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# Backyard Worlds: Cool Neighbors—Post-launch Performance and a First Proper Motion Discovery

Grady Robbins,[1,2] Aaron M. Meisner,[2] Austin Humphreys,[3,2] Eden Schapera,[4,2] Dan Caselden,[5] J. Davy Kirkpatrick,[6] Adam C. Schneider,[7] Svetoslav Alexandrov,[8] Thomas P. Bickle,[8,9] Martin Kabatnik,[8] Jörg Schümann,[8] Cledison Marcos da Silva,[8] Christopher Tanner,[8] L. Clifton Johnson,[10,11] Marc J. Kuchner,[12] Jacqueline K. Faherty,[5] S. L. Casewell,[13] Federico Marocco,[6] Adam J. Burgasser,[14] The Backyard Worlds: Planet 9 Collaboration, and The Backyard Worlds: Cool Neighbors Collaboration

[1] *Department of Astronomy, University of Florida, Gainesville, Florida, USA;* `gradyrobbins1115@gmail.com`

[2] *NSF National Optical-Infrared Astronomy Research Laboratory, Tucson, Arizona, USA;* `aaron.meisner@noirlab.edu`

[3] *Department of Astronomy, University of Maryland, College Park, Maryland, USA*

[4] *Department of Physics, Emory University, Atlanta, Georgia, USA*

[5] *Department of Astrophysics, American Museum of Natural History, New York, USA*

[6] *IPAC, California Institute of Technology, Pasadena, California, USA*

[7] *United States Naval Observatory, Flagstaff Station, Flagstaff, Arizona, USA*

[8] *Backyard Worlds: Cool Neighbors*

[9] *School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK*

[10] *Adler Planetarium, Chicago, Illinois, USA*

[11] *Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) and Department of Physics and Astronomy, Northwestern University, Evanston, Illinois, USA*

[12] *Exoplanets and Stellar Astrophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA*

[13] *School of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK*

[14] *Department of Astronomy & Astrophysics, University of California San Diego, La Jolla, California, USA*

**Abstract.**

Backyard Worlds: Cool Neighbors launched via the Zooniverse online crowdsourcing platform in June 2023, pursuing ultracool dwarf discoveries through citizen science. Since the project's launch, tens of thousands of ultracool dwarf candidates have been reviewed by Cool Neighbors volunteers to visually confirm (or refute) their status as high proper motion objects. We present a summary of the Cool Neighbors launch and highlight CWISE J133605.65+505330.9 as a first moving object discovery from the Cool Neighbors project. Based on photometry available for CWISE J133605.65+505330.9, we estimate it to be an early L or late M dwarf with polynomial relations yielding a photometric type of L1.2 ± 0.7 and a distance estimate of 127 ± 6 pc. The Backyard Worlds: Cool Neighbors project will continue to review ultracool dwarf candidates through crowd-sourcing during future years of operation.

## 1. Introduction

Backyard Worlds: Cool Neighbors (hereafter referred to as Cool Neighbors) is a NASA partner Zooniverse (Simpson et al. 2014) crowdsourcing project dedicated to the discovery of nearby ultracool dwarfs through the combination of machine learning and citizen science (Humphreys et al. 2020). Ultracool dwarfs are stellar and substellar objects that have $T_{\rm eff} < 2,700$ K, while brown dwarfs are the subset of ultracool dwarfs that are insufficiently massive to fuse hydrogen into helium (Kirkpatrick 1998). Brown dwarfs are celestial objects, often solitary, with masses lower than those of the smallest stars ($\sim 80\,M_{♃}$; e.g., Reid & Hawley 2000) and extending into the "planetary-mass" regime ($\lesssim 13\,M_{♃}$; e.g., Luhman et al. 2024).

