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THE ENVIRONMENT OF TYCHO: POSSIBLE INTERACTION WITH A MOLECULAR CLOUD

J.-J. LEE[1], B.-C. KOO[1], AND K. TATEMATSU[2]
[1]Astronomy program, SEES, Seoul National University, Korea
E-mail: jjlee@astro.snu.ac.kr
[2]National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan
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ABSTRACT

The Tycho supernova remnant (SNR), as one of the few historical SNRs, has been widely studied in various wavebands and previous observations have shown evidence that Tycho is interacting with a dense ambient medium toward the northeast direction, In this paper, we report our high-resolution (16″) ^{12}CO observation of the remnant using the Nobeyama 45m radio telescope. The Nobeyama data shows that a large molecular cloud surrounds the SNR along the northeastern boundary. We suggest that the Tycho SNR and the molecular cloud are both located in the Perseus arm and that the dense medium interacting with the SNR is possibly the molecular cloud. We also discuss the possible connection between the molecular cloud and the Balmer-dominated optical filaments, and suggest that the preshock gas may be accelerated within the cosmic ray and/or fast neutral precursor.

Key words : supernova remnants:interactions with molecular clouds, supernova remnants:G120.1+1.4

I. INTRODUCTION

The Tycho supernova remnant (SNR) is known as a remnant of a Type Ia supernova that occurred in the year 1572. As one of the few historical SNRs, the remnant has been widely studied in various wavebands. There are wide range of observations showing evidence that Tycho is interacting with an ambient dense cloud toward its northeast direction (Reynoso et al., 1997; Douvion et al., 2001). From the Five College Radio Astronomy Observatory (FCRAO) ^{12}CO survey of the outer Galaxy (Heyer et al.,1998), we have identified a patch of molecular cloud which could be associated with Tycho and conducted high-resolution ^{12}CO (J=1-0) line observations. More details of the result is published elsewhere (Lee et al. 2004).

II. OBSERVATION AND RESULTS

Observation was carried out for a total of 20 hours during January 11–13, 2003 using the Nobeyama 45m radio telescope (HPBW $\sim$ 16″). BEARS multi beam receiver system was used to cover $12' \times 12'$ area centered at Tycho whose diameter is $\sim 8'$. The emission is generally from regions surrounding Tycho. In particular, at velocities between -63.5 and -61.5 km s^{-1} , the emitting area appears to be in contact with the remnant along its northeastern boundary (Fig. 1).

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III. DISCUSSION

The distance to Tycho has been estimated by several authors using independent methods. Most estimates agree on a distance of $\sim$ 2.3 kpc (Chevalier et al., 1980; Albinson et al., 1986) except for the estimate based on H I absorption observations (Schwarz et al., 1995), which gives as large as 4.5 kpc. Applying the H I absorption technique to Tycho is not straightforward due to the non-circular motion of the gas in the Perseus arm. We carefully considered the non-circular velocity structure of the Perseus arm and found that distance of 4.5 kpc is likely to be overestimated and smaller distance of 2.3 kpc is preferable. The velocity of the CO molecular cloud in the NE area of the Tycho is ~ -62 km/s, which is slightly lower than the minimum velocity of the H I absorption feature. The cloud, and other clouds, seem to be part of a large-scale distribution of molecular gas presumably representing the high-density ridge behind the spiral shock whose distance is estimated to be about 2.3 kpc. Hence, it is likely that the distances to the Tycho SNR and to the molecular clouds surrounding it are comparable. More details can be found in Lee et al. (2004).

There are wide range of observations showing evidence that Tycho is interacting with an ambient dense cloud toward its northeast direction. Above discussion, together with an interesting morphology of the molecular cloud clearly indicates that Tycho could actually be interacting with this molecular cloud.

