} (Kaspi et al. 1994; Gaensler et al. 1999). We therefore used the pulsar as a reference point. The positions are determined by two dimensional Gaussian fit using *Sherpa*. In the calculation we used the PSF images created by *CIAO* as the convolution kernel. Then we compared the new observation with the image taken in Aug 2000. The arrow labels in the Figure 1 show the moving directions of plasma clouds. Lengths of arrows are the travel distances elongated by a factor of 50. The cross labels represent position uncertainties with 1σ confidences. We see that the clouds moved radially from the pulsar. The average of the radial velocity is $0.24'' \pm 0.09$ yr^{-1}, which corresponds to $\sim 5800 \pm 2300$ km s^{-1} assuming a distance 5.2 kpc.

3. DISCUSSION

3.1. What accelerates the clouds?

There are two possibilities which accelerates the plasma clouds up to 5800 km s^{-1}, the pulsar wind and the Supernova. We evaluate the variation in speed by the pressure of pulsar wind,

$$\Delta v = \int_{t_0}^{t} \frac{S}{M} \frac{\dot{E}(t)}{4\pi R^2 c} dt = 0.87 \quad \text{km s}^{-1} \tag{1}$$

where $R(\sim 5')$is the distance between the pulsar and the plasma cloud, $r(\sim 5'')$ the typical radius of the cloud, S the cross section of the cloud, and $M(\sim 10^{31}$ g) the mass of the cloud. We set the time t_0, when the pulse period was 20 ms. The obtained velocity variation is much smaller than observed velocity 5800 km s^{-1}. We therefore conclude that the plasma clouds are accelerated by SN explosion.

3.2. Transverse time

Assuming uniform motion of the emission region in RCW 89, we constrain the transverse time as,

$$\Delta t = \frac{R}{5800 \text{ km s}^{-1}} \sim 1800 \quad \text{yr.} \tag{2}$$

This timescale corresponds to the pulsar's characteristic age 1700 yr and is consistent with the scenario in which the SNR and the pulsar are originated in the same progenitor star. The rapid expansion of the SNR requires the low density ISM or the unusual powerful SN explosion as suggested by Seward et al. 1983.

REFERENCES

[1] Caswell, J. L., Milne, D. K., & Wellington, K. J. 1981 MNRAS, 195, 89

[2] Gaensler, B. M., Arons, J., Kaspi, V. M., Pivovaroff, M. J., Kawai, N., & Tamura, K. 2002, ApJ, 569, 878

[3] Gaensler, B. M., Brazier, K. T. S., Manchester, R. N., Johnston, S., & Green, A. J. 1999, MNRAS, 305, 724

[4] Kaspi, V. M., et al. 1994, ApJ, 422, L83

[5] Manchester, R. N., 1987, A&A, 171, 205

[6] Rodgers A. W., Campbell C. T., Whiteoak J.B., 1960 MNRAS, 121, 103

[7] Seward, F. D., Murdin, P., & Clard, D. H., 1983, ApJ, 267,698

[8] Tamura, K., Kawai, N., Yoshida, A., & Brinkmann, W., 1996, PASJ, 48, L33

[9] Yatsu, Y., Kawai, N., Kataoka, J., Tamura, K., Brinkmann, W., 2005, ApJ, 631, 312