Because brown dwarfs have masses lower than stars, they are only able to fuse deuterium (for $M \gtrsim 13\ M_{♃}$) and not protium. As a result, they glow faintly and emit light mostly in the infrared. This makes brown dwarfs difficult to observe, especially at optical wavelengths. Thanks to modern data sets like that of the Wide-Field Infrared Survey Explorer (WISE; Wright et al. 2010), brown dwarfs can be discovered through sensitive, wide-area infrared imaging. WISE has surveyed the entire sky over the course of more than a decade, representing an excellent opportunity to mine a vast time-domain data set for ultracool dwarf discoveries. Cool Neighbors leverages this discovery potential by creating an opportunity for citizen scientists to sift through WISE data and thereby discover new ultracool dwarfs.

Cool Neighbors stems from its sibling project Backyard Worlds: Planet 9 (Kuchner et al. 2017), which launched in 2017 and aims to find moving objects, including the hypothetical "Planet 9" in our solar system (Trujillo & Sheppard 2014; Batygin & Brown 2016; Sheppard & Trujillo 2016; Brown & Batygin 2021). The primary difference between Backyard Worlds: Planet 9 and Cool Neighbors is that Cool Neighbors employs a machine learning pre-selection step to more efficiently discover candidate ultracool dwarfs; for comparison, Backyard Worlds: Planet 9 only shows randomly selected sky locations. Both Cool Neighbors and Backyard Worlds: Planet 9 use motion as a proxy for nearness—objects in our own solar system or ultracool dwarfs in the solar neighborhood will appear to move across the sky rapidly compared to much more distant stars and galaxies. Unlike Backyard Worlds: Planet 9, Cool Neighbors does not render its "flipbooks" (time series movies shown to volunteer participants) using difference imaging. Cool Neighbors uses the SMDET machine learning methodology (Caselden et al. 2020) to analyze the entire sky in an automated fashion, returning a list of potentially promising moving objects for citizen scientists to further scrutinize. This alternative data visualization approach is more appropriate than difference imaging for detecting ultracool dwarfs, which appear to move across the sky far slower than objects in our own solar system.

Section 2 describes the Cool Neighbors beta test, initial launch “subjects” (ultracool dwarf candidates), and project logistics. The results of the completed crowdsourcing campaign for the initial batch of Cool Neighbors candidates are discussed in Section 3. CWISE J133605.65+505330.9, a first example of Cool Neighbors discovering a moving object, is presented in Section 4; its spectral type and distance are photometrically estimated.

## 2. Cool Neighbors Launch

Cool Neighbors was officially launched on 27 June 2023, after a successful “beta test” trial run (Humphreys et al. 2020). During the beta test, volunteers visually inspected flipbooks and answered ‘yes’ or ‘no’ to the question “Is there a mover that passes near the center of this frame?” where “mover” means a celestial moving object. Beta testers analyzed 175 potential ultracool dwarfs selected by the SMDET machine learning algorithm and 30 known brown dwarfs included as true positives. Thirty-five quasars and 35 random sky location flipbooks were also included as false positives to further assess the accuracy of participants’ classifications. Within our complete beta test data set, we found that about 70% of the beta testers successfully identified the known brown dwarfs, and 94% of the beta testers correctly classified subjects known to not be ultracool dwarfs as not moving.

Based on the Cool Neighbors beta test, we chose a “retirement limit” of 20 classifications, which means that each candidate must be classified by citizen scientists a total of 20 times before being marked “complete” by Zooniverse. This retirement limit balances the need to provide a sufficient sample of independent volunteer classifications with our desire for large numbers (tens of thousands) of candidates to reach fully classified status in a reasonable amount of time. Comments and feedback from users during the beta test were addressed prior to official Cool Neighbors launch, improving our flipbook presentation and Zooniverse training materials.

For the collection of known brown dwarf samples in the beta test, we found that all were successfully classified as “movers” using the criterion that at least 20% of the beta testers marked them as moving objects, which also resulted in no false positives among the quasar and random sky location samples. As a result, we adopted a minimum of 20% “moving” classifications for a subject to be considered a strong ultracool dwarf candidate for further review (see Section 3).

