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TRIGONOMETRIC DISTANCE AND PROPER MOTION OF IRAS 20056+3350: A MASSIVE STAR FORMING REGION ON THE SOLAR CIRCLE

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ABSTRACT

We report our measurements of the trigonometric distance and proper motion of IRAS 20056+3350, obtained from the annual parallax of H_2O masers. Our distance of $D = 4.69^{+0.65}_{-0.51}$ kpc, which is 2.8 times larger than the near kinematic distance adopted in the literature, places IRAS 20056+3350 at the leading tip of the Local arm and proximal to the Solar circle. We estimated the proper motion of IRAS 20056+3350 to be $(\mu_\alpha \cos\delta,\, \mu_\delta) = (-2.62 \pm 0.33,\, -5.65 \pm 0.52)$ mas yr^{-1} from the group motion of H_2O masers, and use our results to estimate the angular velocity of Galactic rotation at the Galactocentric distance of the Sun, $\Omega_0 = 29.75 \pm 2.29$ km s^{-1} kpc^{-1}, which is consistent with the values obtained for other tangent points and Solar circle objects.

Key words: Masers - Stars; individual (IRAS 20056+3350) - Galaxy: structure and dynamics

1. INTRODUCTION

The morphology of a galaxy is determined visually and is highly influenced by the distribution of massive stars which are bright and typically confined to the spiral arms (Reid et al., 2014). Although the exclusivity of massive star formation to the spiral arms is not yet understood it does bring to light a strong interplay between the spiral pattern itself and the conditions required to trigger massive star formation. Thus, neither phenomenon can be understood independently; we cannot explain massive star formation without explaining the role of the spiral pattern and we require the byproducts of massive star formation to understand the morphology of galaxies by tracing the arms.

Combining the proper motions and line of sight motions of masers sometimes allows the estimation of the three-dimensional secular motions of a star forming region in the plane of the Galaxy. This is one of the unique advantages of VLBI maser investigations and is a dominant approach to understand the kinematics and structure of the Milky Way Galaxy (MWG) via the evaluation of the Galactic constants, R_0, Θ_0 and Ω_0 (Honma et al., 2012; Reid et al., 2014). These parameters can be evaluated more reliably for star forming regions (SFRs) that reside at special locations in the MWG such as the tangent points and Solar circle (Nagayama et al., 2011; Burns et al., 2014).

2. Observations

Data were obtained using VERA in dual-beam mode. By observing H_2O masers in IRAS 20056+3350 and the J2010+3322 reference continuum source simultaneously we calibrated tropospheric phase fluctuations using the reference source and applied solutions directly to the maser data in real-time without interpolation. The scan integration time of the pair was about 9 minutes. Intermittent observations of BL Lac or 3C454.3 were made every 1.5 hours for bandpass calibration. A typical observation session lasted roughly 8 hours, providing ~ 3.3 hours on-source integration and good coverage in the uv plane. Phase tracking centers for the maser and continuum source were set to $(\alpha, \delta)_{\rm J2000.0} = (20^{\rm h}07^{\rm m}31^{\rm s}.2593, +33^\circ59'41.491'')$ and $(\alpha, \delta)_{\rm J2000.0} = (20^{\rm h}10^{\rm m}49^{\rm s}.7233, +33^\circ22'13.810'')$, respectively. The positional reference J2010+3322 is listed in the VLBA calibrator search catalogue Fomalont et al. (2003).

3. RESULTS

Parallax and proper motion fitting was performed simultaneously on two maser spots which were identifiable in observations spanning more than one year. Absolute motions were deconstructed into sinusoidal (from the annual parallax) and linear components. In the fitting

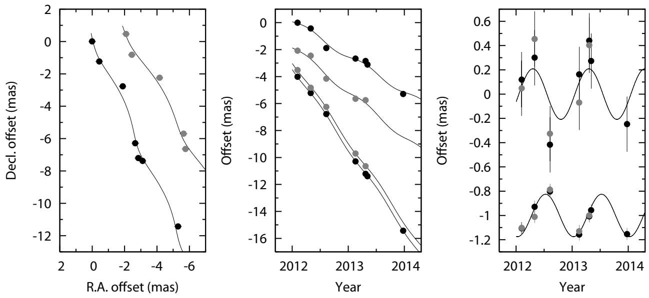

Figure 1. Parallax fitting results for IRAS 20056+3350.

procedure, nominal fitting errors in R.A. and Dec. were applied and reduced iteratively until a χ^2 value of unity was reached. These error floors were 0.227 mas in R.A. and 0.050 mas in Dec. The poor fitting in R.A. was found to be caused by elongation of the maser structure in the interferometric images.

