FGS OBSERVATIONS OF TWO HIGH-VELOCITY STARS

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ABSTRACT. The Hubble Space Telescope Fine Guidance System has been used to obtain precise astrometry in the fields of two stars of large space velocity: R 50 = G 166-37 and W 624 = G 16-25. The measures indicate a relative trigonometric parallax for R50 of 4.0 mas, which implies a space velocity in the galactocentric rest frame of 467 km/sec. The derived parallax for W 624 is probably about 3.0 mas but there is a large uncertainty.

Key Words: stars: individual, high-velocity, parallaxes

1. INTRODUCTION

The escape velocity from the Galaxy at the solar distance, R₀, is a fundamental parameter for modeling the kinematics and mass distribution of the Galaxy. The value, however, is difficult to determine, with recent estimates spread over the range 380 - 640 km/s. The usual approach to determining Vₑ is to adopt the upper limit of the space velocities of the stars in the solar neighborhood under the assumption that all stars are bound to the Galaxy. Any errors in the velocities of the fastest moving stars have an important influence on such a determination. The radial velocities and proper motions of the critical stars are well-determined, but the photometric distances used to calculate the
tangential components of the motions are rather uncertain and compromise the reliability of the space motions.

This paper describes astrometric observations made with the Hubble Space Telescope Fine Guidance System (FGS) of two of the stars of largest space velocity in the galactocentric rest frame. Our objective was to determine trigonometric parallaxes, and therefore improve the tangential velocities, of these stars which help define the local escape velocity.

It is natural to ask what this topic has to do with the focus of this conference which is “Thirty years of Astronomy at the Van Vleck Observatory - a Meeting in Honor of Arthur R. Upgren.” The answer involves the fact that both authors have had long friendships with Arthur Upgren and have spent time at Van Vleck Observatory. It was from these associations that our interest in galactic kinematics arose and we gained experience with astrometry and trigonometric parallax determinations. Thus, Art Upgren and Van Vleck Observatory were ultimately the reasons this project was carried out.

2. THE OBSERVING PROGRAM

Candidate stars were selected from the list of Carney, Latham & Laird (1988), and a final selection was made based on Cudworth’s (1990) results for the stars of largest known velocity. Two stars were observed: R 50 = G 166-37 and W 624 = G 16-25. Finding charts for the two stars are shown in Figs. 1 and 2 while basic information about them is presented in Table 1. The table shows the V, B-V and V-Rc magnitudes, the galactic coordinates, the radial velocity and proper motion, and the photometric parallax and resulting space velocity in the galactocentric rest frame, VRF.

The observing program called for FGS POSition-mode measurements in each field on 36 orbits. Observations would be made at five successive epochs, with three sets of six observations at one parallax factor extremum and two sets of nine observations at the other. For both stars the parallax factor extrema occur in February and August. The observing sequence for each orbit would begin and end with the program star (P) with the reference stars - five for R 50 and seven for W 624 - observed between. The planned observing program is summarized in Table 2.
Table 1. Properties of the observed stars

<table>
<thead>
<tr>
<th>Star</th>
<th>V</th>
<th>B-V</th>
<th>V-R</th>
<th>l</th>
<th>b</th>
<th>RV</th>
<th>μ</th>
<th>π</th>
<th>VRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 50=G 166-37</td>
<td>12.64</td>
<td>0.67</td>
<td>0.41</td>
<td>34</td>
<td>67</td>
<td>+369</td>
<td>0.33</td>
<td>5.7</td>
<td>461</td>
</tr>
<tr>
<td>W 624=G 16-25</td>
<td>13.4</td>
<td>0.59</td>
<td>0.39</td>
<td>16</td>
<td>40</td>
<td>+23</td>
<td>0.43</td>
<td>3.4</td>
<td>467</td>
</tr>
</tbody>
</table>

Table 2. The planned observing program

<table>
<thead>
<tr>
<th>Star</th>
<th>Observing Sequence</th>
<th>Number of observing sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 50</td>
<td>B I F P</td>
<td>6 9 6 9 6</td>
</tr>
<tr>
<td>W 624</td>
<td>P A B C D F G I P</td>
<td>6 9 6 9 6</td>
</tr>
</tbody>
</table>

This project was the first attempt to carry out milli-arcsecond level parallax observations with the HST and a number of unexpected obstacles arose. The most serious of these was that the low star density of the high galactic latitude fields limited the number of suitable guide stars and reference stars and severely constrained when observations could be made. Even with exceptional spacecraft roll, the August-epoch observations of R 50 could not be made at parallax factor maximum, nor could all reference stars be positioned in the FGS pickle. Overestimates of the brightnesses of some of the fainter stars and locations near the edge of the pickle for others at times caused the FGS to not acquire the star or to lose lock during the observation. Finally, the fifth epoch of observations for W 624 could not be obtained. These and other problems forced on-going modification of the observing program and a subsequent difficulty in the analysis. A cardinal rule of astrometry is have all observations made in a consistent manner.

3. DATA OBTAINED

Both parallax stars were successfully acquired and observed at all epochs. In the field of R 50, we attempted to observe the five reference stars labelled in Fig. 1. They range in V mag from star A at 12.57, slightly brighter than R 50, to star F at 18.0. Star A was often near the pickle edge and was not
Fig. 1. Finding chart for G 166-37 = R 50. LP 381-86 is indicated.

