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HST IMAGES DO NOT SUPPORT THE PRESENCE OF THREE HIGH-VELOCITY, LOW-MASS RUNAWAY STARS IN THE CORE OF THE ORION NEBULA CLUSTER[1]

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ABSTRACT

A recent article has employed the determination from ground-based images of high proper motions in the Orion Nebula cluster to argue that JW 349, JW 355, and JW 451 are high-velocity (38, 89, and 69 km s^{-1}, respectively) low-mass runaway stars. We report on the measurement of the proper motions of these stars using images made by the *Hubble Space Telescope*'s WFPC2 imager and find that there is no evidence of motions above 6.2 km s^{-1} for JW 349 or above 7.9 km s^{-1} for JW 355, while the motion of 5.5 km s^{-1} for JW 451 is only slightly larger than the measurement uncertainty of 3.9 km s^{-1}. We conclude that there is no observational support for these stars being high-velocity runaway stars.

Subject headings: astrometry — stars: kinematics — stars: pre–main-sequence

1. INTRODUCTION

A recent study of proper motions of stars near the center of the Orion Nebula cluster (ONC, sometimes referred to as the Trapezium cluster) revealed the fact that three low-mass stars appear to be moving at high tangential velocities (Poveda et al. 2005). These high velocities naturally raise the possibility that these are runaway stars that have obtained their velocities through a dynamic process involving close young stars (Poveda et al. 1967). Recent studies have firmly established (Rodríguez et al. 2005; Gómez et al. 2005) the presence of high-velocity objects in the BN/KL grouping of infrared stars that is embedded northwest from the center of the ONC but have successfully disputed the arguments for these objects presented by Tan (2004).

The Poveda study (Poveda et al. 2005, hereafter PAH-A) used the results of the photographic astrometry of Jones & Walker (1988, hereafter JW). JW used 47 images made at the prime focus of the Lick Observatory Shane 3 m reflector over the intervals 1960.1–1961.9 and 1981.8–1983.0. Because of the high Galactic latitude of the cluster ($b \simeq -20°$) and the fact that it is located on the near side of a molecular cloud that is optically thick even at the near-infrared wavelengths (103a-U or I-N emulsions) used for the imaging, there are relatively few field stars contaminating the sample, and most of the stars lie within a proper-motion vector of 0.″2 per century. Stars with motions lying far outside of this value were classified as field stars, rather than cluster members. It was only appropriate that PAH-A would reassess the astrometric results with the intention of seeing if any of the high proper motion stars were actually cluster members with high spatial velocities. They identified three candidate stars (JW 349, JW 355, and JW 451) as being runaways. These objects not only have large proper motions in JW but must be members of the ONC because the presence of associated ionized gas indicates that they are proplyds, ionized by the O6 star Θ^1 Ori C in the Trapezium cluster (O'Dell & Wen 1994).

The importance of this result, i.e., that there are objects in the ONC identified as runaway stars, is such that it seemed appropriate to examine the observational arguments for this conclusion. Fortunately, the Wide Field Planetary Camera 2 (WFPC2; Holtzman et al. 1995) on the *Hubble Space Telescope* (*HST*) has been used frequently for imaging the ONC since soon after its installation in 1993 December, so that the time base of observations for astrometry can be about 10 years. This is only about half of the time base for the JW observations, but the resolution of the WFPC2 images is more than 10 times better than that of the Shane telescope without compensation for seeing. Not only does the better resolution allow us a more accurate determination of the position of the ONC, but it also allows us to avoid confusing it with other objects in the vicinity, such as structure in the nebula. This means that the WFPC2 observations potentially offer us valuable information that allows us to test the reliability of the reported high proper motion stars.

2. OBSERVATIONS

In this study, we draw upon two sets of observations, the first clustered soon after installation of the WFPC2 and the second being quite recent, giving us the widest possible time base for comparison of first- and second-epoch images. Three early image sets were made under programs GO 5085 (PI: C. R. O'Dell), GO 5193 (an Early Release Observations program), and GO 5469 (PI: J. Bally). Two recent programs have reimaged the same areas near the Trapezium cluster (GO 9141, PI: C. R. O'Dell; GO 10246, PI: M. Robberto).

