ASCA OBSERVATIONS OF TWO SNRS AND NEI ANALYSIS

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ABSTRACT

Based on the data from the ASCA observation of SNRs Kes79 and W49B, we present here the analysis of their X-ray spectra and morphologies. The Kes79 spectrum can be well fitted by a single NEI component, and the narrow-band images of that source show an inhomogeneous distribution of heavy elements. The heavy elements are richest in the positions S, SE and SW of Kes79, where there may exist interaction between shocks and molecular clouds implied by radio observations. For W49B we present here the non-equilibrium ionization (NEI) analysis based on its emission line diagnostics, and the spectral fit using two NEI components. The reverse shock in W49B may be still hot and we don’t find evidence for a hotter blast wave in ASCA spectra.

1 INTRODUCTION

In radio Kes79 is a shell type SNR but with a complex structure. It has an incomplete outer shell with radius $\sim 6'$ and two prominent indentations in the east and northeast. And it also has strong emission from the center - "an inner ring" (Frail & Clifton, 1989). No pulsar has been found (Velusamy et al. 1991). Scoville et al. (1987), Green & Dewdney (1992; hereafter GD) found strong CO emission from the east, southeast and south of this source. And GD also found bright, extended HCO$^+$ emission from the east of this source. GD estimated the global average density of the molecular cloud surrounding Kes79 at $\sim 180$ cm$^{-3}$ and showed that appreciable HCO$^+$ emission requires a density of $10^5$ cm$^{-3}$. Green et al. (1997) detected OH (1720 MHz) maser emission from this source. They suggested that this emission is due to the interaction between shock waves and molecular materials. In X-ray Kes79 has strong central emission and diffuse outer emission with diameter $\sim 5'$. Seward & Velusamy (1995) once used the Sedov model to analyse this source according to the ROSAT data. Its distance is about 10±2 kpc (Frail & Clifton, 1989) based on 21 cm neutral hydrogen absorption spectra of Kes79.

In radio W49B is a bright shell type SNR with radius $\sim 2'$, brightest along the west and southeast edges. (Moffett & Reynolds, 1994). In X-ray it is a center-brightened SNR and the diffuse emission is extended all over the source (see ROSAT HRI image). Based on the ASCA data, Fujimoto et al. (1995) concluded that its spectrum has a thermal nature and multiple plasma components are required to explain this spectrum. They also found that the iron ions are mostly confined to the inner part. Its distance is about 8 kpc (Radhakrishnan et al. 1972 ; Moffett & Reynolds, 1994).

2 DATA REDUCTION AND ANALYSIS
Table 1: Single NEI fit to the spectrum of Kes79

| Parameter                            | Value $^a$ |
|--------------------------------------|------------|
| $N_H(10^{22}\text{ cm}^{-2})$       | $1.75^{+0.07}_{-0.07}$ |
| Temperature (keV)                    | $0.88^{+0.07}_{-0.07}$ |
| $n_e t\ (10^{10}\text{ cm}^{-3}\text{s})$ | $5.9^{+1.4}_{-1.0}$ |
| Ne                                   | $0.56_{-0.38}^{+0.43}$ |
| Mg                                   | $1.8_{-0.3}^{+0.2}$ |
| Si                                   | $1.2_{-0.1}^{+0.2}$ |
| S                                    | $1.1_{-0.2}^{+0.2}$ |
| Fe                                   | $1.8_{-0.4}^{+0.3}$ |
| $\chi^2$                            | $131.6/123$ (d.o.f) |

$^a$ Single-parameter 2.706 $\sigma$ errors

2.1 Kes79

Kes79 was observed by ASCA from April 22 to April 23, 1995. Approximate exposure time is 37.1 ks for SIS and 40 ks for GIS. SIS data are in 1-CCD mode. All data are screened using the standard REV2 processing. After screening we obtain about 20000 events from SIS0 and about 16000 events from SIS1 (here we only analyse the SIS data).

