DISCOVERY OF X-RAY-EMITTING O–Ne–Mg-RICH EJECTA IN THE GALACTIC SUPERNOVA REMNANT PUPPIS A

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1. INTRODUCTION

X-ray emission from evolved supernova remnants (SNRs) is dominated by the interstellar medium (ISM) swept up by expanding SN ejecta. Therefore, evolved SNRs had been considered to be more suitable for studies of high-Mach number (>10) shock physics, ISM/shock interactions, or the ISM itself, and less suitable for studies of the true explosion/nucleosynthesis. However, over the last two decades, the ASCA, ROSAT, Chandra, and XMM-Newton X-ray Observatories have uncovered a number of ejecta features in evolved SNRs such as the Vela SNR (e.g., Aschenbach et al. 1995; Tsunemi et al. 1999), the Cygnus Loop (e.g., Miyata et al. 1998; Katsuda et al. 2008b), and several large Magellanic Cloud (e.g., Hughes et al. 2003; Borkowski et al. 2006) and Small Magellanic Cloud SNRs (e.g., Park et al. 2003; Hendrick et al. 2005).

Puppis A is one of the brightest SNRs in the X-ray sky and shows both ISM/shock interactions and SN ejecta. The large extent (~50' in diameter) as well as the high surface brightness allows us to study detailed structures in the remnant. It has been suggested that the expanding shell of Puppis A is interacting with dense H I and CO clouds from the eastern (E) rim to the northern (N) rim, based on its asymmetric X-ray surface brightness (e.g., Petre et al. 1982) and the alignment of these dense clouds with the edge of the remnant (e.g., Dubner & Armal 1988). Chandra observations of the most prominent cloud–shock interaction at the E rim can be compared directly to scaled laboratory simulations to infer a mature interaction of age 2000–4000 years (Hwang et al. 2005; Klein et al. 2003). Thus, Puppis A is an excellent astrophysical laboratory where we can study detailed structures of cloud–shock interactions.

On the other hand, evidence of SN ejecta has been detected in Puppis A. From optical observations, Winkler & Kirshner (1985) discovered an O-rich fast-moving filament (named Ω filament) in the northeastern (NE) portion of the remnant. Subsequently, several O-rich optical knots have been found near the Ω filament, with proper-motion vectors suggesting constant expansion from a common center with a dynamical age of 3700 ± 300 years (Winkler et al. 1988). Recently, signatures of ejecta have been found in X-ray observations as well. Hwang et al. (2008) noticed Si-rich ejecta localized in the NE quadrant, based on a Suzaku survey of this SNR (see also Hwang et al. 2008 for a review of metal-rich ejecta indicated by earlier X-ray observations). Katsuda et al. (2008a) also reported the discovery of fast-moving metal-rich ejecta knots with blueshifted lines in the NE portion of the remnant, based on XMM-Newton observations. So far, the composition of all these ejecta features indicates that Puppis A originated from a core-collapse SN. This is consistent with the presence of a central compact object (CCO; Petre et al. 1996).

Here, we report the discovery of an O–Ne–Mg-rich ejecta filament in the NE quadrant of the remnant from Chandra and XMM-Newton observations. We also discuss the origin of the filament.

2. OBSERVATIONS AND DATA REDUCTION

Puppis A has been observed several times by the CCD cameras onboard Chandra and XMM-Newton, with objectives such as the cloud–shock interactions, the CCO, or possible SN ejecta. Together, these observations provide almost complete coverage of this large X-ray remnant, as shown in Figure 1.

All the raw data from XMM-Newton were processed using version 8.0.0 of the XMM Science Analysis Software (SAS). We select X-ray events corresponding to patterns 0–12.6 We further clean the data by rejecting high background (BG) intervals and removing all the events in bad columns listed in Kirsch (2006). After the filtering, the data were vignetting-corrected using the SAS task evigweight. As for Chandra, we reprocessed all the level-1 event data, applying the standard data reduction using CIAO version 4.1 and CALDB version 3.5.3. There is

http://cxc.harvard.edu/ciao/threads/createL2/
http://heasarc.nasa.gov/docs/xmm/abc/
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Table 1
Summary of XMM-Newton and Chandra Observations