2.1. *First-Epoch Observations*

The first-epoch field for JW 349 was taken from the GO 5085 (pointing 5; O'Dell & Wong 1996) F656N image in CCD2. This was composed from two 200 s images combined

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[1] Based in part on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

to produce a good cosmic-ray event correction. They were made on 1995 January 19. The first-epoch field for JW 355 was taken from the GO 5469 (LV3 pointing; O'Dell & Wong 1996) F547M image in CCD2. This was composed from three 30 s images combined to produce a good cosmic-ray event correction. They were made on 1995 March 21. The first-epoch field for JW 451 was taken from the GO 5193 F547M image in CCD4. This was composed from two 100 s images combined to produce a good cosmic-ray event correction. They were made on 1993 December 29.

2.2. *Second-Epoch Observations*

The second-epoch observations used in our analysis were drawn from two recent programs. Program GO 9141 (O'Dell et al. 2003) imaged a single field centered southwest of the Trapezium cluster. The much larger program GO 10246 (Robberto et al. 2004) has recently imaged over 100 fields that cover the entire inner region of the Orion Nebula cluster with both the WFPC2 and the Advanced Camera for Surveys and partially cover this same field with the Near-Infrared Camera and Multi-Object Spectrometer. The second-epoch field for JW 349 was the WFPC2 F656N image in CCD4 of program GO 9141, this image having been made at the same pointing with a pair of 140 s exposures on 2002 January 22. The second-epoch field for JW 355 used the WFPC2 F336W, F439W, and F814W images in CCD3 of program GO 10246 (position 38), combined to produce a good cosmic-ray event correction and increase the signal as the exposures were 400 (twice), 80, and 10 s, respectively. These were made on 2005 April 10. The same field was used for the second-epoch image of JW 451, except that it was selected from CCD2.

3. DETERMINATION OF PROPER MOTIONS OF THE THREE TARGETED STARS

The WFPC2 images are quite stable within a single CCD detector, but the relative positions of the CCDs on the plane of the sky drift with time. This means that one cannot use the entire mosaic for the alignment of the first- and second-epoch images. We have therefore adopted a procedure used previously for the measurement of shocks and jets (Bally et al. 2000; Doi et al. 2002). The individual CCD images were cosmic-ray–cleaned when possible using STSDAS tasks, which are packaged within IRAF.[2] These were then combined using the STSDAS task `wmosaic`, which applies a field distortion correction to each CCD image before combining them. Overlapping fields (each lying within a single CCD) were identified in both the first- and second-epoch images that contained both the star of suspected high velocity and a surrounding set of other cluster stars. In each case, there were five nearby reference stars. These cluster stars were used with IRAF task `geomap` to find the relative orientation of the two images on the plane of the sky, and then the two were coaligned using the task `geotran`, moving the first-epoch image into alignment with the later image. The `geomap` task gives the 1 σ values of the accuracy of the relative position of the reference stars, which we use as the source of the uncertainty values of our final measurements since the uncertainty of measuring the position of the target stars was significantly smaller than these values. In all cases, the positions were determined using the IRAF task `imcntr`. The position of the target star was then compared on the two images, and from the difference in position the velocity in the plane of the sky was calculated. For this calculation we assumed, as did PAH-A, that the distance to the cluster is 470 pc. All of the images were in the low-resolution portion of the WFPC2, which means that motion across 1 pixel ($0''.0996$) in 1 year would correspond to an angular motion of $9''.96$ per century or 222 km s^{-1} in the plane of the sky.

Since the reference stars have proper motions comparable to the JW average for the ONC, the motions we derive will be relative to the cluster as a whole. Gómez et al. (2005) find from radio astrometry that the spatial motion of the cluster is 5.4 ± 0.6 km s^{-1} toward the south-southeast and that absolute motions for our stars would have to be corrected for this small value of the cluster motion.

