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THE PARALLAX OF VHS J1256–1257 FROM CFHT AND PAN-STARRS 1

Trent J. Dupuy,¹ Michael C. Liu,² Eugene A. Magnier,² William M. J. Best,³ Isabelle Baraffe,^{4,5} Gilles Chabrier,^{5,4} Thierry Forveille,⁶ Stanimir A. Metchev,⁷ and Pascal Tremblin⁸¹*Gemini Observatory, Northern Operations Center, 670 N. A’ohoku Place, Hilo, HI 96720, USA*²*Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA*³*The University of Texas at Austin, Department of Astronomy, 2515 Speedway C1400, Austin, TX 78712, USA*⁴*University of Exeter, Physics and Astronomy, EX4 4QL Exeter, UK*⁵*École Normale Supérieure, Lyon, CRAL (UMR CNRS 5574), Université de Lyon, France*⁶*Université Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France*⁷*The University of Western Ontario, Department of Physics and Astronomy, 1151 Richmond Avenue, London, ON N6A 3K7, Canada*⁸*Maison de la Simulation, CEA, CNRS, Univ. Paris-Sud, UVSQ, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France**Keywords:* astrometry — brown dwarfs — stars: individual (VHS J1256–1257b)

VHS J125601.92–125723.9 (VHS J1256–1257) comprises a nearly equal-flux 0′.12 binary (“AB”) and 8′.1 companion (“b”), with spectral types of $M7.5 \pm 0.5$ INT-G (combined-light) and $L7.0 \pm 1.5$ VL-G, respectively (Gauza et al. 2015; Stone et al. 2016; Rich et al. 2016). The Gauza et al. (2015) parallactic distance of 12.7 ± 1.0 pc indicates the companion is unusually faint relative to known young objects and may be planetary mass ($11_{-2}^{+10} M_{\text{Jup}}$), but Stone et al. (2016) infer a spectrophotometric distance of 17.2 ± 2.6 pc for the binary host and a companion mass of up to $35 M_{\text{Jup}}$. Gaia DR2 reports combined-light photometry for VHS J1256–1257AB but no parallax or proper motion and does not detect the companion.

We monitored the companion VHS J1256–1257b with the Canada-France-Hawaii Telescope (CFHT) from 2016–2019. Using 20-s exposures in the *J* band, we achieved $S/N = 30 - 50$ on the target in individual frames, from which we measured the (*x*, *y*) positions of it and 244 reference stars. (The primary VHS J1256–1257AB was saturated in our data, but it did not impact our measurements.) Using our custom pipeline (Dupuy & Liu 2012; Dupuy et al. 2015), we reduced these individual measurements into high-precision multi-epoch relative astrometry, with the absolute calibration provided by 35 low-proper-motion 2MASS stars (Cutri et al. 2003). We derived the relative parallax and proper motion for VHS J1256–1257b using our standard MCMC approach and then converted to an absolute reference frame using the Besançon galaxy model to simulate the distances of the reference stars (Robin et al. 2003). Our eight epochs of astrometry spanning 3.16 years yield a parallax of 45.0 ± 2.4 mas and proper motion of $(-286.1 \pm 1.3, -189.3 \pm 1.6)$ mas yr⁻¹, with reduced $\chi^2 = 1.15$ with 11 degrees of freedom (dof).

