PROCEEDINGS OF SCIENCE

Where are you, Scutum? Tracking down a spiral arm with maser astrometry

Katharina Immer*
Joint Institute for VLBI-ERIC (JIVE), Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
E-mail: immer@jive.eu

Jingjing Li
Purple Mountain Observatory CAS, No.8 Yuanhua Road, Qixia District, Nanjing 210034, The People's Republic of China
E-mail: jjli@pmo.ac.cn

Luis H. Quiroga-Nuñez
Leiden Observatory, Leiden University, Niels Bohrweg 2, NL-2333CA, Leiden, The Netherlands
Joint Institute for VLBI-ERIC (JIVE), Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
E-mail: quiroganunez@strw.leidenuniv.nl

Mark J. Reid
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
E-mail: mreid@cfa.harvard.edu

Bo Zhang
Shanghai Astronomical Observatory, 80 Nandan Road, Shanghai 200030, China
E-mail: zb@shao.ac.cn

Luca Moscadelli
Instituto Nationale di Astrofisica, Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, I-50125 Firenze, Italia
E-mail: mosca@arcetri.astro.it

In these proceedings, we discuss the parallax and proper motion measurements towards 43 high-mass star forming regions in the Scutum spiral arm. These observations were conducted with the Very Long Baseline Array within the framework of the Bar and Spiral Structure Legacy (BeSSeL) survey. The pitch angle of the spiral arm was found to be $18.6^\circ \pm 2.9^\circ$, which is much larger than in other spiral arms. In this arm, many sources have large peculiar motions, especially a group between l=29° and 32° which shows ordered motion > 25 km s^{-1} towards the Galactic Center.

14th European VLBI Network Symposium & Users Meeting (EVN 2018)
8-11 October 2018
Granada, Spain

*Speaker.

PoS(EVN2018)055

1. Introduction

Due to our position in the Milky Way, we still do not know the exact shape of our Galaxy. de Vaucouleurs (1970) identified it as a spiral galaxy with a bar, however, the number and exact position of the spiral arms as well as the shape of the bar are still under debate. To pinpoint the spiral arms, we have to reliably measure their distances at a number of positions along the arms. Maser sources located in high-mass star forming regions (HMSFRs) within the arms are ideal targets to determine trigonometric parallaxes with high astrometric accuracy, using Very Long Baseline Interferometry (VLBI) observations.

Over the past eight years, the Bar and Spiral Structure Legacy (BeSSeL Brunthaler et al., 2011) survey, an NRAO Very Long Baseline Array (VLBA) key science project, has measured the distances to over 100 HMSFRs across the Galaxy (Reid et al., 2014; Sato et al., 2014; Wu et al., 2014; Choi et al., 2014; Sanna et al., 2014; Hachisuka et al., 2015). In these proceedings, we will discuss recent astrometric results for maser sources in the Scutum spiral arm.

The Scutum arm is the second spiral arm from the Sun towards the Galactic Center, located between the Sagittarius (Rygl et al., 2019) and the Norma arms. Strong condensations in longitude-velocity plots in neutral hydrogen and CO observations lead to the identification of this arm (Shane, 1972; Cohen et al., 1980; Dame et al., 1986, 2001). First parallax observations towards maser sources in this arm were published by Sato et al. (2014) for 16 sources. Now, parallaxes for 43 sources are available and will be published in Immer et al. (2019, subm.) and Li et al. (2019, in prep.).

2. Observations

Multi-epoch phase-referenced VLBA observations were carried out towards 43 sources in three maser transitions: 6.7 GHz CH_3OH, 12.2 GHz CH_3OH, and 22 GHz H_2O. For the methanol masers, four observing epochs are spread over one year to optimally sample the peaks of the sinusoidal parallax signature in right ascension and minimize the correlation between the linear proper motion and the sinusoidal parallax contribution. Since water maser spots can be shorter lived than a year, two additional epochs are included for this maser type. As position reference for the maser targets, compact background sources from the ICRF2 catalog (Fey et al., 2015) and a dedicated VLBA survey (Immer et al., 2011) were observed.

Two correlation passes were conducted, one for the continuum and one for the line data. The frequency resolution of the line data was 8, 16 or 32 kHz, depending on the year in which the targets were observed. This corresponds to a velocity resolution of less than 1.5 km s^{-1} for all three maser groups. A detailed description of the observational setup and the data reduction and calibration procedures of the BeSSeL survey can be found in Reid et al. (2009).

The calibrated data was then imaged, and the positions of the maser spots and quasars were measured. For each maser, different numbers of maser spots were selected for the parallax and proper motion fitting. The fitting was conducted on the positional differences between the maser spots and the quasars, using a combination of a linear proper motion and a sinusoidal parallax component. In the combined fit of all maser spots of a target maser, we allowed for different proper motion values of each spot to account for internal motions in the star forming regions.