The background-subtracted SIS spectrum of Kes79 is shown in Figure 1. The background spectrum is taken from the Galactic Ridge observations that are near to Kes79. We can see the Fe-L "clump", Mg He\(\alpha\), Si He\(\alpha\), Si He\(\beta\) and S He\(\alpha\) clearly in this spectrum. Then we consider to use a NEI model to fit its spectrum. The code that we adopt here is the SPEX code (Kaastra et al. 1993). The fitting result is in Table 1. It is clearly shown in Table 1 that a single NEI component is good enough to describe the spectrum of Kes79. The best-fit value of $n_e t$ is much lower than $1.0\times10^{12}\text{ cm}^{-3}\text{s}$, which implies that the plasma in Kes79 still doesn’t reach equilibrium ionization. At that situation the emission of the lines tend to be much stronger than in equilibrium. To show this we make the abundance of all the heavy elements in the best fit (Table 1) as zero and keep the other parameters as those in the best fit. We call it "continuum" and estimate that only 30% of the emission comes from the so-called "continuum", so the remainder all comes from the emission of the heavy elements. Then we make some narrow band images of Kes79 to see the distribution of heavy elements in this source. The results are shown in Figure 2. In this figure we can see that the emission of "continuum" is more center-brightened than others. The images of (b) - (d) are all most bright in the S, SE and SW of Kes79, where there may exists interaction between shocks and molecular clouds, but there also exists some difference between these images. Though there indeed exist the difference of absorption between the N and the S (about $1.65\times10^{22}\text{ cm}^{-2}$, $1.95\times10^{22}\text{ cm}^{-2}$ respectively from the analysis of ROSAT spectra), we find that this difference can’t explain the change of surface brightness from the N to the S. Due to its relative high energy, the narrow band image of Si (plus continuum) is not sensitive to the change of absorption. In Figure 2, We don’t find clearly brightening in the N, even in (c) and (d). So we may conclude that the heavy elements are richer in the S, SE and SW of Kes79 and the N of Kes79 is intrinsically fainter than the other parts. Where do those heavy elements come from, those excavated from the molecular clouds or the ejecta stopped by the molecular clouds? We need further observations.
Fig. 2: Narrow band images of Kes79: (a) - (d) from the left to the right, the top to the bottom. (a): 0.5-10 keV; (b): 1.2-1.4 keV, continuum + Mg He\(\alpha\) lines; (c): 1.7-2.0 keV, continuum + Si He\(\alpha\) lines; (d): 2.6-10 keV, mainly continuum. Each image covers the same region. They are all exposure-corrected and vignetting-corrected. (a)-(c) are deconvolved images. Due to the limited photons, (d) is only smoothed. The size of each image is about 10\(\prime\).

2.2 W49B

W49B was observed by ASCA several times. Here we mainly use the SIS data in April 24, 1993 (PV phase) and use other data as a supplement (e.g. estimate the background). Approximate exposure time is 49.4 ks for SIS. All data are screened using the standard REV2 processing. After screening we obtain about 67000 events from SIS0 and about 52000 events from SIS1. The RDD effect should not be severe in the PV phase but we still only use 2CCD mode data to analyse its spectrum.

First we obtained the spectrum of W49B (Figure 4). The emission lines of Si, S, Ar, Ca, Fe-K are all clear in this spectrum. The emission lines of Mg, Ne and Fe-L can’t be seen due to the high absorption. We notice that there seems to exist an emission line at about 5.7 keV. Based on the data from the best calibrated chip (S0 chip1), the centroid of this line is 5.71\(\pm\)0.06 keV. The expected line centroid of the Cr He\(\alpha\) lines is : 5.63-5.68 keV (Shirai et al. 1993). Considering the uncertainty of the calibration, these two value are consistent to each other. But more observations with more exposure time are needed to clarify the nature of this possible line. From previous work (e.g. Fujimoto et al. 1995) We know that the spectrum of W49B is too complicated to get satisfactory fits, but the emission lines shown in the spectrum provide a good opportunity to perform plasma diagnostics. The diagnostics are: the ratio of Ly\(\alpha\) / He\(\alpha\) and He\(\beta\) (or He3p(+4p)) / He\(\alpha\); the energy centroid of He\(\alpha\) lines. We list these value in Table 2 and the results in Figure 3. Our results have some difference from the results of Fujimoto et al. (1995) mainly because of different plasma codes we applied. In Figure 3 we can see that iron, argon and calcium are all very hot, at least hotter than 2 keV if we admit that the plasma in W49B is now in NEI situation because of its young age (Fujimoto et al.1995). And we can also see in Figure 3 that at least two components of Silicon and Sulfur are needed. Now we begin to try spectral fitting. A single NEI component fit is bad, so we consider to try a two component NEI fit. As implied by Figure 3 and in order to prevent too many free parameters, we make the abundances of Fe, Ca, Ar in the second component zero and fix \(N_H\) at 4\(\times\)10\(^{22}\) cm\(^{-2}\). The results are shown in Table 3. The first component is a hard component and its overabundance implies that it may come from the shocked ejecta. The second soft component it may come from the diffuse ejecta. We don’t find evidence for a hot blast wave, even in the GIS spectrum.
Fig.3 : The derived ranges for Si, S, Ar, Ca and Fe by line ratios in the $n_e$-$T$ plane based on the SPEX code. S1 means the region determined by the ratio $\text{He}\beta$ (or $\text{He}\beta_3(+4p)$) / $\text{He}\alpha$; S2 means the region determined by the ratio $\text{Ly}\alpha$ / $\text{He}\alpha$. Si1 and Si2 are similar as the above mentioned.

| Ratio                  | Value $^a$         |
|------------------------|--------------------|
| Si $\text{He}(3p+4p)/\text{Si He}\alpha$ | 0.081±0.050        |
| Si $\text{Ly}\alpha/\text{Si He}\alpha$    | 0.497±0.068        |
| S $\text{He}(3p)/\text{S He}\alpha$       | 0.037±0.024        |
| S $\text{Ly}\alpha/\text{S He}\alpha$      | 0.520±0.053        |
| Ar $\text{Ly}\alpha/\text{Ar He}\alpha$    | 0.376±0.079        |
| Ca $\text{Ly}\alpha/\text{Ca He}\alpha$    | 0.204±0.080        |
| Fe $\text{Ly}\alpha/\text{Fe He}\alpha$    | < 0.020            |

| Energy centroid       | Value $^a$         |
|-----------------------|--------------------|
| Fe $^b$ (keV)         | $6.660^{+0.007}_{-0.006}$ |

$^a$ Single-parameter 2.706 σ errors  
$^b$ Using the best calibrated chip SIS0 chip1.