Fig. 2. Finding chart for G 16-25 = W 264.
acquired in all data sets. Off-nominal roll allowed it to be observed in some sets, but several observations were compromised by its nearness to the edge. Star L at \( V = 14.72 \) was acquired on nearly all attempts, however star B, at \( 16.38 \), was successfully acquired in only 60% of the attempts. The success ratio was small for the two stars fainter than 17, stars I and F, and they were eliminated in later epochs in favor of more observations of the brighter stars.

In the field of W 624 there were many more possible reference stars. However the brightest of these, Y, is 2.3 mag fainter than W 624 while three, A, B, and G, are fainter than \( V = 17.0 \). Again, there were difficulties in observing some reference stars, and the fainter ones were eliminated in the later sets in favor of more observations of the brighter stars.

The processing of the data was done with the University of Texas - Austin Astrometry Team packages. Relative positions in instrument coordinates that accounted for spacecraft jitter and roll, differential aberration, and optical field corrections were first calculated. The fitting program GaussFit (Jeffreys et al. 1988) was then used to combine the separate data sets and compute the parallax and proper motion of the program star.

4. RESULTS

In neither case is the parallax solution well constrained. This is caused by the poor distribution, small number, and variation between observation sets of the reference stars. Consequently, a number of independent solutions were made with different initial conditions. These included solutions where the proper motion of the program star was calculated and ones where the accepted value was adopted, where all reference star proper motions were fixed as zero and where they were computed under the assumption that their sum was zero in each coordinate, and where a reference star might also have a significant parallax.

The results for R 50 indicate a parallax of \( 4.0 \pm 0.7 \) mas. The derived proper motion was consistent with Cudworth's value. The reference stars have small, but statistically significant, proper motions but they have little effect on the parallax solution. The brightest reference star, A, was found to have a parallax of about 8 mas. This is consistent with the photometric distance from its BVR photometry. The parallax result for R 50 combined with its proper motion yields a space velocity of 467 km/s, slightly larger than the values derived by Cudworth (1990) and Carney et al. (1988). We know of no normal star having a confirmed rest-frame velocity higher than this. We note the interesting fact that R 50 has a common proper motion companion, LP 381-86,
about 4 mag fainter and 3.3 distant. The companion is identified in Fig. 1.

Our result for W 624 is inconclusive. The preliminary simultaneous solutions for parallax and proper motion produced a parallax of $0.2 \pm 0.9$ mas but with either a proper motion direction and magnitude significantly different from the previously well-determined motion or spacecraft roll angles several degrees from the nominal values. Adopting the previously accepted proper motion, the derived parallax was between 1.0 and 3.7 mas depending on the assumed spacecraft roll.

We conclude that the elimination of the final epoch of observations has produced a situation where our solutions forced any parallactic motion into other variables. Further analysis is needed, but the parallax of W 624 is less than 3.7 mas and probably about 3.0 mas. The space velocity of this star is almost entirely determined by its tangential velocity, and hence the distance.

5. LESSONS LEARNED ABOUT OBSERVING WITH THE FGS

A number of things were learned during the course of this project about POS-mode observing with the FGS system. We found that the rms error of a relative position from a single "good" observation is about $\pm 3$ mas in each coordinate for stars brighter than $V = 16$. However, obtaining a good observation requires taking a number of precautions.

First, one needs a suitable reference frame. At least four well-distributed reference stars observable at all epochs and compatible with two guide stars are necessary. The unusual pickle shape of the observable field and its changing orientation can make this requirement a challenge, particularly for fields away from the galactic plane. Ideally, a reference star should be within 2' of the program star, but in any case must not be located near the pickle edge, where the field calibration is poorly known and the edge can interfere with the measuring arm. The telescope scheduling software permits the field to be displayed for different dates and spacecraft rolls and these must be carefully reviewed in preparing the observing program.

Second, one must know the magnitudes of the targets to about 0.1 mag so that the observing software sets the exposure times correctly. Fortunately, the FGS astrometry system is photomultiplier based which makes the FGS an excellent photometer. We obtained ground-based BVR photometry of our fields, and this has been used to derive an approximate calibration of the FGS3 instrumental system. We found $V$ magnitudes could be computed to a few
hundredths of a magnitude by

\[ V = 19.98 - 2.5 \log (CNT - 11.2) \]

where CNT is the sum of the average counts per second from the four photomultipliers. Fig. 3 shows the difference between the ground-based measures and those derived from the FGS photomultiplier counts as a function of brightness. Open circles indicate the ground-based magnitudes had errors > 0.1 mag. This calibration is adequate to \( V = 17 \), and can be used to adjust the exposure times after the initial set of data is obtained.

Finally, one needs to examine the raw data critically. The FGS will occasionally have locked on the target late, lost the lock during observation, or had a false lock even though the data transmission flags indicated a valid data stream. Erroneous measures must, of course, be removed before data processing. One's reduction code must be able to compensate for the occasional jitters and wobbles in the spacecraft and for changes in the scale and roll of the system. At the mas level, even small effects are significant.

![Fig. 3. Difference between the ground-based and FGS-determined V mags.](image-url)
6. CONCLUSIONS

In summary, we confirm that the Hubble Space Telescope FGS system is an excellent astrometric instrument capable of determining relative positions from a single observation with a precision of 3 mas. We have utilized such observations to observe two stars of large space velocity. We deduce a parallax for R 50 of 4.0 mas, implying a space velocity in the galactocentric rest frame of 467 km. The parallax for W 624 is probably about 3.0 mas.

ACKNOWLEDGMENTS

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REFERENCES