Ejecta distribution of the Type Ia supernova remnant G344.7−0.1 with deep Chandra observations

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ABSTRACT: Despite decades of intense efforts, many fundamental aspects of Type Ia supernovae (SNe Ia) remain elusive. X-ray measurements of the element distributions in supernova remnants (SNRs) offer the key to understanding the explosion mechanism for SNe Ia. Here we present deep Chandra observations of G344.7−0.1, a middle-aged SN Ia remnant on the Galactic plane. The age of this SNR (3-6 kyr; [1],[2]) is sufficiently large for all of the ejecta to have been shock- heated, thus becoming visible in X-rays. Moreover, these ejecta are still hot enough to emit strong Fe K lines ([7]), in contrast to other evolved SNRs, like G299.2−2.9 and DEM L71 ([4];[3]). Thanks to this uniqueness, G344.7−0.1 is an ideal object for investigating the ejecta distribution in the entire SNR.

We performed ACIS-I observations of this SNR with a total exposure of ~ 205 ks. The X-ray images show a centrally-peaked distribution of the Fe ejecta, surrounded by an arc-like structure of intermediate-mass elements (IMEs: Si, S, Ar Ca). Moreover, the centroid energy of the Fe K emission is significantly lower in the central Fe-rich region than in the outer IME-rich regions, suggesting that the Fe ejecta were heated by the reverse shock more recently. These results are consistent with a prediction of standard SN Ia models, where the heavier elements are synthesized in the interior of an exploding white dwarf. We find, however, that the peak location of the Fe K emission is slightly offset to the west with respect to the geometric center of the SNR. This apparent asymmetry is likely due to the inhomogeneous density distribution of the ambient medium, confirmed by our radio observations.

1. Introduction

X-ray measurements of the element distributions in supernova remnants (SNRs) offer the key to understanding the explosion and nucleosynthesis mechanisms for SNe Ia. However, it has been challenging to observe in X-rays the whole ejecta in young SNRs, because the central ejecta have yet been heated by the reverse shock. The Type Ia SNR G344.7−0.1 is an ideal object in this sense, whose age is old enough for the reverse shock to reach the SNR center (3-6 kyr: [1][2]), allowing us to investigate the distribution of the whole SN ejecta. Moreover, these shocked ejecta are still hot enough to emit strong Fe K lines ([7]), of which the atomic processes are well studied theoretically ([8]), compared to other evolved SNRs like G299.2-2.9 and DEM L71 ([4],[3]) dominated by Fe L lines.

