



The POKEMON Speckle Survey of Nearby M Dwarfs. III. The Stellar Multiplicity Rate of M Dwarfs within 15 pc

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Abstract

M dwarfs are ubiquitous in our Galaxy, and the rate at which they host stellar companions, and the properties of these companions, provide a window into the formation and evolution of the star(s), and of any planets that they may host. The Pervasive Overview of “Kompanions” of Every M dwarf in Our Neighborhood (POKEMON) speckle survey of nearby M dwarfs is volume limited from M0V through M9V out to 15 pc, with additional targets at larger distances. In total, 1125 stars were observed, and 455 of these are within the volume-limited, 15 pc sample of M-dwarf primaries. When we combine the speckle observations with known companions from the literature, we find that the stellar multiplicity rate of M dwarfs within 15 pc is $23.5\% \pm 2.0\%$, and that the companion rate is $28.8\% \pm 2.1\%$. We also find that the projected separation distribution for multiples that are known to host planets peaks at 198 au, while the distribution for multiples that are not yet known to host planets peaks at 5.57 au. This result suggests that the presence of close-in stellar companions inhibits the formation of M-dwarf planetary systems, similar to what has been found for FGK stars.

Unified Astronomy Thesaurus concepts: M dwarf stars (982); Low mass stars (2050); Binary stars (154); Solar neighborhood (1509)

Supporting material: machine-readable tables

1. Introduction

Due to their small sizes and low temperatures and luminosities, the M dwarfs currently have the most favorable observing characteristics for finding Earth-sized planets in the habitable zone via the radial velocity and transit methods (e.g., Shields et al. 2016). The M dwarfs also comprise over 70% of the stars in the Milky Way (Henry et al. 2006; Winters et al. 2015), and have lifetimes on the order of the age of the Universe (Laughlin et al. 1997), giving planets a place and the time to form and evolve.

However, it has been shown that the presence of a stellar companion can impact or inhibit the formation and evolution of planetary systems. In particular, close-in stellar companions can dynamically impact the evolution of protoplanetary disks and planetesimals during the early stages of planet formation (Desidera & Barbieri 2007; Haghighipour & Raymond 2007; Rafikov & Silsbee 2015a, 2015b; Jang-Condell 2015). However, recent studies have suggested that even wide stellar companions might affect the formation or orbital properties of giant planets (Fontanive et al. 2019; Fontanive & Bardalez Gagliuffi 2021; Hirsch et al. 2021; Su et al. 2021; Mustill et al. 2022).

Additionally, stellar companions inhibit our ability to detect and characterize planets once formed. Stellar companions can induce “third light” contamination in light curves from missions such as Kepler (Borucki et al. 2011), K2 (Howell et al. 2014), and the Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2015), which can inhibit the detection of Earth-sized planets via the transit method (Lester et al. 2021), as well as the characterization of planets in general (Hirsch et al. 2017; Bouma et al. 2018; Teske et al. 2018; Furlan & Howell 2020; Howell 2020). Stellar companions can also inhibit our ability to detect planets via the radial velocity method if the signal from the companion is not taken into account (e.g., Ortiz et al. 2016). Furthermore, any statistical value for $\eta_{\oplus}$ will be affected by unseen companions, as actual planet radii are larger than observed radii in multistar systems (Ciardi et al. 2015).

In addition to impacting observed planetary properties, stellar companions may also affect the physical properties of any planets in the multistar system, such as their orbits and masses (Eggenberger et al. 2004).

As the M dwarfs offer such a significant opportunity for finding and characterizing Earth-sized planets in the habitable zone (e.g., López-Morales et al. 2019), understanding the rate at which the M dwarfs host stellar companions—and the properties of these companions—is crucial to the field of exoplanet studies.