PoS(EVN2018)055

3. Results

Figure 1 shows an example of a parallax fit for the source G29.98+0.10. The parallax of this source is (0.156 ± 0.010) mas, corresponding to a distance of ($6.41^{+0.44}_{-0.39}$) kpc from the Sun. For the proper motion, we obtain μ_x = (−1.39 ± 0.03) mas yr^{-1} and μ_y = (−3.49 ± 0.20) mas yr^{-1}.

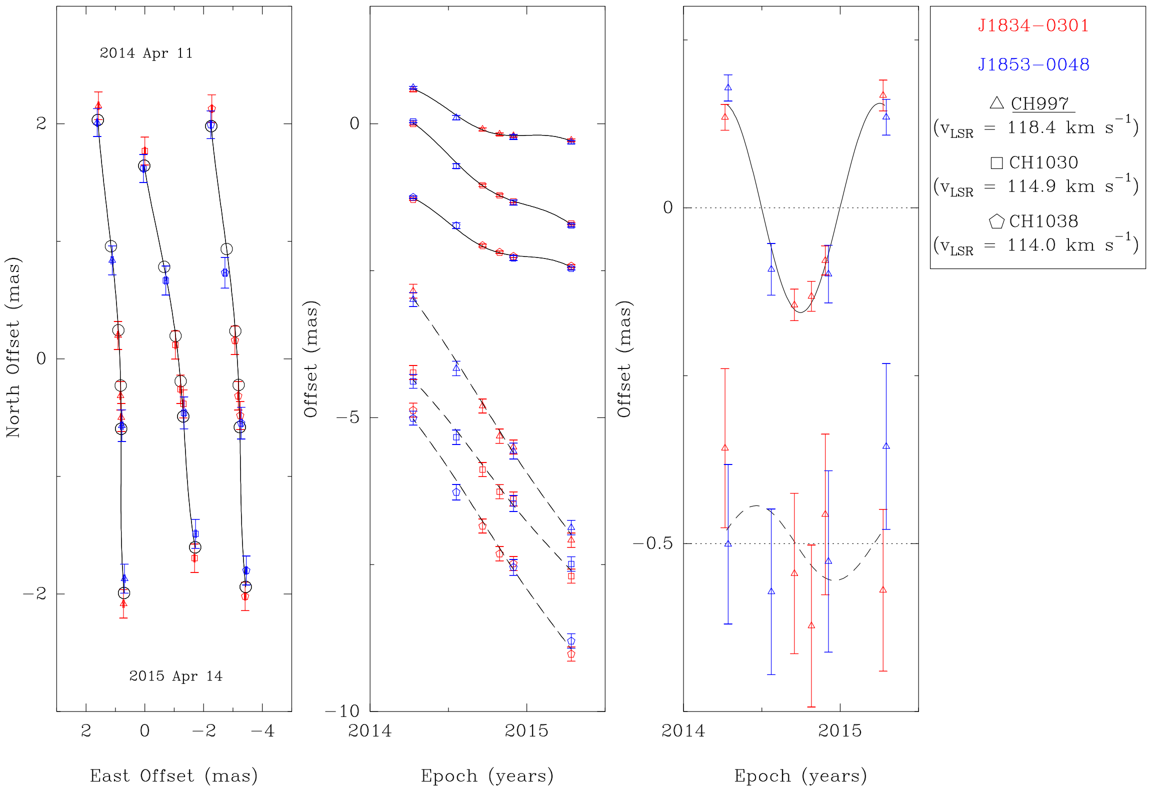
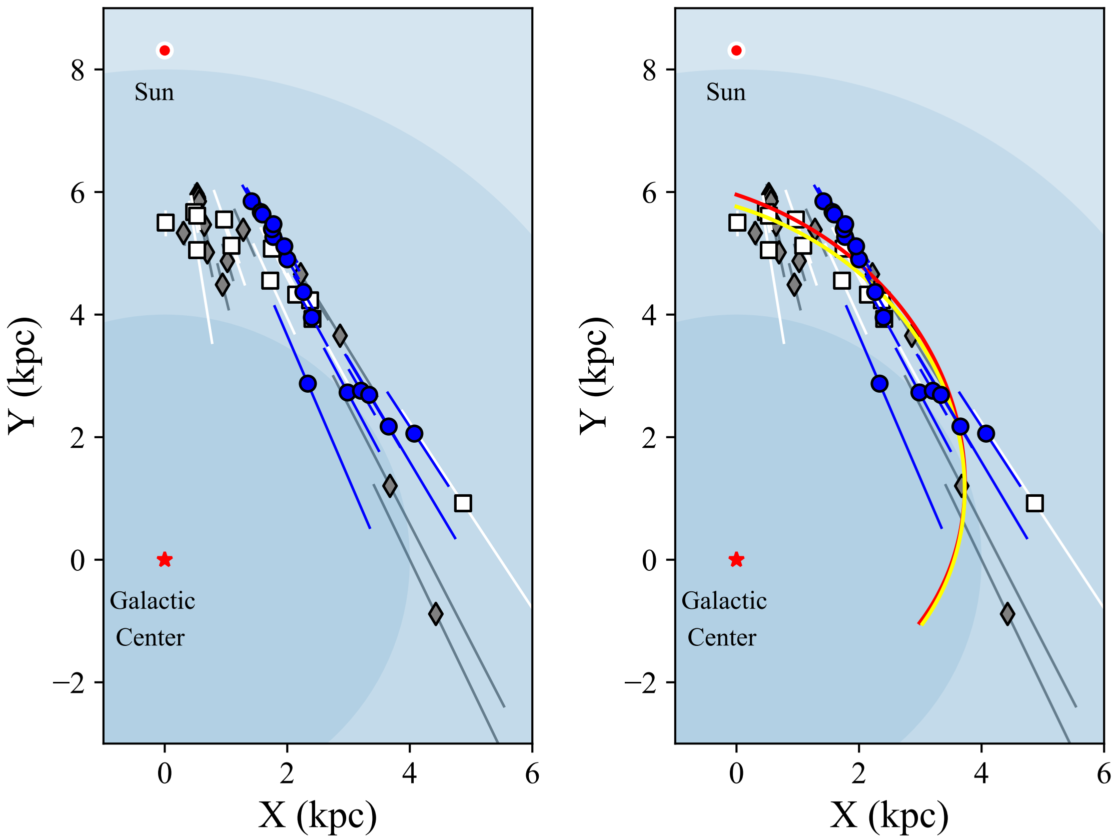