| Field   | Obs.ID   | Instruments | Obs.Date   | Coordinate (J2000) | Exposure Time (ks) |
|---------|----------|-------------|------------|---------------------|--------------------|
| Center1 | 0113020101 | MOS         | 2001 Apr 15| 125.486, −43.0272   | 22.0               |
| Center2 | 0113020301 | MOS         | 2001 Nov 8 | 125.486, −43.0053   | 10.8               |
| North   | 0150150101 | MOS+pn      | 2003 Apr 17| 125.487, −42.6161   | 6.3                |
| East1   | 0150150201 | MOS+pn      | 2003 Jun 25| 126.045, −42.9778   | 3.6                |
| East2   | 0150150301 | MOS+pn      | 2003 Jun 25| 126.046, −43.0058   | 4.3                |
| West    | 0303530101 | MOS+pn      | 2005 Oct 9 | 125.100, −42.9203   | 9.8                |

| North   | 1949     | ACIS-S      | 2002 Mar 9 | 125.529, −42.6426   | 19.9               |
| Northeast1 | 1950  | ACIS-S      | 2001 Oct 1 | 125.841, −42.7031   | 14.9               |
| East    | 1951     | ACIS-S      | 2001 Nov 4 | 126.048, −42.9141   | 11.7               |
| Northeast2 | 5564 | ACIS-I      | 2005 Sep 4 | 125.782, −42.6906   | 34.5               |
| Northeast3 | 6371 | ACIS-I      | 2006 Feb 11| 125.788, −42.6981   | 28.3               |

Note. The fields of view of MOS and pn are 30′ diameter circles. Those of ACIS-S and ACIS-I are 8.5′ side and 17.1′ side boxes, respectively.

Figure 1. Fields of view of XMM-Newton (white circles) and Chandra (white boxes) overlaid on a ROSAT HRI image of the entire Puppis A SNR. The data have been smoothed by a Gaussian kernel of \( \sigma = 15'' \). The intensity scale is square root.

Figure 2. Three-color image of the merged XMM-Newton and Chandra data. Red, green, and blue correspond to 0.5–0.7 keV (mostly O K-shell lines), 0.7–1.2 keV (mostly Ne K-shell lines), and 1.2–5.0 keV bands, respectively. The data have been smoothed by a Gaussian kernel of \( \sigma = 4'' \). The intensity scale is logarithmic.

no high BG intervals during the Chandra observations. These observations are summarized in Table 1.

3. IMAGE ANALYSIS

The moderate spectral resolution of the CCD cameras together with good spatial resolution of the X-ray telescopes onboard Chandra and XMM-Newton allows us to investigate the detailed spectral variation within Puppis A. Figure 2 shows an exposure- and vignetting-corrected three-color image of merged XMM-Newton and Chandra data. Red, green, and blue correspond to 0.5–0.7 keV (mostly O K-shell lines), 0.7–1.2 keV (mostly Ne K-shell lines), and 1.2–5.0 keV bands, respectively. We see clear color variations such as a blue (hard emission) belt crossing the remnant from the NE to the southwest (SW) as was previously noticed with ROSAT and ASCA observations (Aschenbach 1993; Tamura 1995; Hwang et al. 2005; Hui & Becker 2006), and the western (W) limb that is enhanced in red (soft emission). We will briefly discuss their origins based on our spectral analyses later in this paper.

Since the CCD spectra show strong lines especially from Ne as shown in Figure 3(a) which is a spatially integrated MOS1 spectrum, we generate a line-ratio map of H-like Ly\( \alpha \) line to He\( \alpha \) line blend for Ne in Figure 3(b), covering the same region as the three-color image (Figure 2). The energy bands used to generate the line-ratio map are indicated in Figure 3(a): 0.97–1.1 keV for H-like Ly\( \alpha \) and 0.86–0.97 keV for the He\( \alpha \) blend. We focus on a filamentary feature enclosed in the white box in Figure 3(b). This feature (hereafter, the NE filament) is clearly seen in Figure 2 as a bright filament with different colors from those in its vicinity, indicating that it is spectrally distinct. In the NE filament, the surface brightness and line ratio seem anticorrelated, with the low line ratio indicating less emission from H-like ions. Another feature showing such an anticorrelation is marked by a black arrow in Figure 3(b). This feature is the previously noted O–Ne–Mg-rich ejecta knot (Katsuda et al. 2008a) which is coincident with the optical \( \Omega \) filament (Winkler & Kirshner...
marks the edge of fields of view.