3.1. *JW 349*

In the case of JW 349, the vector sum of the errors along the two axes from the `geomap` fit was 0.20 pixels, and the measured difference of position of the star was 0.17 pixels in the direction of the position angle (P.A. = 223°). This means that the formal value of the motion is less than the probable error of measurement. The difference of epoch of the observations was 7.01 yr, so that we can conclude that the motion of JW 349 is no more than $0''.28$ per century or 6.3 km s^{-1}.

3.2. *JW 355*

The vector sum of the errors of the `geomap` fit for JW 355 reference stars was 0.36 pixels, and the measured difference of the star's position was 0.16 pixels toward P.A. = 190°. The difference of time in the observations was 10.06 yr, so that we conclude that the motion of JW 355 is no more than $0''.36$ per century or 7.9 km s^{-1}.

3.3. *JW 451*

The vector sum of the errors along the two axes of the fit was 0.20 pixels, and the measured difference of the star's position was 0.28 pixels toward P.A. = 233°. Since the difference in time of the observations was 11.28 yr, this means that the measured motion was only slightly greater than the errors in its determination (3.9 km s^{-1}) and corresponds to $0''.25$ per century or 5.5 km s^{-1}.

4. SUMMARY AND CONCLUSIONS

The motions given in § 3 are in marked contrast to those reported in JW. That publication gave vector motions of $1''.72$ per century (38 km s^{-1}) for JW 349, $4''.01$ per century (89 km s^{-1}) for JW 355, and $3''.08$ per century (69 km s^{-1}) for JW 451. The probable errors given in JW for these three stars are much larger than almost all the stars in their study, with vector-summed errors of $0''.38$ per century, $0''.41$ per century, and $1''.71$ per century, respectively. The differences between this *HST* study and JW are large and outside the assigned errors of both studies.

The cause of these differences is unknown; however, the background nebular emission is bright in the region of each, and the lower angular resolution of the ground-based material could have made it difficult to measure the stars' positions. The reason may be that the three stars are all bright proplyds; i.e., each has an extended ionized region surrounding it, thus making them more difficult to measure at ground-based resolution. We note that 65 similar proplyds in the JW study have

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[2] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science foundation.

a vector uncertainty of 0″.83 per century, whereas the 648 JW stars that are not known proplyds and that have a probability of membership in the cluster of more than 90% also have a vector uncertainty of only 0″.16 per century. This summary of results from the JW study indicates that, systematically, there is a larger uncertainty of the position of the proplyds, and this may contribute to the large errors in the three stars of this study.

Another way of addressing the situation is to predict the changes on the *HST* images from the ground-based–determined values. In this case, the expected motions would have been 1.2 pixels (JW 349), 4.3 pixels (JW 355), and 3.5 pixels (JW 451). Motions of the size of the latter two predicted shifts would have been easily visible when comparing the first- and second-epoch WFPC2 images, and the value of 1.2 pixels predicted for JW 349 is much larger than the uncertainties in the *HST* measurement (0.2 pixels). On the basis of the quality of the WFPC2 images, we conclude that there is no evidence that any of these three stars have a high velocity in the plane of the sky.

Therefore, we are forced to conclude that the discussion of the status of JW 349, JW 355, and JW 455 as low-mass runaway stars as presented in PAH-A is not valid, since the observations upon which they are founded are not supported by our new *HST* results.

Gómez et al. (2005) find large motions for two of their radio sources near the ONC center. Source 7 (GMR 14 [Garay et al. 1987], proplyd 155-338 [O'Dell & Wong 1996]) and source 14 (Zappata 46 [Zappata et al. 2004], JW 503, and proplyd 160-353 [O'Dell & Wong 1996]) have values of 16.5 ± 2.4 and 23.0 ± 4.9 km s^{-1}, respectively. They question the former's high velocity on the basis that it could be due to changes in the structure of this extended source, and they question the latter's velocity because of possible confusion with the signal from a nearby separate source. This leaves evidence of high-velocity motion for only the sources near the BN/KL region.

Although this study disputes the measurements for the three optical candidate runaway stars, a search for others using the WFPC2 would be worthwhile. This would require duplicating the pointing of the first-epoch images, so that good astrometry could be performed over entire CCD fields, rather than the fractional fields employed in this investigation.

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Facilities: HST(WFPC2)

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