2. Chemical Stratification

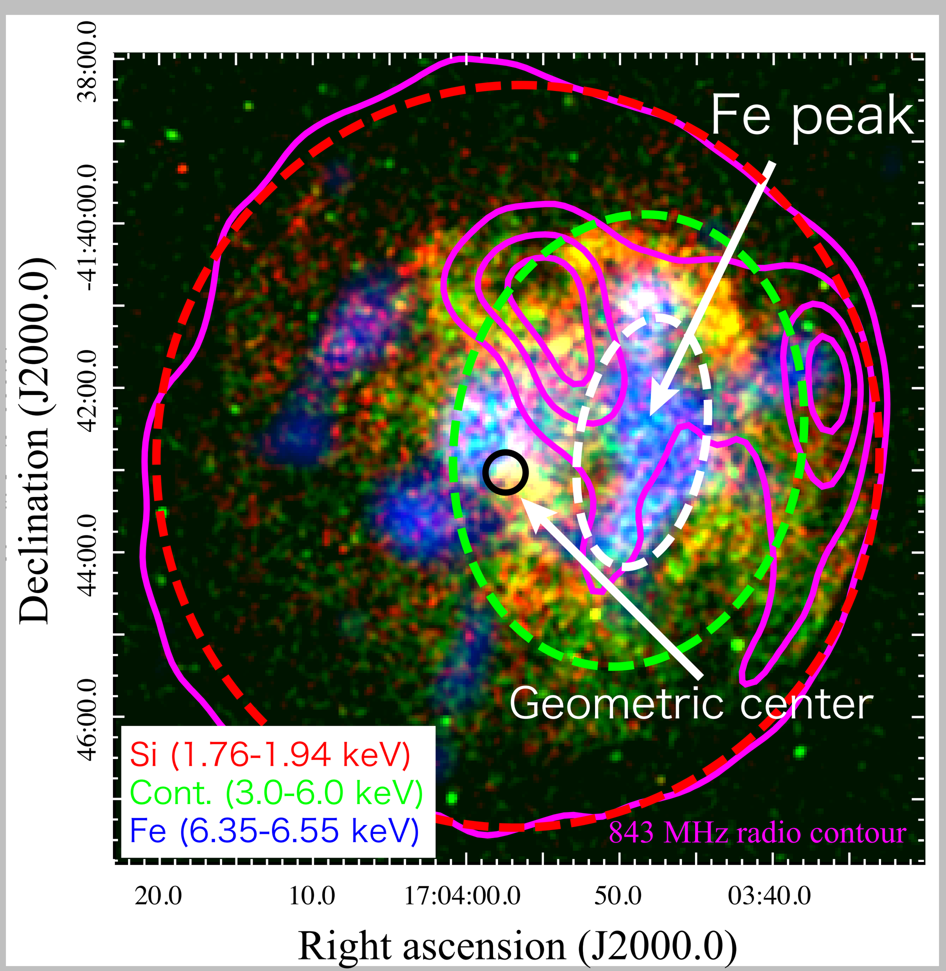

Fig.1 The three-color ACIS-I image of G344.7-0.1. Overlapped radio contours are derived from the data with the Molonglo Observatory Synthesis Telescope ([6]).

- The peak location of the Fe K emission is surrounded by an arc-like structure of the Si K emission, and is slightly offset to the west with respect to the geometric center of the SNR (Fig.1).
- The surface brightness profile of intermediate-mass elements (IMEs), centered on the Fe peak, is reproduced by a uniform density shell with R_{in}=1' and R_{out}=3'.
- The profile of Fe is explained by a uniform density sphere just inside of the IME shell (Fig.2).

→ The Fe ejecta fill the interior of the IME shell.