The other regions are covered by only Fil-1; we extract spectra from each and combine them to improve \( \sim \)′′ regions range from 20

Based on the morphology, we divide the feature into four regions; two filaments and two

The numbers of counts after the local-BG subtraction are 7287, 6281, 2641, and 11722 for Fil-1, 2, Knot-1, and 2, respectively. To perform a \( \chi^2 \) test, each spectrum is grouped into bins with at least 20 counts. Figure 5 shows the Fil-1 and Knot-1 spectra in black together with their BG spectra in red. The source spectrum below \( \sim 1.5 \) keV shows excess emission which is dominated by O and Ne K-shell lines for Fil-1, and O, Ne, and Mg K-shell lines for Knot-1.

The spectral similarity between the NE filament and the \( \Omega \) filament leads us to speculate that the NE filament may also be an ejecta feature.

4. SPECTRAL ANALYSIS

4.1. Analysis of the NE Filament

Figure 4 shows a close-up Chandra three-color image of the NE filament and its surroundings. Based on the morphology, we divide the feature into four regions; two filaments and two knotty features. These regions are marked by white ellipses labeled as Fil-1/2 and Knot-1/2 in Figure 4. The sizes of these regions range from 20′′ (the diameter for Knot-1’s circle) to 120′′ (longer diameters for Fil-1/2’s ellipses), corresponding to \( \sim 0.21-1.26 \) pc at a distance of 2.2 kpc (Reynoso et al. 2003).

Two Chandra observations (ObsIDs 5564 and 6371) cover Fil-1; we extract spectra from each and combine them to improve signal-to-noise ratio. The other regions are covered by only one Chandra observation (ObsID 6371). We subtract local BGs estimated from the surroundings using the box and pie-shaped regions shown in Figure 4. The numbers of counts after the local-BG subtraction are 7287, 6281, 2641, and 11722 for Fil-1, 2, Knot-1, and 2, respectively. To perform a \( \chi^2 \) test, each spectrum is grouped into bins with at least 20 counts. Figure 5 shows the Fil-1 and Knot-1 spectra in black together with their BG spectra in red. The source spectrum below \( \sim 1.5 \) keV shows excess emission which is dominated by O and Ne K-shell lines for Fil-1, and O, Ne, and Mg K-shell lines for Knot-1.

Based on the spectral similarity, we divide the four spectra into two groups: Fil-1/2 and Knot-1/2. We simultaneously fit the two spectra in each group (either Fil-1/2 or Knot-1/2). We employ an absorbed, single-component, plane-parallel shock model (the Tbabs and the vpho\( \alpha \)ck model (NEI version 2.0, e.g., Borkowski et al. 2001) in XSPEC version 12.5.1). We freely vary the electron temperature, \( kT_e \), the ionization timescale, \( n_e \tau \), and the volume emission measure (VEM = \( \int n_e^n_H dV \)), where \( n_e \) and \( n_H \) are number densities of electrons and protons, respectively, and \( V \) is the X-ray-emitting volume) for individual spectra. Above, \( n_e \tau \) is the electron density times the elapsed time after shock heating, and we take a range from zero up to a fitted maximum value. The relative abundances of each group are tied together. The abundances of several elements, whose emission lines are prominent in the spectrum, are treated as free parameters: O, Ne, Mg, and Fe (\( = \)Ni) for Fil-1/2, and O, Ne, Mg, Si (\( = \)S), and Fe (\( = \)Ni) for Knot-1/2. The other elements are fixed to the solar values. Throughout this paper, we employ solar abundances of Anders & Grevesse (1989). We find that the abundances for Fil-1/2 are super-solar (>1000 times the solar values). In such a metal-rich plasma, it is difficult to precisely determine the absolute abundances from the X-ray spectra since H does not contribute to the continuum emission in this band. We thus set the O abundance to be 2000 times the solar value as we did for our spectral analysis of the \( \Omega \) filament (Katsuda et al. 2008a; see also Winkler & Kirshner 1985).