Figure 1: Parallax and proper motion data and fits for the 22 GHz water maser G029.98+0.10 with respect to the quasars J1834−0301 (red) and J1853−0048 (blue). Left panel: Measured positions of the maser on the sky. Middle panel: East (upper data) and North (lower data) position offset versus time. Right panel: As middle panel, but with proper motion contribution removed. In this panel, only the data for the underlined maser spot is shown. In the other panels, the data and fits for different maser spots are offset for clarity.

The BeSSeL masers are assigned to a spiral arm by associating their host HMSFR with molecular clouds in the CO Galactic plane survey of Dame et al. (2001). Those clouds are then connected to a spiral structure in $l-v$ space. In plan view plots of the Milky Way, these sources then tend to trace out continuous arcs that are identified as individual spiral arms. In Fig. 2a, we plot the positions of all 43 maser sources in such a plan view plot. The error bars show the distance uncertainty of each source. The spiral arm is traced between l=6° and 33°. The sources cover distances between 2 and 10 kpc from the Sun.

To measure the pitch angle, the inclination of the spiral arm to the direction of Galactic rotation, we fitted the spiral arm with a log-periodic model. In logarithmic arms, the pitch angle is constant. Sato et al. (2014) measured a pitch angle of 19.8°± 3.1° for 16 sources in the Scutum arm. Re-fitting the 43 sources, we yield a value of 18.6°± 2.9° which is consistent with the previous value. The two pitch angle models are overlayed on the plan view plot in Fig. 2b. The pitch angle of the Scutum arm is much larger than measured in other spiral arms of the Galaxy which range between 7° and 15° (Xu et al., 2013; Choi et al., 2014; Wu et al., 2014; Hachisuka et al., 2015).



(a) (b)

Figure 2: Left panel: XY plot of the 43 masers in the Scutum spiral arm (grey diamonds: published sources in Sato et al. (2014), blue circles: sources in Immer et al. (2019, subm.), white squares: sources in Li et al. (2019, in prep.)). The position of the Sun and the Galactic Center are marked. Distance uncertainties are shown as continuous lines. Right panel: As left panel, but with two pitch angle fits overlayed (yellow: Sato et al. (2014), red: Li et al. (2019, in prep.)).

The parallax observations do not only yield the distances to the sources but also their proper motion. Applying a Galactic rotation model (Reid et al., 2014, Univ fit), we can transform the three-dimensional motions of the masers to a reference frame that rotates with the Galactic disk. These peculiar motion vectors are plotted in Fig. 3. Fourteen sources in the arm have absolute peculiar motion larger than 20 km s^{-1} (right panel of Fig. 3). From these, two groups of masers show similarly oriented peculiar motion vectors. However, it is not clear yet if these sources were accelerated by the same astrophysical event.