The central binary VHS J1256–1257AB was observed by the Pan-STARRS 1 (PS1) telescope from 2009–2013, largely as part of the Pan-STARRS 3π Steradian Survey (Chambers et al. 2016), with 9, 10, 16, 12, and 15 epochs in the $g_{P1}r_{P1}i_{P1}z_{P1}y_{P1}$ filters, respectively. The 3π Survey was well-suited to parallaxes as every survey region was observed at opposition as well as evening and morning twilight. Astrometric calibration and automated calculation of parallaxes and proper motions are described by Magnier et al. (2016). The resulting astrometry is tied to the Gaia DR1 inertial system, with a correction for the proper motion bias introduced by Galactic rotation and solar motion. We re-analyzed VHS J1256–1257AB, adding one 2MASS and six PS1 epochs excluded from the automated analysis. The resulting astrometric solution is consistent with the automatic analysis, with slightly smaller errorbars. We used 53 likely quasars from Hernitschek et al. (2016) within 1° of VHS J1256–1257 to conclude that absolute corrections to the PS1 parallax and proper motions are negligible (mean quasar parallax of 0.3 ± 3.5 mas and proper motions of $(0.1 \pm 1.4, 2.2 \pm 0.6)$ mas yr⁻¹). Our final PS1 results give a parallax of 51.6 ± 3.0 mas and proper motion of $(-272.0 \pm 1.7, -194.9 \pm 2.1)$ mas yr⁻¹, with reduced $\chi^2 = 2.0$ (125 dof). We conducted the same analysis without the