We initially treated the hydrogen column density, \( N_{\text{H}} \), as a free parameter, and obtained the best-fit value of \( \sim 5.5 \times 10^{23} \) cm\(^{-2} \). This value is quite large compared with a typical value of 3 \( \times 10^{21} \) cm\(^{-2} \) for Puppis A derived from recent Suzaku observations (Hwang et al. 2008) as well as our spectral analysis shown in...
the following section. Given that the color of Fil-1/2 is red in Figure 4 (which means that Fil-1/2 has soft spectra), the large absorption would be strange. Furthermore, it is not reasonable that only the NE filament shows such a large absorption. We thus fix $N_{\text{H}}$ to the typical value of $3 \times 10^{21}$ cm$^{-2}$ in the analysis of Fil-1/2 and Knot-1/2. Formally, the fit for Fil-1/2 is far from acceptable ($\chi^2$/degrees of freedom (dof) = 480/248), but this is likely due to the imperfect subtraction of the local BGs. While the count rates after the local-BG subtraction are negative in some energy bands, separate fits for Fil-1 and Fil-2 do not yield a better fit for Fil-2 (while the abundances obtained for the two regions are consistent with each other). In this context, we introduce systematic errors on the model, with the error for each spectral bin being defined as $\sqrt{C_{\text{data}} + (C_{\text{model}} \times \alpha)}$, where $C_{\text{data}}$, $C_{\text{model}}$, and $\alpha$ denote data counts, model counts, and the factor of the systematic error, respectively. We set the values of $\alpha$, so that we can obtain null hypothesis probabilities of the best-fit models to be $\sim$5%.

Figure 6 shows the local-BG-subtracted spectra along with the best-fit models ($N_{\text{H}} = 3 \times 10^{21}$ cm$^{-2}$). Lower panels show the residuals. Right: same as left but for Knot-1/2.

4.2. Radially Resolved Spectral Analysis

We have performed spectral analyses of the NE filament including both the filamentary and knotty features, and found them to be rich in O, Ne, and Mg. If other ejecta regions are found, then it is possible that the contact discontinuity and the reverse shock might be identified within the remnant based on the extent of the X-ray-emitting ejecta. To search for these features, we perform radially resolved spectral analysis of pie-shaped areas from the NE rim to the W rim shown in Figure 7. The center of the pie-shaped area is the inferred expansion center of the O-rich optical knots (Winkler et al. 1988). We divide the area into thin annular regions such that each region contains $\sim$10,000 photons. The thickness of these regions ranges from $3''$ to $11''$ for Chandra covering part of the NE portion, and from $13''$ to $180''$ for XMM-Newton covering the entire area. As BG, we use regions outside Puppis A in the same observations for Chandra. For XMM-Newton, we use the data set accumulated from blank sky observations prepared by Read & Ponman (2003) because it provides much better statistics than the BG available from Puppis A observations. We have checked for a few regions that different BGs (either the blank sky or the source-free region
around Puppis A) do not affect the spectral parameters within 90% confidence limits.

We fit the spectra using an absorbed, single-component vpsahock model. Free parameters are $N_{\text{H}}$, $kT_e$, $n_{e,t}$, VEM, and abundances of O, Ne, Mg, Si, S, and Fe (=Ni). Abundances of other elements are fixed to the solar values. For some regions in the W rim, the source emission above 2 keV is so weak that we tie the abundance of S to that of Si. Figure 8 depicts example spectra from three regions whose radial positions are indicated by arrows with letters A, B, and C in Figure 7. The fit levels for these regions are typical, with reduced $\chi^2$-values ranging from 1.02 (A) to 1.56 (C). These examples show good matches between the data and the model. The best-fit parameters for all regions are plotted as a function of radius in Figure 9. The

Figure 7. Area used for radially resolved spectral analysis overlaid on an X-ray wide band (0.5–5.0 keV) image from the merged XMM-Newton and Chandra data. The SNR center (R.A., decl.) = (125.6145, −42.9579) J2000 is the expansion center of O-rich optical fast-moving knots (Winkler et al. 1988). We divide this area into thin annular regions for our spectral analysis. Arrows with letters A, B, and C indicate the radial positions where we show example spectra in Figure 8.

Figure 8. Example spectra from three regions indicated by arrows in Figure 7 along with the best-fit models. Lower panels show the residuals.