When the data were fit using the two most stable and brightest maser spots together we derived an annual parallax of $\pi = 0.213 \pm 0.026$ mas (*uncertainty of* 12.4%), corresponding to a distance of $D = 4.69^{+0.65}_{-0.51}$ kpc. Results of the fitting procedure are illustrated in Fig. 1.

Proper motions were measurable for 3 maser spots. We evaluated the group averaged proper motion for all maser spots in IRAS 20056+3350 to be $(\mu_\alpha \cos\delta, \mu_\delta) = (-2.62 \pm 0.33, -5.65 \pm 0.52)$ mas yr^{-1}. Error values are the standard error of the mean, $\sigma/\sqrt{3}$, where σ is the standard deviation of the proper motion of 3 spots.

4. DISCUSSION

4.1. Proper Motion of IRAS 20056+3350

The small number of maser spots does not allow direct interpolation of maser motions to a kinematic center, as is demonstrated in Imai et al. (2011). However, Zhang et al. (2005) presented an on-axis outflow mapped in CO in which the CO spectrum exhibits a triple-peak morphology. All of of our masers are consistent with the limit of the blue lobe velocity. Thus, we are able to make a reasonable assumption that the sky-plane proper motions of maser spots with respect to the driving source are small, since the largest velocity components can be expected along the line of sight, in agreement with the direction of the outflow. As such, the average proper motion of maser spots should give a reasonable approximation to the secular motion of the SFR.

4.2. Galactic Structure: Local Arm

The nature of the Local Arm is discussed in the work of Xu et al. (2013) where the authors consider three possible scenarios; that *1.* The Local Arm is a branch of the Perseus Arm. *2.* The Local Arm may be part of a major arm and connects to the Carina Arm. *3.* It is an independent arm segment - a 'spur'.

As seen in Fig. 2, the Galactic location of IRAS 20056+3350 diverges somewhat from the logarithmic curve determined for the Local Arm by Reid et al. (2014). Deviation is in the direction of the Perseus Arm

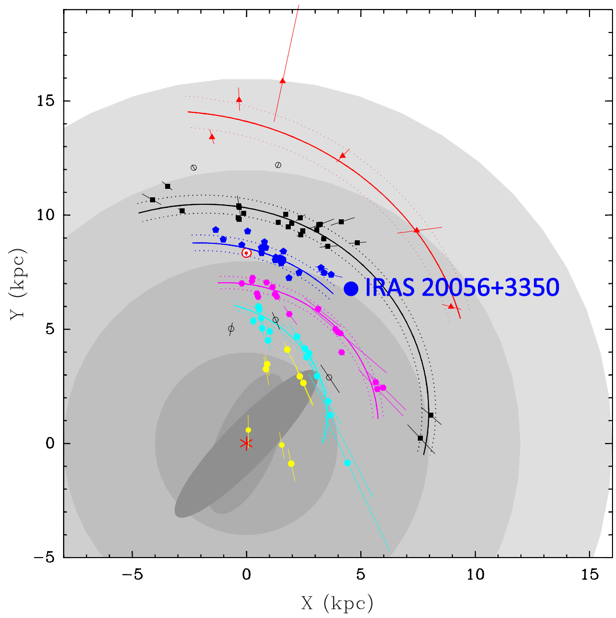

Figure 2. Position of IRAS 20056+3350 in the context of MSFRs from Reid et al. (2014).

and follows the example of three other MSFRs at the leading tip of the arm; G075.76+00.33, G075.78+00.34 and AFGL 2591. The location of IRAS 20056+3350 is generally consistent with what would be expected in the scenario where the Local Arm joins onto the Perseus Arm further down into the spiral pattern - scenario *1.* of Xu et al. (2013). However, the alternative scenarios cannot be ruled out until this region of the Galaxy is mapped in more detail.

4.3. Evaluation of the Ω_0 Galactic Constant

Nagayama et al. (2011) demonstrated that the angular velocity of Galactic rotation at the Galactocentric distance of the Sun, Ω_0 (expressed as the ratio of the Galactic constants), can be estimated for objects near the Solar circle and tangent points with relaxed assumptions on the adopted value of R_0. For objects with negligible peculiar motion, the angular velocity of Galactic rotation at the Sun is given by

$$\Omega_0 \quad = \quad -a_0\mu_l + v_r\left(\frac{1}{D\tan l} - \frac{1}{R_0 \sin l}\right). \qquad (1)$$

Using our results obtained with VERA, and the special geometry applicable to Solar circle objects, we evaluated the angular velocity of Galactic rotation at the Sun, $\Omega_0 = 29.75 \pm 2.29$ km s^{-1} kpc^{-1}, which is consistent with other Solar circle and tangent point sources estimated using the same procedure. IRAS 20056+3350 included, all estimates are higher than the value derived from the ratio of the Galactic constants recommended by the IAU of $\Omega_0 = \Theta_0/R_0 = 25.9$ km s^{-1} kpc^{-1}.

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