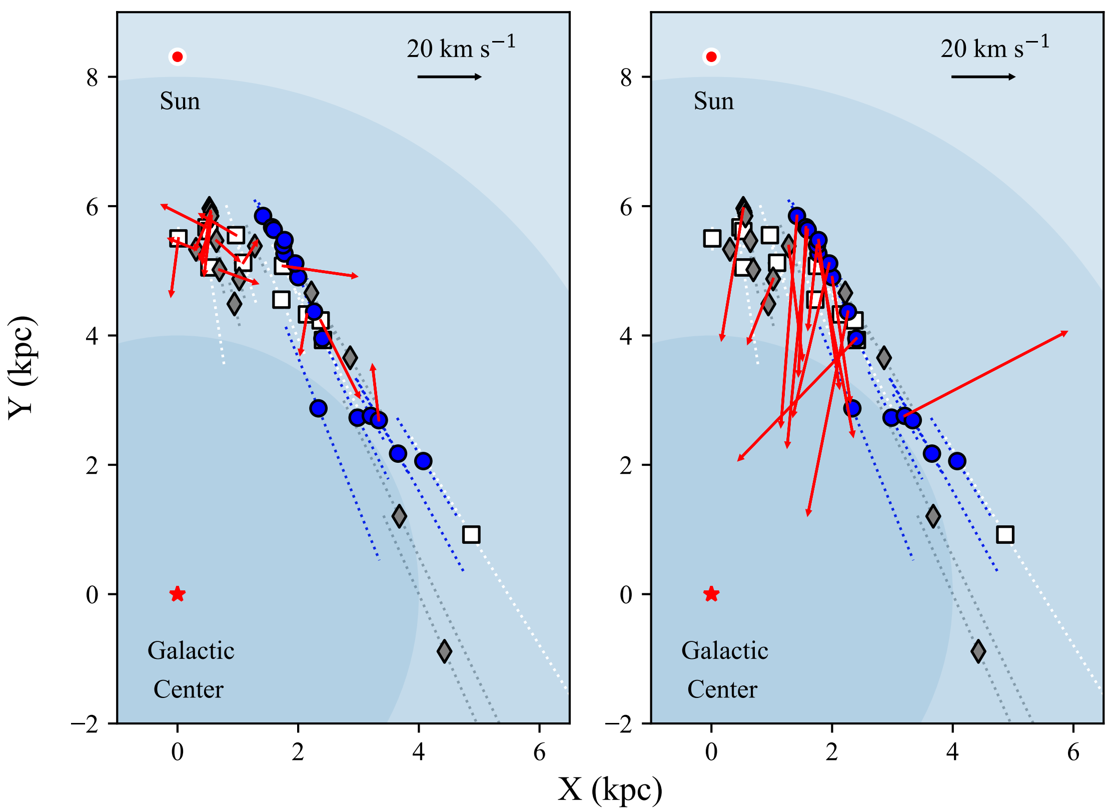


Figure 3: Same as Fig. 2a but with peculiar motion vectors overlayed (left: peculiar motion $\leq$ 20 km s^{-1}, right: peculiar motion > 20 km s^{-1}. The vectors have uncertainties of < 20 km s^{-1}. Distance uncertainties are shown as dashed lines.

References

Brunthaler, A., Reid, M. J., Menten, K. M., et al. 2011, Astronomische Nachrichten, 332, 461

Choi, Y. K., Hachisuka, K., Reid, M. J., et al. 2014, ApJ, 790, 99

Cohen, R. S., Cong, H., Dame, T. M., & Thaddeus, P. 1980, ApJ, 239, L53

Dame, T. M., Elmegreen, B. G., Cohen, R. S., & Thaddeus, P. 1986, ApJ, 305, 892

Dame, T. M., Hartmann, D., & Thaddeus, P. 2001, ApJ, 547, 792

de Vaucouleurs, G. 1970, in IAU Symposium, Vol. 38, The Spiral Structure of our Galaxy, ed. W. Becker & G. I. Kontopoulos, 18

Fey, A. L., Gordon, D., Jacobs, C. S., et al. 2015, AJ, 150, 58

Hachisuka, K., Choi, Y. K., Reid, M. J., et al. 2015, ApJ, 800, 2

Immer, K., Brunthaler, A., Reid, M. J., et al. 2011, ApJS, 194, 25

Reid, M. J., Menten, K. M., Brunthaler, A., et al. 2014, ApJ, 783, 130

Reid, M. J., Menten, K. M., Zheng, X. W., et al. 2009, ApJ, 700, 137

Rygl, K. et al. 2019, PoS(EVN2018)036

Sanna, A., Reid, M. J., Menten, K. M., et al. 2014, ApJ, 781, 108

Sato, M., Wu, Y. W., Immer, K., et al. 2014, ApJ, 793, 72

Shane, W. W. 1972, A&A, 16, 118

Wu, Y. W., Sato, M., Reid, M. J., et al. 2014, A&A, 566, A17

Xu, Y., Li, J. J., Reid, M. J., et al. 2013, ApJ, 769, 15