| Parameter | Fil-1 | Fil-2 | Knot-1 | Knot-2 |
|-----------|-------|-------|--------|--------|
| $N_{\text{H}}$ ($\times 10^{21}$ cm$^{-2}$) | 3 (fixed) | | | |
| $kT_e$ (keV) | 0.43 (0.28–0.71) | 0.33 (0.26–0.54) | 0.79 (0.55–1.26) | 0.80 (0.60–1.06) |
| $\log(n_{e,t}/\text{cm}^{-3} \text{s})$ | 10.20 (9.82–10.74) | 10.24 (9.88–10.61) | 10.45 (10.25–10.68) | 10.59 (10.44–10.82) |
| O (O$_\odot$) | 2000 (fixed) | | | |
| Ne (Ne$_\odot$) | 3400 (2800–4500) | | | |
| Mg (Mg$_\odot$) | 3400 (1800–8000) | | | |
| Si (Si$_\odot$) | 1 (fixed) | | | |
| Fe (Fe$_\odot$) | 0 (<470) | | | |
| Ne/O (Ne$_\odot$/O$_\odot$) | 1.75 (1.45–2.15) | | | |
| Mg/O (Mg$_\odot$/O$_\odot$) | 1.85 (1.30–2.65) | | | |
| Si/O (Si$_\odot$/O$_\odot$) | | | | |
| Fe/O (Fe$_\odot$/O$_\odot$) | | | | |
| $\int n_e n_d dl$ ($\times 10^{17}$ cm$^{-5}$) | 0.21 (0.14–0.35) | 0.62 (0.39–1.39) | 360 (170–900) | 420 (200–880) |
| $\int n_e n_\text{tot} dl$ ($\times 10^{17}$ cm$^{-5}$) | 0.36 (0.24–0.60) | 1.06 (0.66–2.37) | 0.55 (0.26–1.38) | 0.64 (0.31–1.35) |
| $\chi^2$/dof | 287/250 | | 204/186 |

Notes.

- VEM normalized by the region area, $dl$ is the plasma depth, and $n_O$ is the number density of O. Values in parentheses indicate the 90% confidence ranges (calculated by including the systematic errors of 40% and 10% to the data for Fil-1/2 and Knot-1/2, respectively). The errors of relative abundances are calculated after fixing $N_{\text{H}}$, $kT_e$, and $\log(n_{e,t})$ at the best-fit values. Other metals are fixed to the solar values (Anders & Grevesse 1989).
black and red data are derived from XMM-Newton and Chandra, respectively. Note that in these plots we exclude the region of the NE filament ($-810'' < R < -720''$), since we already know that at least two spectral components (i.e., the O–Ne–Mg-rich ejecta and its surroundings) are required to reproduce spectra there. As we can see in the Figure 9 bottom right panel (i.e., reduced $\chi^2$), this model represents all the spectra fairly well. The general consistency of the results between XMM-Newton and Chandra validates our analysis.

The fitted abundances are all lower than the solar values. The abundances relative to O are consistent with the solar ratios within a factor of 2, showing that there is no strong evidence of
ejecta in this region except for the O–Ne–Mg-rich NE filament.
The electron temperature is almost constant at 0.7 keV in the E portion of the SNR, while it gradually decreases toward the W rim to \( \sim 0.4 \) keV. This temperature decrease presumably makes the W limb appear reddish in the three-color image of the SNR (see, Figure 2, left). The gradual decrease of the ionization timescale from the E rim to the W rim may reflect the gradual increase of electron density toward E (Petre et al. 1982). The slight increase of \( N_H \) toward the NE rim might reflect the extinction by the dense cloud sitting in front of Puppis A (Reynoso et al. 1995). With the exception of the NE rim, the value of \( N_H \) is almost constant at \( 3 \times 10^{21} \) cm\(^{-2} \), consistent with recent Suzaku observations (Hwang et al. 2008). Given that the area we investigate lies both inside and outside the hard emission (blue color in Figure 2, left) belt across Puppis A (e.g., Aschenbach 1993; see Section 3), the blue belt-like feature is more likely caused by variations in the temperature and the ionization timescale than in column density.

5. DISCUSSION AND SUMMARY

The X-ray surface brightness map and the Ne K line-ratio map reveal a distinct filamentary feature (i.e., the NE filament) and two knots in the NE portion of Puppis A. Our spectral analysis shows that these features are rich in O, Ne, and Mg, with abundance ratios of Ne/O, Mg/O twice solar, and that of Fe/O less than solar. The super-solar (>1000) fitted metal abundances of the NE filament clearly show that its origin is likely O–Ne–Mg-rich ejecta. The relative abundances of the O–Ne–Mg-rich ejecta can then be used to estimate the progenitor mass. We compare the relative abundances measured in the filament with those predicted by the theoretical calculations (Rauscher et al. 2002) for different progenitor masses of 15 \( M_\odot \), 25 \( M_\odot \), 30 \( M_\odot \), and 35 \( M_\odot \). We find that the data agree with those calculations for the O–Ne–Mg-rich layers in progenitor stars of \( \leq 25 M_\odot \) masses. We note that the same conclusion can be derived by using the relative abundances of the \( \Omega \) filament (Katsuda et al. 2008a), since the relative abundances of Fe/H, Si/H are almost consistent with those of the \( \Omega \) filament. This is also consistent with the progenitor-mass range of 15–25 \( M_\odot \) inferred from comparisons of relative abundances of metal-rich (especially Si-rich) ejecta in the NE portion with several nucleosynthesis models (Hwang et al. 2008). We caution however that we only measured abundances of just a small fraction of the total ejecta, and so the estimate of the progenitor mass is still not conclusive.