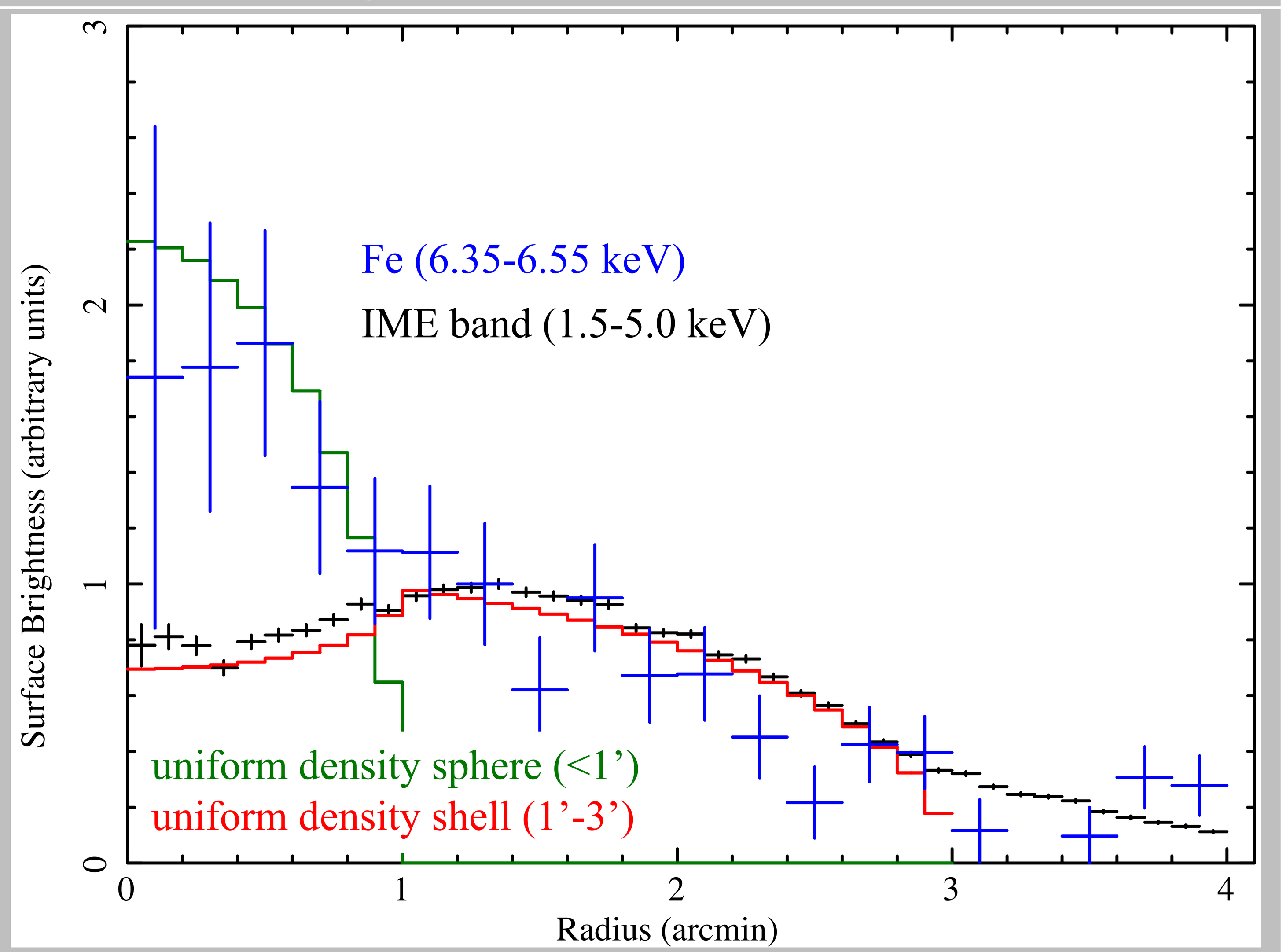

Fig.2 Radial profiles of the surface brightness in the Fe and IME band, centered on the Fe peak (Fig.1). Model surface brightness profiles assuming a uniform density shell (1'-3'), and a uniform density sphere (<1') are also plotted.