The optical filaments in Tycho are located along the NE boundary of the remnant, where interaction with a molecular cloud is likely. The emission is predominantly hydrogen Balmer emission and is believed to

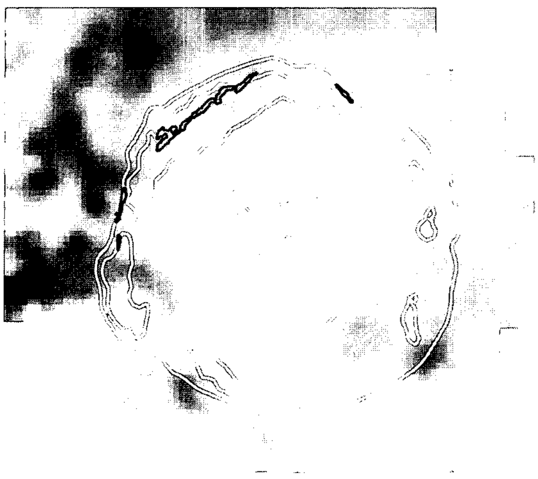

Fig. 1.— Integrated image of $v_{\rm LSR} = -60 \sim -63$ km s^{-1}. White contour for radio continuum, black contour for Hα filament.

originate from a collisionless nonradiative shock, characterized by broad and narrow emission components whose velocity distribution represent that of postshock and preshock gas, respectively. The expansion velocities of these filaments, which are compatible with radio expansion rate at this region ($\sim 0.15''$/yr, Reynoso et al. 1997), is relatively small ($\sim$ 30 %) compared to the other parts of the remnant. The implied large preshock density suggests its association with the molecular cloud. Ghavamian et al.(2000) obtained high-resolution echelle spectrum of knot g and their observed central velocity is $v_{\rm LSR} = -53.9 \pm 1.3$ km s^{-1}. For comparison, most of the ^{12}CO emission around Tycho is between -67 and -60 km s^{-1}. Therefore, there is a non-negligible velocity difference between the H alpha filament and the ^{12}CO cloud. If Tycho and the molecular cloud are physically interacting, this velocity discrepancy must be explained.

The width of the narrow Hα line in the non-radiative shocks has been a puzzle since it is unusually large for neutral hydrogen. Various physical mechanisms have been proposed to explain this line width (Smith et al. 1994) and the cosmic ray precursor and/or fast neutral precursor scenario has been regarded as the most likely case (Smith et al., 1994; Ghavamian et al., 2000). But firm evidence is yet to be found. Some of the proposed mechanisms, which include a interaction with heavy particles (like protons), also predict a systematic acceleration of the gas before their excitation. We propose that the velocity difference between Hα and ^{12}CO can be explained by this gas acceleration.

Observed peak velocity of the broad Hα component is red-shifted by 132 ± 35 km s^{-1} from that of the narrow one, indicating that the shock is not completely edge on. With a shock velocity v_s = 2000 km s^{-1} (fluid velocity $\sim \frac{3}{4}v_s$), viewing angle is estimated to be about $\theta \sim 5°$. If the gas is accelerated, the Hα narrow component will be red-shifted from the unperturbed medium, which is qualitatively consistent with our interpretation where ^{12}CO typifies the velocity of the unperturbed medium. The observed velocity difference then implies that the actual acceleration is about $\Delta v \sim 100$km s^{-1}.

IV. CONCLUSION

In this paper, we report our ^{12}CO observation toward the Tycho SNR. We found a molecular cloud surrounds the SNR along the northeastern boundary. The careful distance estimate of both Tycho and molecular cloud yield to a similar distance, suggesting that they are physically interacting, which is augmented by morphology of the molecular cloud and other indirect evidences of interaction.

If our above inference is correct, there is a velocity shift between the ambient molecular cloud, which is believed to be the unperturbed preshock gas, and the Hα filaments. We interpret this as an gas acceleration in the cosmic ray and/or fast neutral precursor. We, however, note that our conclusion is based on the single velocity measurement and more observations are needed to test it.

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