For this reason, a number of studies have been carried out to measure the multiplicity rate of exoplanet host stars (e.g.,



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Table 1
Previous Studies of M-dwarf Multiplicity

References	Multiplicity Rate (%)
Henry (1991)	30–40
Fischer & Marcy (1992)	42 ± 9
Simons et al. (1996)	40
Leinert et al. (1997)	26 ± 9
Reid & Gizis (1997)	35
Law et al. (2008)	$13.6^{+6.5}_{-4.0}$
Bergfors et al. (2010)	32 ± 6
Janson et al. (2012)	27 ± 3
Jódar et al. (2013)	$20.3^{+6.9}_{-5.2}$
Janson et al. (2014)	21–27
Ward-Duong et al. (2015)	23.5 ± 3.2
Cortés-Contreras et al. (2017)	19.5 ± 2.3
Winters et al. (2019a)	27.5 ± 1.4
This Work	$23.5 \pm 2.0\%$

Mugrauer & Michel 2020, and subsequent papers in this series), as well as the multiplicity rate of field M dwarfs (Table 1). However, many of these studies were limited by the size of their sample, due to the fact that the M dwarfs are quite faint in the optical, and that a reasonably complete inventory of later M dwarfs did not even exist until recently (Kirkpatrick et al. 2014; Luhman & Sheppard 2014; Winters et al. 2021). Additionally, many of these studies were not sensitive to close-in stellar companions due to the resolution limits of the surveys.

We have therefore carried out the Pervasive Overview of “Kompanions” of Every M dwarf in Our Neighborhood (POKEMON) speckle survey of nearby M dwarfs. The POKEMON survey was designed to be volume limited from M0V through M9V and out to 15 pc, with additional brighter targets at larger distances. This volume-limited nature of the sample allowed for uniform sampling of close-in stellar companions. Additionally, since the targets are nearby, the spatial resolution of the systems is improved. In total, 1125 targets were observed at diffraction-limited resolution. The first paper in the series presented the new discoveries (Clark et al. 2022b), and the second paper in the series presented all companions detected within our speckle images (Clark et al. 2023b). In this third paper in the series, we refine the assessment of the stellar multiplicity rate of M dwarfs within 15 pc.

In Section 2, we define the 15 pc POKEMON sample of M-dwarf primaries. In Section 3, we present the stellar companions to the targets in our 15 pc sample that are known to the literature. In Section 4, we describe the observed gap between the projected separation distributions for planet-hosting and non-planet-hosting multiples. Finally, in Section 5, we summarize our conclusions and detail the additional work on the POKEMON sample that will be carried out in the future.

2. Definition of the Sample

The creation of the POKEMON sample as a whole has been described extensively in the previous two papers in the series (Clark et al. 2022b, 2023b). Briefly, the POKEMON sample was designed to be volume limited through M9V out to 15 pc, though it also includes additional brighter targets at larger distances for a total sample size of 1125 targets. At the time the POKEMON catalog was constructed (circa 2015), the generally

accepted cutoff for the stellar-fusion-burning limit was M9V; however, Dieterich et al. (2014) defined the barrier between the lowest-mass stars and the brown dwarfs at a spectral type of L2V. We continue to use the former definition in order to establish the stellar multiplicity of the M-dwarf sequence in particular.

In order to determine the stellar multiplicity and companion rates of the M dwarfs from a volume-limited sample, we needed to constrain the POKEMON targets to only include only those within 15 pc. The volume-limited nature of the sample allows for uniform sampling of close-in stellar companions among our low-mass neighbors.

We used Gaia Data Release 3 (DR3; Gaia Collaboration et al. 2023) parallaxes, as well as parallaxes from other literature sources when Gaia DR3 data were not available, to define the 15 pc POKEMON sample. 70 of the 1125 objects in the original POKEMON sample do not have parallaxes in Gaia DR3; we obtained parallaxes from 18 additional sources to determine whether or not they lie within 15 pc. We were unable to obtain distance measurements for two of these objects.

We note that the initial POKEMON catalog was developed before data from Gaia were available. When the parallax sources for the POKEMON targets were updated using the Gaia astrometric data, some sources left the 15 pc sample, and we did not add additional sources into the sample. This represents a source of incompleteness, but there was no bias in how the sources were removed from the volume. The sample is therefore smaller—meaning the error bars on our multiplicity and companion rates are larger—but it remains unbiased.