3. Fe K centroid energy

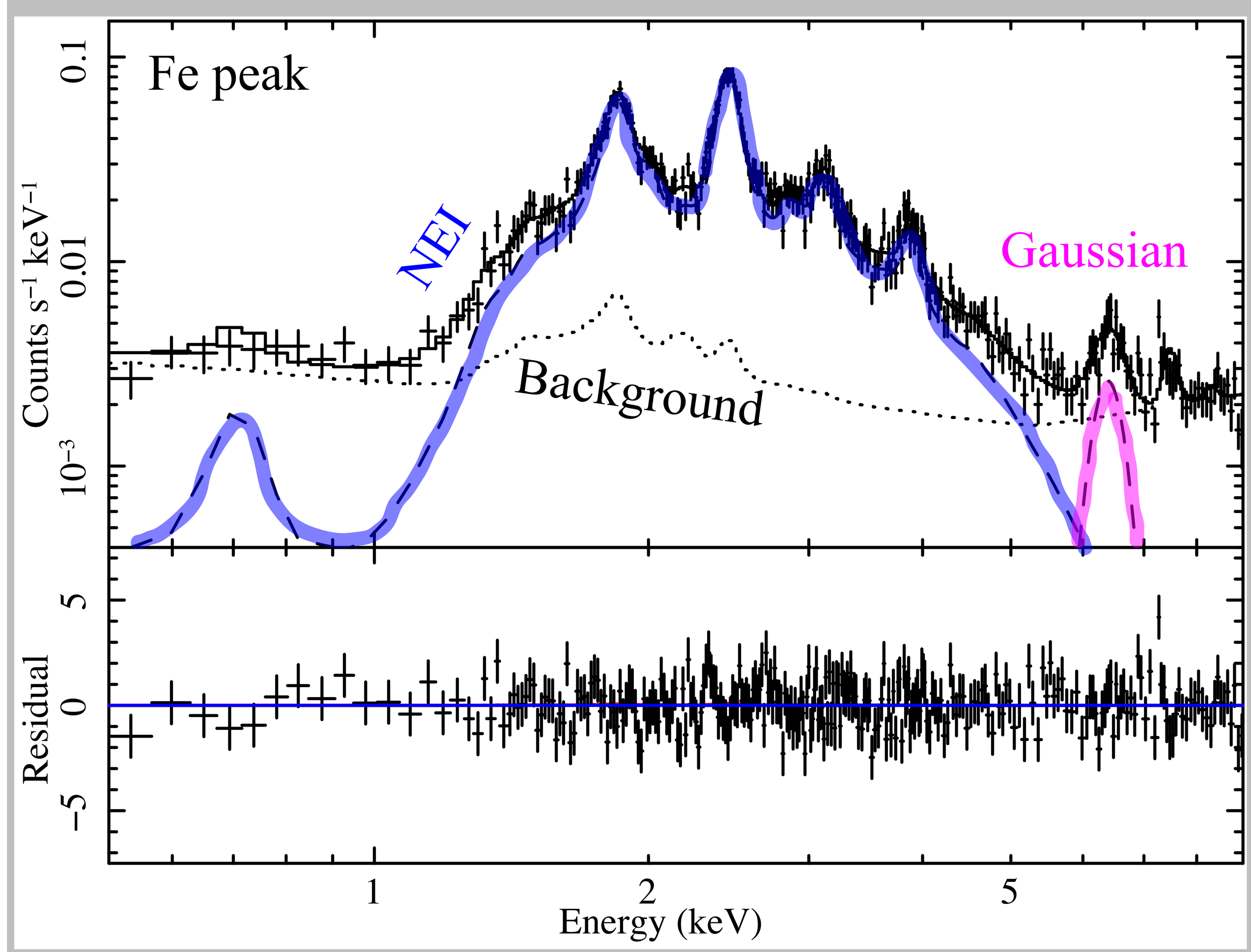

Fig.3 ACIS-I spectrum of the Fe peak region.

- The spectra of the SNR are reproduced by an optically-thin plasma in the non-equilibrium (NEI) state and a Gaussian (for Fe K emission) model (Fig.3).
- The centroid energy of the Fe K emission is lower in the central Fe-rich region than in the outer regions (Fig.4).

→ The Fe ejecta in the Fe peak have the lowest ionization degrees.

