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Kinematic Distance of Galactic Radio Objects

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Abstract. We briefly summarize the method of kinematic distances of Galactic radio objects and discuss the ambiguity in this method. Both HI absorption and HI self-absorption are effective tools to solve the kinematic distance ambiguity. We build the 21 cm HI absorption spectrum of the complex G35.6-0.5, and suggest SNR G35.6-0.4, one component of the complex, is located at the near side distance of about 3.6 kpc.

Keywords. ISM: kinematics and dynamics, ISM: supernova remnants

1. Kinematic distance

Distance helps to obtain basic physical parameters of celestial bodies, e.g. their sizes, masses and luminosities. Kinematic method is frequently used to derive distances of objects on the Galactic plane. This method assumes that the rotation curve (RC) of the Galaxy is flat out side the bulge region. For objects that follow the RC well, e.g. HII region and molecular cloud (MC), their kinematic distances could be directly deduced from their radial velocities. For other objects which lack the radial velocity measurements, e.g. supernova remnants, we usually derive distance limits to them with the help of 21 cm HI emission and absorption line (e.g. Tian & Leahy 2013).

In the ideal Galactic RC model, the distance of one object to the local standard of rest (LSR), d, can be calculated by two equations: $R^2 = {R_0}^2 + (d\cos b)^2 - 2R_0 d\cos b\cos l$ and $V_r = V_0(\frac{R_0}{R} - 1)\sin l\cos b$. V_0 and R_0 are the circular velocity and galactocentric distance of the LSR. V_r and R represent the observed radial velocity and galactocentric distance of the object. l and b are the Galactic longitude and latitude of the object. Outside the solar circle ($R > R_0$), only one solution of d is positive that means one radial velocity corresponds to one distance. Within the solar circle ($R < R_0$), both solutions are positive that means one radial velocity corresponds to two distances, the near side distance and the far side distance. This problem is known as the kinematic distance ambiguity (KDA). Figure 1 is a cartoon which shows the KDA problem at the direction of $l = 25°$, $b = 0°$.

One effective method to solve the KDA problem (especially for HII region) is to employ HI absorption. Cold neutral HI gas between HII region and us will absorb the continuum emission from HII region when the HI gas has temperature lower than the temperature of background HII region. If HI absorption is detected at the velocity larger than radio recombination line velocity, the HII region is at the far side distance of the recombination line velocity. If not, the HII region is more likely at the near side distance.

Cold HI gas will absorb the emission from background warm HI gas at the same velocity. This phenomenon is called HI self-absorption (HISA) which can be used to solve the KDA problem of the MC and HII region. Previous observations (e.g., Williams & Maddalena 1996) show that Galactic MCs contain HI gases. The HI gases share similar temperature with their associated MCs and are usually colder than HI in the diffuse interstellar medium. According to the work of Anderson *et al.* (2009), about 80% HII regions in

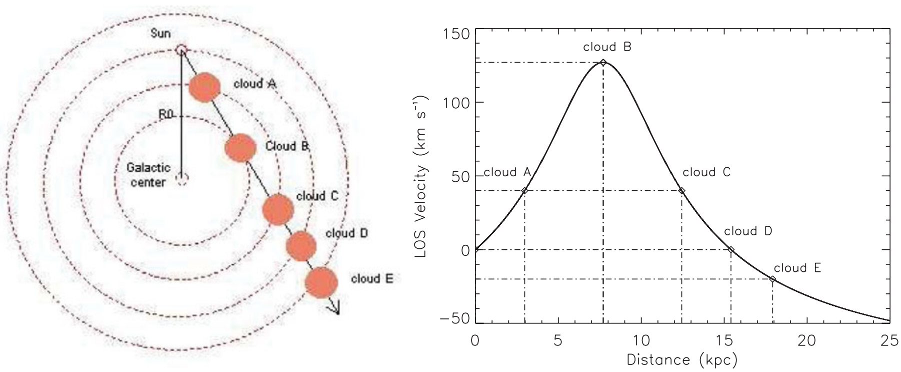

Figure 1. Left: A cartoon of the cloud distribution at the direction of $l = 25°$, $b = 0°$. Right: The relationship between radial velocity and distance at the direction of $l = 25°$, $b = 0°$. Assume $V_0 = 220$ km s^{-1}, $R_0 = 8.5$ kpc. Clouds A and C show the KDA problem clearly.

their sample have associated CO clouds. The detection of an HISA at same velocity of a CO emission line implies that the MC or the HII region is at the near side distance (Anderson *et al.* 2012). MC at the far side distance usually dose not show HISA because of the lack of background warm HI gas with the same velocity.

For objects without radial velocity measurements, HI absorption can help to constrain their distances. According to the equation of radiative transfer, the observed brightness temperature at the velocity of v can be expressed by $T_b(v) = (T_s - T_c)(1 - e^{-\tau(v)})$. T_s is the spin temperature of the HI cloud. T_c is the brightness temperature of the background continuum source. $\tau(v)$ is the optical depth at velocity of v. If T_s of one foreground HI cloud is lower than T_c of the background source, we could see an absorption feature at the radial velocity of the HI cloud and this velocity could be used to derive a lower distance limit to the continuum source. If a cloud is behind the continuum source, we could only observe emission line which provide an upper distance limit.