Corresponding author: Trent J. Dupuy

tdupuy@gemini.edu

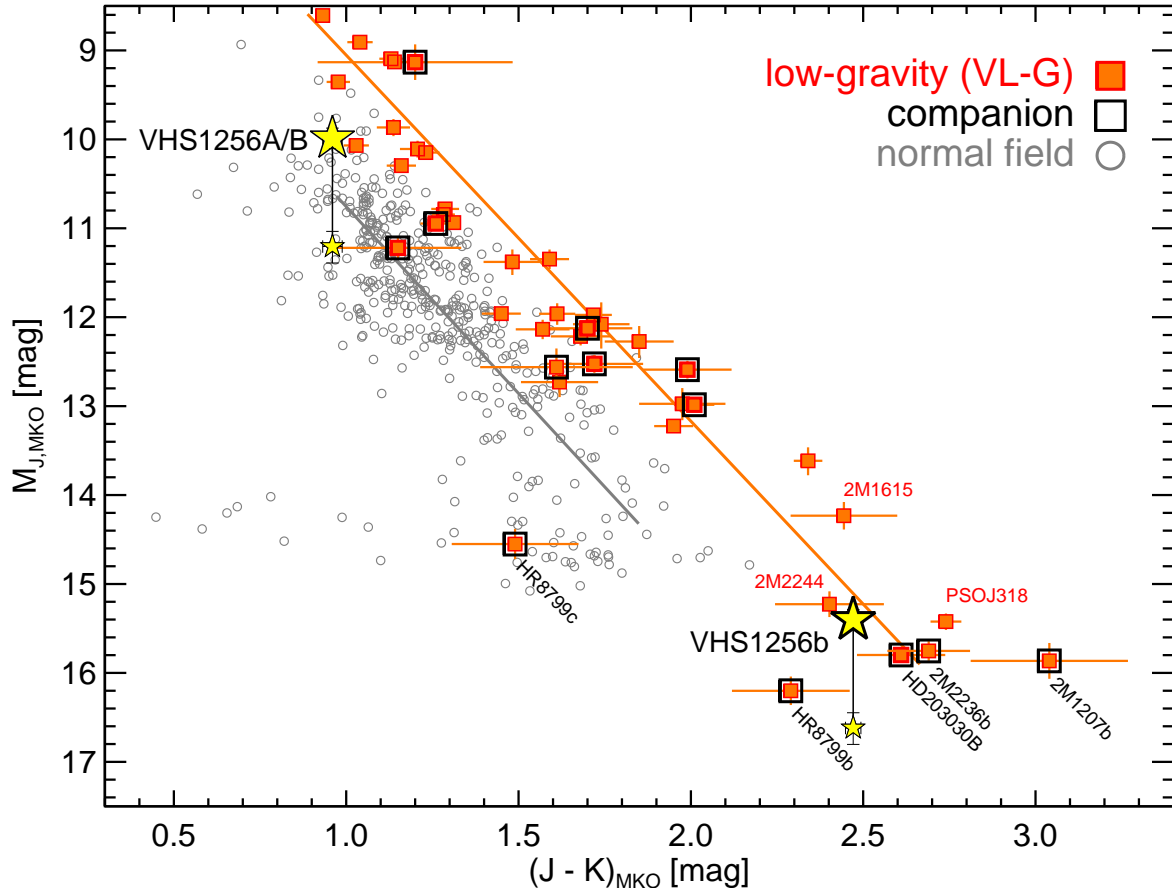


Figure 1. Color–magnitude diagram (CMD) showing the old (small yellow stars) and new locations (large yellow stars) of the VHS J1256–1257 components. (Deblended photometry is plotted for the equal-flux AB pair.) The system is now more consistent with the locus of low-gravity objects. Data for field and young objects come largely from *Gaia* DR2, Best et al. (in press), and Liu et al. (2016). (Also note that the first directly imaged planet 2MASS J1207–39b (Chauvin et al. 2004) appears brighter here than in previous plots in the literature because of its new DR2 parallax.)

g_{P1} data, which in principle could be most affected by photometric variability of the binary components, and found consistent results and uncertainties.

Our parallaxes from CFHT and PS1 are consistent, and we adopt the higher-precision CFHT parallax. The two proper motions are inconsistent, especially in Right Ascension, which is plausibly due to VHS J1256–1257b’s orbital motion being incorporated into the CFHT data. We therefore adopt the PS1 proper motion, which also has the benefit of its reference frame being defined by quasars.

Our parallaxes make all three components consistent with known low-gravity (young) objects (Figure 1). Likewise, the infrared absolute magnitudes are in accord with young objects of the same spectral types from Liu et al. (2016).

The system’s new UVW space motion and XYZ location, from our astrometry and the Gauza et al. (2015) radial velocity, continues to indicate that the system is not a member of known young moving groups, based on comparison with the Torres et al. (2008) groups and analysis with the BANYAN Σ webpage (Gagné et al. 2018).

We calculated component luminosities of $\log(L_{\text{bol}}/L_{\odot}) = -2.94 \pm 0.07$, -2.95 ± 0.07 , and -4.54 ± 0.07 dex using photometry and spectral types from Gauza et al. (2015), our CFHT parallax, and the BC_{K_S} –SpT relation for young objects (Filippazzo et al. 2015). For VHS J1256–1257AB, we derived properties from Baraffe et al. (2015) evolutionary models via rejection sampling following Dupuy et al. (2018), assuming a linear-uniform prior in age, a log-uniform prior in mass, and a conservative lithium depletion limit of $>99.9\%$, consistent with the Li I non-detection from Gauza et al. (2015). Assuming a maximum age of 300 Myr, as in previous work, the resulting masses were each $94^{+10}_{-11} M_{\text{Jup}}$. The