Table 2: Some diagnostic values of W49B (based on the fit using a bremsstrahlung continuum and some Gaussians)

3 DISCUSSION

3.1 Kes79

In the above analysis we see that the heavy elements are inhomogeneously distributed in Kes79. Seward & Velusamy once concluded that the variation of the spectra around this source is little by analysing the ROSAT data, when combining with the single NEI component nature of its spectrum, it seems that
the plasma in this source is in an isothermal condition, which may come from the thermal conduction. There still remains a question. Where do these heavy elements come from? Though their abundance is only a little higher than solar, from Figure 2 we see that the emission of these heavy elements is mainly concentrated at the S, SW and SE of Kes79, where there may exist the interaction of the shock with molecular clouds. And we see that the emission of the continuum is center-brighted. So it seems that the heavy elements are rich in that region. But as it now stands, we can’t distinguish whether the heavy elements come from the ejecta stopped by the dense molecular clouds, or from the molecular clouds, or from both of them. Further observation of higher spatial and spectral resolution are needed.

3.2 W49B

As mentioned in the above, the ejecta in W49B may be still hot, even hotter than the blast wave. This case is somewhat similar to the case of Tycho (Hwang et al. 1998), where the Fe ejecta have a higher temperature than the Si, S ejecta (maybe also Ar, Ca ejecta). It is against the result of Chevalier (1982) under the assumption of the power-law ejecta profiles, which would imply higher density and lower temperature at inner radii. Recently Dwarkadas & Chevalier (1998) obtained a relatively flat temperature profile under the assumption of the exponential ejecta density profile for Type Ia SN. And the presence of a small amount of circumstellar matter may increase the temperature contrast. But now, before getting more data with better spatial and spectral resolution, it is hard to make a definite conclusion. And there is still another possibility that the blast wave is very hot and has quite a small emission measure, so now we can’t separate this component from the spatially integrated spectrum. As for the Cr line, it also needs further investigation due to its low signal-to-noise in ASCA observation now.

| Parameter | Value | - | - | - | - | - |
|-----------|-------|---|---|---|---|---|
| EM1 \(10^{58} \text{ cm}^{-3}\) | 7.0 | 6.0 | 5.0 | 4.0 | 2.0 | 1.0 |
| log(\(n_e t_1\)/cm\(^{-3}\)s) | 11.92 | 11.93 | 11.89 | 11.87 | 11.80 | 11.71 | 11.76 |
| kT1 (keV) | 1.98 | 2.06 | 2.12 | 2.18 | 2.34 | 2.52 | 2.41 |
| Si1 | 2.2 | 2.6 | 3.0 | 3.8 | 7.2 | 13. | 28. |
| S1 | 3.2 | 3.7 | 4.4 | 5.3 | 9.9 | 18. | 38. |
| Ar1 | 3.4 | 4.1 | 4.8 | 6.0 | 12. | 22. | 46. |
| Ca1 | 4.6 | 5.3 | 6.3 | 7.8 | 15. | 28. | 58. |
| Fe1 | 3.1 | 3.5 | 4.0 | 4.7 | 8.4 | 15. | 32. |
| M1 \((\text{M}_\odot)\) | 6.7 | 6.2 | 5.6 | 5.0 | 3.6 | 2.5 | 2.0 |
| EM2 \(10^{58}\text{cm}^{-3}\) | 5.5 | 7.4 | 8.5 | 9.4 | 11.3 | 12.1 | 12.4 |
| log(\(n_e t_2\)/cm\(^{-3}\)s) | 10.15 | 10.13 | 10.13 | 10.13 | 10.14 | 10.15 | 10.13 |
| kT2 (keV) | 0.97 | 1.17 | 1.23 | 1.31 | 1.44 | 1.52 | 1.57 |
| Si2 | 1.7 | 0.95 | 0.78 | 0.64 | 0.47 | 0.41 | 0.39 |
| S2 | 0.49 | 0.52 | 0.47 | 0.46 | 0.43 | 0.43 | 0.37 |
| M2 \((\text{M}_\odot)\) | 13. | 15. | 17. | 18. | 20. | 21. | 21. |
| \(\chi^2\) (236 d.o.f) | 391.3 | 379.6 | 376.3 | 373.1 | 369.5 | 367.6 | 368.8 |

\(a\) \(N_H\) is fixed to \(4.0 \times 10^{22} \text{ cm}^{-2}\).

\(b\) Ar, Ca, Fe in component 2 are fixed to 0.

\(c\) The mass of heavy elements are all included and take \(f_1\) as 0.05, \(f_2\) as 0.25.

note: \(n_e/n_H = 1.20 - 1.27\) according to the fitting results.

Table 3: Spectral fitting results with two NEI components for the spectrum of W49B

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