2. The complex G35.6-0.5

The complex G35.6-0.5 consists of SNR G35.6-0.4, planetary nebulae (PN G0.5.5-00.4, IRAS 18551+0159) and HII region G35.6-0.5 (see the upper-left panel of Figure 2). Since SNR G35.6-0.4 is overlapped on HII region G35.6-0.5, we could only build the mixed absorption spectrum of both objects. The maximum absorption velocity in the spectrum is about 61 km s^{-1}. Paron & Giacani (2010) found a 55 km s^{-1} ^{13}CO cloud on the southern border of SNR G35.6-0.4. The profile of the ^{13}CO J=1-0 emission line is asymmetric and has a slight broadening. They suggested the cloud is interacting with SNR G35.6-0.4. The velocity of 55 km s^{-1} indicates both objects are at the near side distance of 3.6 kpc or at the far side distance of 10.2 kpc. The absorption spectrum is in favor of the near side distance because all the absorption features have velocities lower than 61 km s^{-1}. However, since the complex is faint, the lack of absorption at velocity larger than 61 km s^{-1} may be caused by the absence of cold HI clouds. The right two panels of Figure 2 show that HISA features with velocity of about 82 km s^{-1} appear around the complex. The features also associate with CO clouds (red contour). This implies there are very cold HI clouds at the distance of 5.4 kpc (the near side distance of 82 km s^{-1}). The lack of HI absorption at 82 km s^{-1} suggests SNR G35.6-0.4 is likely at the near side distance of 3.6 kpc. For more details about the complex G35.6-0.5, we refer to Zhu *et al.* (in preparation).

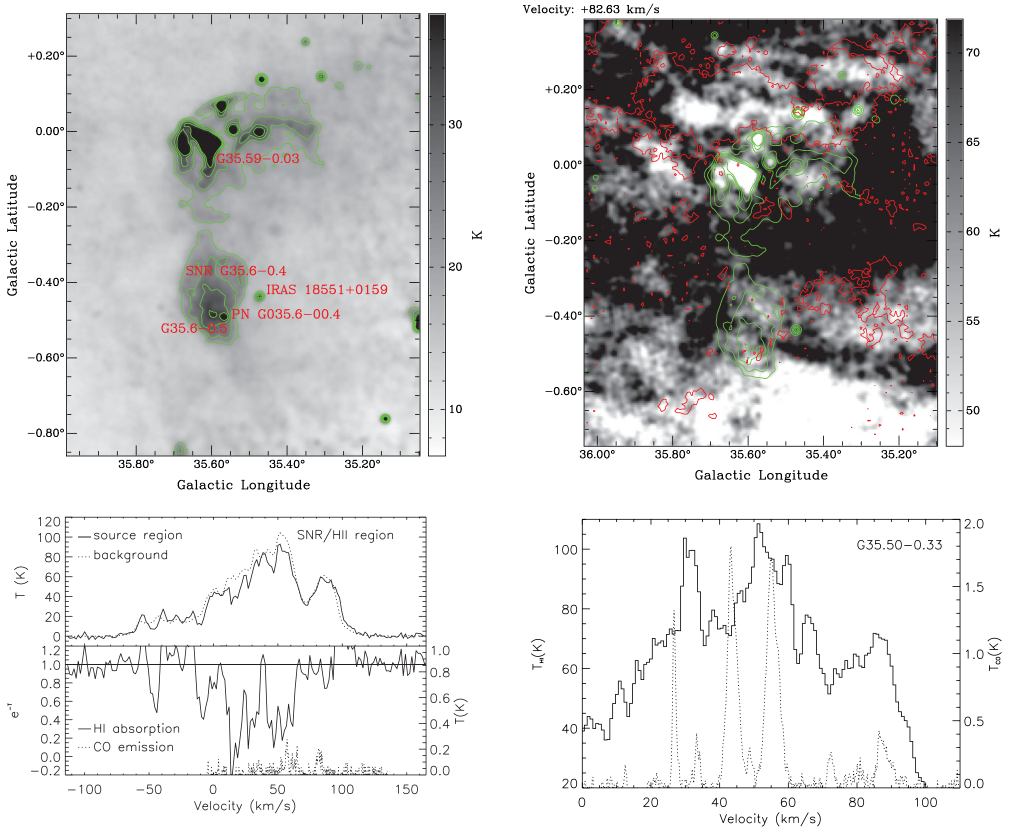

Figure 2. Upper-left: 1420 MHz continuum image of the complex G35.6-0.5. The Green contours show the brightness temperature with levels of 20 K, 25 K, 30 K and 35 K. Upper-right: HI channel maps at 82.63 km s^{-1} overlap with 1420 MHz continuum contours (green) and ^{13}CO J=1-0 emission contour of 0.3 K per Channel (red). Lower-left: The HI absorption spectra of SNR G35.6-0.4 and HII region G35.6-0.5. Lower-right: The HI (histogram) and ^{13}CO J=1-0 emission (dot line) at coordinate $l = 35.50°$, $b = -0.33°$.

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