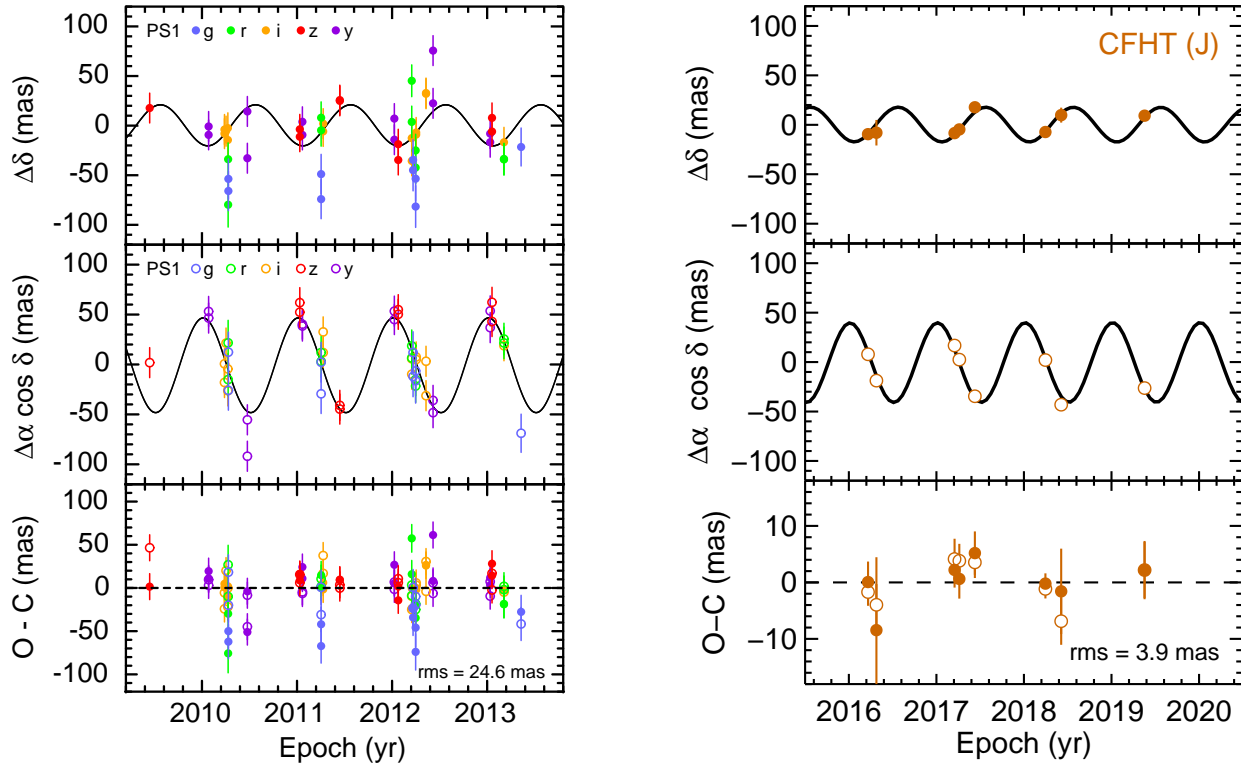


Figure 2. Relative astrometry of the inner binary VHS J1256–1257AB in integrated light from PS1 (left) and of the wide companion VHS J1256–1257b from CFHT/WIRCcam (right). In the top two panels of each plot, the best-fit proper motions have been subtracted, and the best-fit parallax solution is plotted as a solid black line. The bottom panel of each plot shows the residuals about the best-fit solution.

resulting age posterior had a 2σ lower limit of 150 Myr but otherwise mirrored our input prior. We used this output posterior as the input prior to estimate the properties of VHS J1256–1257b from the [Saumon & Marley \(2008\)](#) hybrid evolutionary models, finding a mass of $19 \pm 5 M_{\text{Jup}}$, $T_{\text{eff}} = 1240 \pm 50 \text{ K}$, and $\log(g) = 4.55^{+0.15}_{-0.11} \text{ dex}$, all substantially higher than previous estimates. (For comparison, using the parallax from [Gauza et al. \(2015\)](#) with our approach yields VHS J1256–1257AB masses of $70^{+2}_{-3} M_{\text{Jup}}$, a much narrower age posterior of 255–300 Myr (2σ), and companion properties of $14.9^{+1.7}_{-1.4} M_{\text{Jup}}$, $T_{\text{eff}} = 960 \pm 30 \text{ K}$, and $\log(g) = 4.47^{+0.07}_{-0.05} \text{ dex}$.)

In summary, our new parallax places VHS J1256–1257 at $22.2^{+1.1}_{-1.2} \text{ pc}$, raising the mass, temperature, and surface gravity estimates for the wide companion and moving the CMD position of the system’s components into better agreement with previously known objects.

Facilities: CFHT (WIRCAM), PS1 (GPC)

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