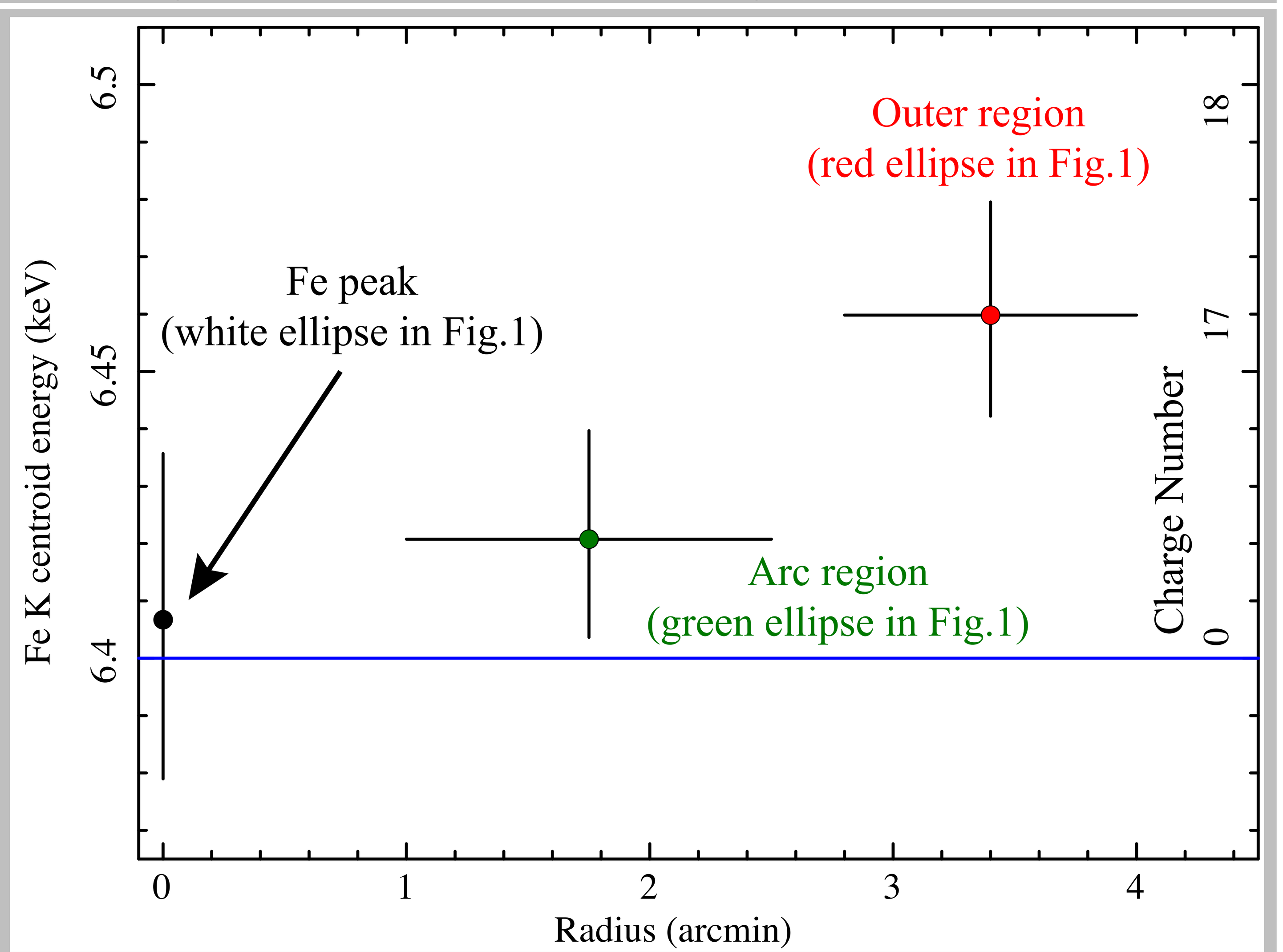

Fig.4 Fe K centroid energy as a function of the radial distance from the Fe peak location.