Cool Neighbors was initially launched with a batch of 27,800 total flipbooks (subjects) for citizen scientists to classify. Among those launch subjects, 1,000 were known quasars, 1,000 were known white dwarfs, 1,000 were random sky locations, and 866 were known brown dwarfs (see Table 1). We used these truth samples to characterize the accuracy of Cool Neighbors volunteers in performing the classification task. Our retirement limit of 20 classifications per subject meant that a total of 556,000 classifications were needed to complete the initial launch subject set.

Table 1. Breakdown of the ultracool dwarf candidates and truth samples shown to citizen scientists by Backyard Worlds: Cool Neighbors at the time of launch in June 2023.

| Object Type | Number of Launch Subjects |
|---|---:|
| Ultracool Dwarf Candidate | 23,934 |
| Known Brown Dwarf | 866 |
| Quasar | 1,000 |
| White Dwarf | 1,000 |
| Random Sky Location | 1,000 |
| Total | 27,800 |

## 3. Post-launch Results and Statistics

Six weeks after the launch of Cool Neighbors, all 27,800 launch subjects were completely classified by citizen scientists, who performed an average of ∼13,500 classifications per day during this time period. In the six months immediately following the launch of Cool Neighbors, the daily rate of classifications gradually decreased to 5,000, as shown in Figure 1.

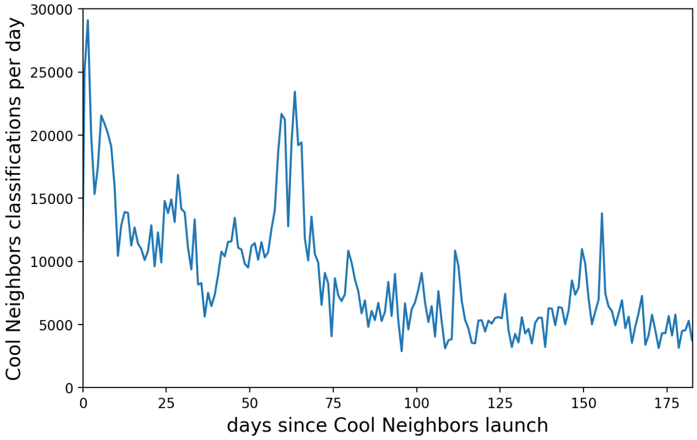

Figure 1. Number of Cool Neighbors classifications performed per day by citizen scientists during the first six months after launch.

We filtered the first 27,800 fully classified subjects to only retain potential movers–candidates rated as moving by ≥ 20% of respondents—and found that 3,343 subjects satisfied this criterion (this tally includes both known moving objects and SMDET candidates). To account for previously discovered objects, we used the astroquery.gaia package (Ginsburg et al. 2019) to perform a Gaia (Gaia Collaboration et al. 2016, 2023) cone search at each subject's central RA and Dec coordinates. With a cone search radius of 15″, we found that 2,401 of 3,343 subjects contained a previously known Gaia source, which means that 942 subjects were not previously cataloged in Gaia. Note that if there was a background Gaia object within 15″ of an undiscovered mover, the cone search would have returned a Gaia source, therefore causing our analysis to miss a potential new moving object discovery; the large Gaia rejection radius chosen emphasizes reliability over completeness.

In addition to the Gaia cone search performed in the vicinity of each candidate moving object, we performed a SIMBAD (Wenger et al. 2000) cone search at each such location using the astroquery.simbad package (Ginsburg et al. 2019) to remove previously known movers. With a cone search radius of 15″, we found that 340 of the remaining 942 subjects had a SIMBAD source within 15″, leaving 602 high-priority potential moving object discoveries from the Cool Neighbors launch subject set.