In any case, we find that the parallax sources used to create the POKEMON catalog are mostly consistent with Gaia; a cursory examination of Gaia DR3 indicates 606 Northern Hemisphere ($\delta > -30^\circ$) late-type dwarfs (based on a $B_p - R_p > 1.80$ cut to select M dwarfs as suggested by Pecaú & Mamajek 2013) within 15 pc. Although this value is larger than the number of targets in the 15 pc POKEMON sample described in this paper, we note that some of the targets in the Gaia sample are secondaries and not primaries (82), brown dwarfs (46), white dwarfs (3), or RR Lyrae variables (1). This means that 474 are M-dwarf primaries. Of these, 403 are within the 15 pc POKEMON sample. As noted in Clark et al. (2023b), Gaia is frequently unable to provide an astrometric solution (including a parallax) for close binaries. As such, the 15 pc POKEMON sample includes 52 targets that were not identified by Gaia as late-type dwarfs within 15 pc. Nonetheless, in the future we plan to present an expanded version of the POKEMON catalog that includes the Gaia late-type dwarfs within 15 pc that we have not yet observed as a part of the POKEMON survey.⁹

In total, the volume-limited, 15 pc POKEMON sample of M-dwarf primaries consists of 455 targets (Figure 1). This sample is characterized in Table 2, where we include the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) ID or name, Gaia DR3 ID, Gaia G magnitude, Gaia G_{RP} magnitude, parallax-derived distance, and reference for the distance. We also note whether the target has any known companions. In Figure 2 we show histograms of the distances and absolute G_{RP} magnitudes for the targets in the POKEMON sample. We use the absolute G_{RP} magnitudes and the mass–magnitude relation from Giovannazzi & Blake (2022) to estimate masses for the POKEMON targets.

⁹ The POKEMON Distance-Limited Catalog (POKEMON-DLC).

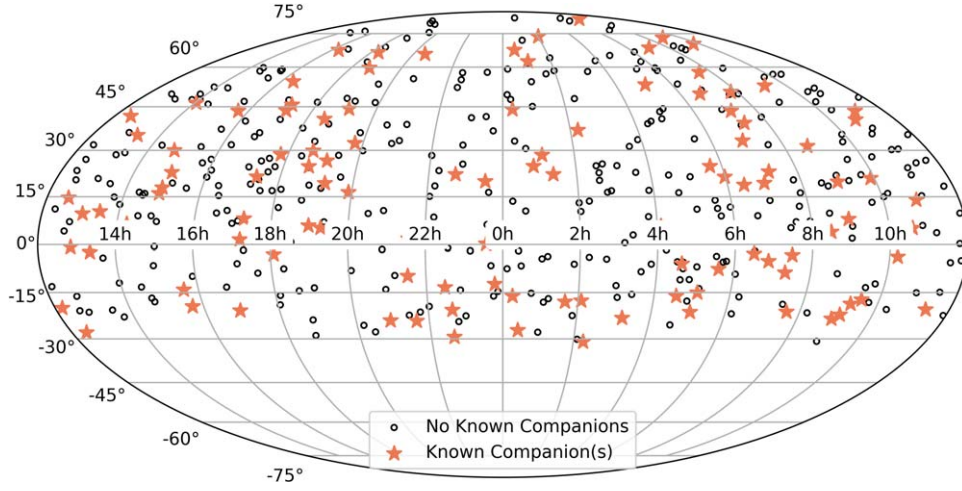


Figure 1. The sky locations of the 455 targets in the volume-limited, 15 pc POKEMON sample. Targets with no known companions are marked with open black circles, while targets with known companions are marked with larger, orange stars.