4. Asymmetricity of G344.7-0.1

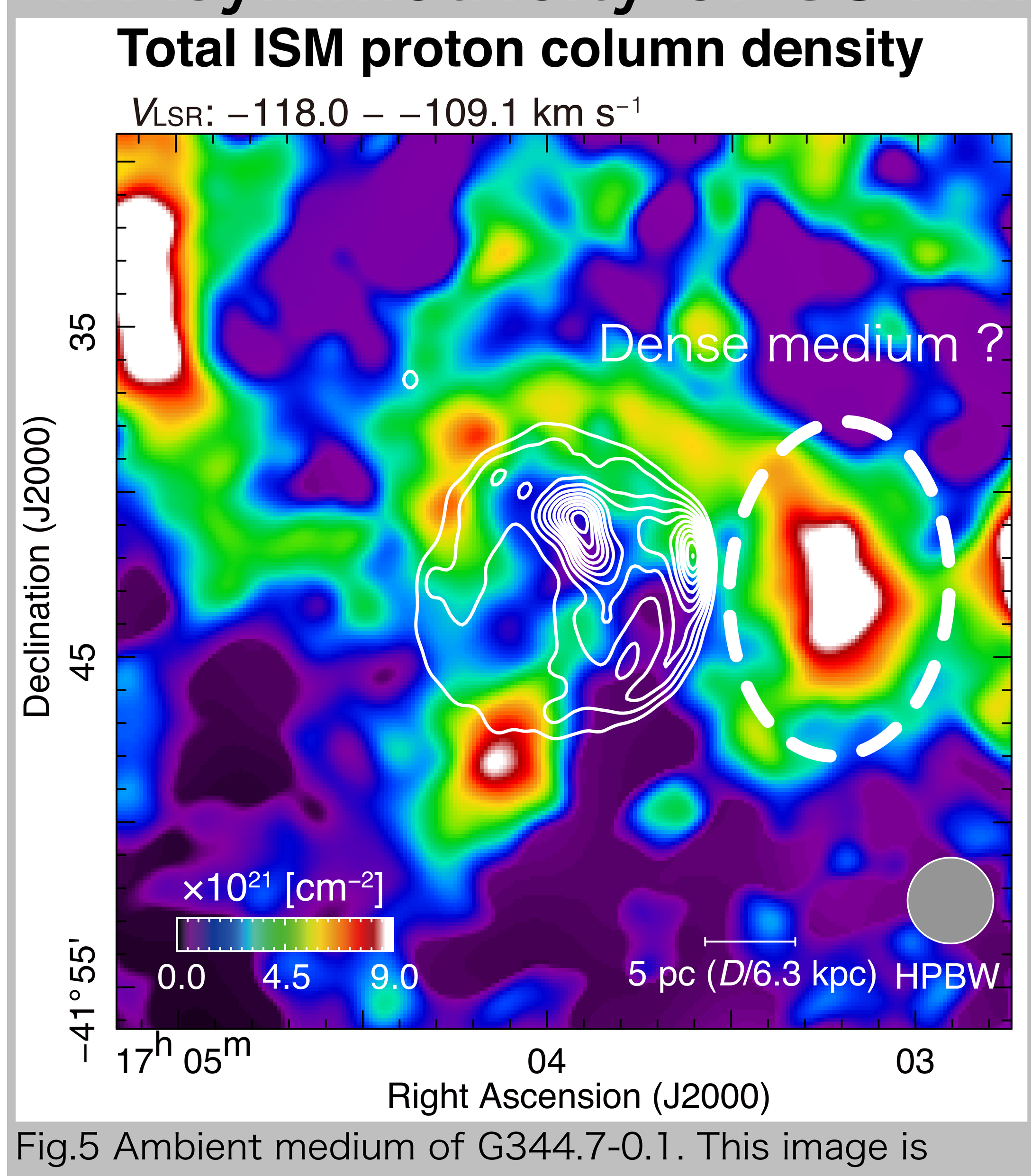

Fig.5 Ambient medium of G344.7-0.1. This image is created by radio observations with ATCA and NANTEN2.

- Ambient medium around the SNR could be dense at the west of the SNR, indicated in the CO and HI map (Fig.5), which explain the offset of the Fe peak region to the west (Fig.1).
- Expanding ejecta are likely to be hampered by these dense clouds at the west side of the SNR.

5. Discussion & Conclusions

1. G344.7-0.1 consists of the centrally-peaked Fe ejecta and the outer IME shell, suggesting a clear stratification of the heavy elements.
2. Relatively lower ionization state suggests the central Fe ejecta were shock heated more recently. The Fe peak location seems to be the real SN explosion center of G344.7-0.1.

These results are consistent with a prediction of standard SN Ia models ([5]), where the heavier elements are synthesized in the interior of an exploding white dwarf.

3. The apparent asymmetry is likely due to the inhomogeneous density distribution of the ambient medium.

■ References

[1] Combi, J. A., Albacete Colombo, J. F., Lopéz-Santiago, J., et al. 2010, A&A, 522, A50
[2] Giacani, E., Smith, M. J. S., Dubner, G., & Loiseau, N. 2011, A&A, 531, A138
[3] Hughes, J. P., Ghavamian, P., Rakowski, C. E., & Slane, P. O. 2003, ApJL, 582, L95
[4] Park, S., Slane, P. O., Hughes, J. P., et al. 2007, ApJ, 665, 1173
[5] Seitenzahl, I. R., Ciaraldi-Schoolmann, F., Röpke, F. K., et al. 2013, MNRAS, 429, 1156
[6] Whiteoak, J. B. Z., & Green, A. J. 1996, A&AS, 118, 329
[7] Yamaguchi, H., Tanaka, M., Maeda, K., et al. 2012, ApJ, 749, 137
[8] Yamaguchi, H., Eriksen, K. A., Badnes, C., et al. 2014a, Apj, 780, 136