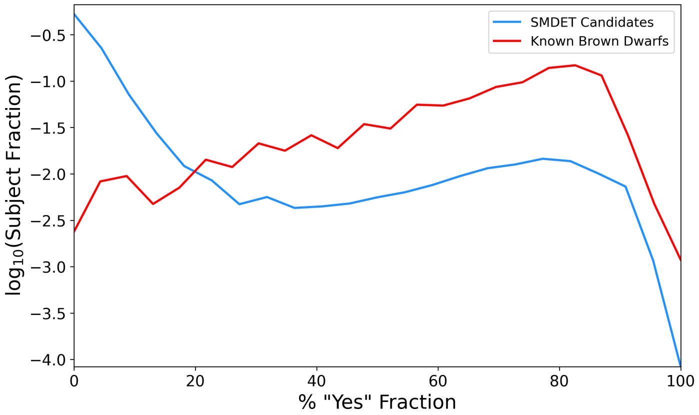

Figure 2. Distribution of “yes”/ total vote fraction per subject for the known brown dwarfs (red) and SMDET candidates (blue) within Cool Neighbors’ launch set of 27,800 subjects.

Figure 2 shows the fraction of subjects binned by the percentage of volunteers who voted “yes” that the corresponding candidate is moving. We see similarly placed peaks for the SMDET ultracool dwarf candidates (blue) and known brown dwarfs (red), near ∼80% “yes” vote fraction, which may represent a locus of relatively high probability true positives among SMDET candidates. Although all known brown dwarfs in the Cool Neighbors beta test were correctly classified as movers (using a minimum “yes” vote fraction of 20%), three percent of the known brown dwarfs were incorrectly classified in the launch subject set. This discrepancy may have resulted from selection effects, as the pool of beta testers differs from the broader set of participants who contributed classifications of the launch subject set.

## 4. First Proper Motion Discovery

One first example of a new moving object discovered through the Cool Neighbors project is CWISE J133605.65+505330.9, hereafter W1336+5053. W1336+5053 is not detected by Gaia and was successfully identified as a previously undiscovered moving object by participants Svetoslav Alexandrov, Cledison Marcos da Silva, Martin Kabatnik, Jörg Schümann, and Christopher Tanner. Thirty-seven percent of participants labeled W1336+5053 as moving, 17% above our minimum requirement. WISE images that illustrate W1336+5053’s motion are shown in Figure 3.

Table 2. CWISE J133605.65+505330.9 Properties and Photometry

Properties

| Parameter | Value |
|---|---|
| RA (deg) | 204.023575 |
| DEC (deg) | 50.8918721 |
| UHS DR2 $\mu_\alpha$ (mas yr$^{-1}$) | $-220.28 \pm 5.42$ |
| UHS DR2 $\mu_\delta$ (mas yr$^{-1}$) | $49.70 \pm 5.26$ |
| UHS DR2 $\mu_{\rm tot}$ (mas yr$^{-1}$) | $225.82 \pm 5.41$ |
| $v_{\rm tan}$ (km s$^{-1}$) | $135.92 \pm 7.24$ |

Photometry

| Parameter | Magnitude[a] |
|---|---|
| UHS DR2 $J_{\rm MKO}$ | $17.336 \pm 0.030$ |
| UHS DR2 $Ks$ | $16.227 \pm 0.048$ |
| Pan-STARRS $i$ | $21.578 \pm 0.247$ |
| Pan-STARRS $y$ | $19.221 \pm 0.034$ |
| Pan-STARRS $z$ | $20.290 \pm 0.032$ |
| CatWISE2020 $W1$ | $15.859 \pm 0.021$ |
| CatWISE2020 $W2$ | $15.640 \pm 0.037$ |
| AllWISE $W1$ | $15.910 \pm 0.045$ |
| AllWISE $W2$ | $15.603 \pm 0.093$ |
| AllWISE $W3$ | $> 12.355$ |

[a] Pan-STARRS magnitudes are in the AB system, while other magnitudes are in the Vega system.