In order to try to identify the contact discontinuity and the reverse shock, we performed radially resolved spectral analysis from the NE rim (including the O–Ne–Mg-rich NE filament) to the W rim. The spectral analysis revealed that all the spectra except for the NE filament show sub-solar metal abundances (~0.5 times the solar values) whose relative abundances are consistent with the solar values within a factor of 2—consistent with those from Suzaku observations covering the same region (Hwang et al. 2008). This result suggests that the X-ray emission is dominated by the ISM everywhere except for the NE filament. Interpretations of the results could be that the outer ejecta heated by the reverse shock have already cooled, while the inner ejecta have not yet been heated by the reverse shock, or that metal-rich ejecta could not be detected (except for the NE filament) because of their faintness compared with the ISM, or that the ejecta has not yet been heated by the reverse shock, although this last case seems unlikely for a remnant of several thousand years’ age such as Puppis A. With the current data, this remains an open question.

In the area we investigated, the only region that shows evidence of SN ejecta is the small region where the O–Ne–Mg-rich NE filament and knots are located. This result may indicate that they are peculiar fragments of ejecta inside and/or outside the SNR. We then note that the NE filament is coincident with three optical O-rich fast-moving knots (Winkler et al. 1988). Figure 10 shows the proper-motion vectors of the O-rich knots on the X-ray image, in which we see that all the vectors, \( \sim 0.18 \) yr\(^{-1} \) (\( \sim 1900 \) km s\(^{-1} \) at a distance of 2.2 kpc) toward the NE, are similar to each other. If the NE filament is physically associated with these optical knots, we expect the same proper motions for the NE filament as well.

On the other hand, it is interesting to note that the NE filament runs parallel to the NE edge of the remnant (see, Figures 2 and 3(b)). This suggests that the morphology of the filament is related to the NE edge of the SNR where the forward shock is suggested to be interacting with dense clouds (e.g., Reynoso et al. 1995). Then, we can speculate that the filament traces ejecta heated by either a strong reflected shock off the dense ambient clouds in the NE rim or a reverse shock strongly developed in this portion of the SNR. Given that we see evidence of ejecta only in the NE filament, we may interpret the inner side of the filament to be the reflection shock and the outer side to be a boundary between the O–Ne–Mg-rich ejecta, and either the ISM or ejecta rich in lighter elements. A problem for this scenario is that the expected temperature signature at the reflected shock is not seen (Figure 9); the temperature should be higher in the twice-shocked outer regions than in the singly shocked inner regions (e.g., Hester et al. 1994). It is also uncomfortable that the filament spans only a portion of the NE edge, whereas it appears that the entire NE edge is interacting with dense clouds (e.g., Reynoso et al. 1995). However, these signatures might be less clear due to projection effects and/or possible density inhomogeneities of the ejecta; the denser ejecta will tend to have the lower temperature, as the temperature is partly determined by the condition that the ram pressure, \( \rho v^2 \), be approximately constant. One way to test the reflection shock scenario would be

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8 In the vicinity of these knots, recent optical observations identified some more knots whose proper-motion vectors are similar with each other (Garber et al. 2010).
to measure the proper motion of the filament, as it should then be slower than the freely expanding ejecta.

We tried measuring proper motions of the NE filament, based on X-ray images of *Einstein* in 1979, *ROSAT* in 1992, 1993, and 1994, and *Chandra* in 2006. Although we indeed found a possible motion, it is difficult to derive conclusive results, because there is no point-like source in the *Einstein* and *ROSAT* images to be used for image registrations, and the brightness of the NE filament seems to change during these observations. In this respect, future *Chandra* observations of the NE filament are desired to firmly detect the possible proper motion and brightness change, and to conclude the origin of the NE filament.

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