WISE-based spectral type and photometric distance estimates for W1336+5053 using the CatWISE2020 (Marocco et al. 2021), AllWISE (Cutri et al. 2013), and unWISE (Schlafly et al. 2019) catalogs (sourced via AstroToolBox 3.3.0; Kiwy 2022) are highly uncertain due to lack of WISE $W1$-$W2$ color variation as a function of spectral type in the relevant regime. Using the object's Pan-STARRS (Flewelling et al. 2020; Chambers et al. 2016) $i$, $y$, and $z$ magnitudes paired with the CatWISE2020 $W1$ and $W2$ detections, we were able to obtain spectral type estimates for W1336+5053 based on color-type diagrams from Best et al. (2018). We derived spectral types of L1 ± 1, L1 ± 1, L3 ± 4, and L4 ± 4 from the $y$-$W1$ vs $W1$-$W2$, $y$-$W1$ vs $z$-$y$, $i$-$z$ vs $z$-$y$, and $z$-$y$ vs $W1$-$W2$ trends respectively. These yield a mean photometric spectral type estimate of L1.2 ± 0.7 for W1336+5053.

The proper motion for W1336+5053 listed in Table 2 was determined from UKIRT Hemisphere Survey (UHS; Dye et al. 2018) data following the methods described in Schneider et al. (2023) and our $J$- and $K$-band photometry was sourced from UHS. With our photometric spectral type estimate in hand, we estimate absolute magnitudes for W1336+5053 at $W1$, $W2$, and $J_{\rm MKO}$ using polynomial relations from Dupuy & Liu (2012), resulting in $M_{\rm W1} = 10.35 \pm 0.42$, $M_{\rm W2} = 10.09 \pm 0.38$, and $M_{\rm JMKO} = 11.84 \pm 0.44$. Combining these absolute magnitudes with observed apparent magnitudes, we derived distances $D_{\rm W1} = 126.10 \pm 10.55$ pc, $D_{\rm W2} = 128.62 \pm 9.81$ pc, and $D_{\rm JMKO} = 125.86 \pm 11.15$ pc. This resulted in a final distance estimate of 126.98 ± 6.04 pc.

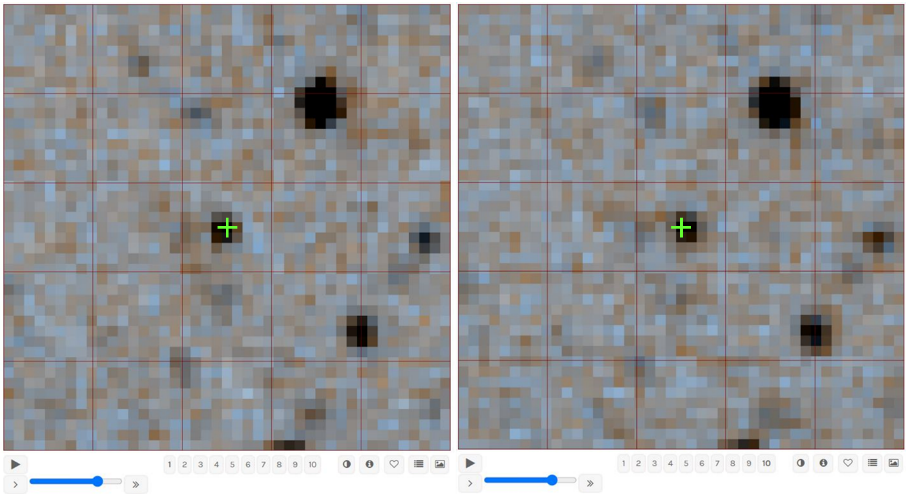

Figure 3. Zooniverse-displayed WISE images of W1336+5053 at the first epoch (left) and the final epoch (right). The images have a field of view of 120″. The central green plus mark in each frame remains fixed and has been added to accentuate movement. These color composite WISE image renderings were generated based on unWISE coadds (Meisner et al. 2018) retrieved via the WiseView visualization tool (Caselden et al. 2018).

## 5. Conclusion

Cool Neighbors aims to support ultracool dwarf discovery by citizen scientists into the future. Beyond the initial 27,800 launch subjects that were completed, Cool Neighbors has by now fully classified ~97,000 subjects (nearly 2,000,000 classifications) 1+ years after launch. For W1336+5053, a red-optical or near-infrared spectrum would allow us to improve upon our photometric classification by assigning a true spectroscopic type.

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