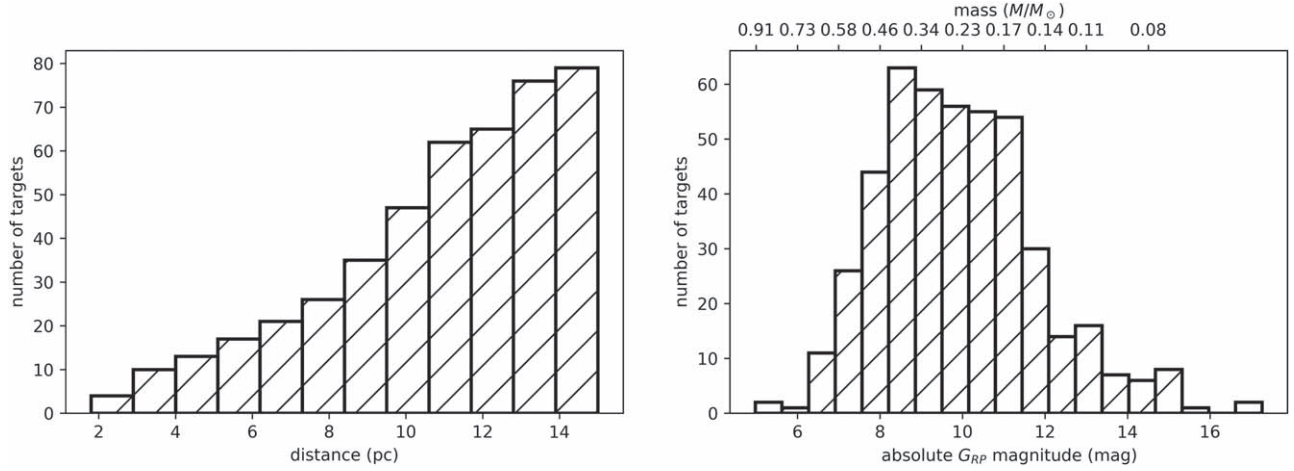


Figure 2. Distance (left) and absolute G_{RP} magnitude (right) distributions for the 455 targets in the 15 pc POKEMON sample. We use the mass–magnitude relation from Giovinazzi & Blake (2022) to estimate the masses of these targets.

Table 2
Targets in the Volume-limited, 15 pc POKEMON Sample of M-dwarf Primaries

2MASS ID or Name	Gaia DR3 ID	G Magnitude (mag)	G_{RP} Magnitude (mag)	Distance (pc)	References	Known Companion(s)?
00064325-0732147	2441630500517079808	11.8	10.4	4.8	(6)	N
00085512+4918561	393621524910343296	14.4	13	14.8	(6)	N
00113182+5908400	423027104407576576	13.5	12.1	9.3	(6)	N
00152799-1608008	2368293487261055488	10.3	8.9	5.0	(10)	Y
00153905+4735220	392350008432819328	10	8.9	11.5	(6)	N
00154919+1333218	2768048564768256512	11.4	10.2	12.2	(6)	N
00182256+4401222	385334230892516480	7.2	6.2	3.6	(6)	Y
00202922+3305081	2863419584886542080	13.9	12.5	12.3	(6)	N
00242463-0158201	2541756977144595712	16.6	15	12.4	(6)	N
00244419-2708242	2322561156529549440	13.2	11.6	7.7	(6)	Y

References. (1) Dittmann et al. (2014); (2) Dupuy et al. (2019); (3) Dupuy & Liu (2017); (4) Finch et al. (2018); (5) Gaia Collaboration (2018); (6) Gaia Collaboration et al. (2023); (7) Henry et al. (2006); (8) Riedel et al. (2010); (9) Torres et al. (2010); and (10) van Leeuwen (2007).

(This table is available in its entirety in machine-readable form.)

We note that most speckle cameras have a faint limit at $I = 15.5$ due to the short exposure times, although by design this magnitude cutoff was expected to be sufficiently faint to include M9V stars out to 15 pc. Kirkpatrick et al. (1991) lists LHS 2924 as the

primary M9V spectral standard, and LHS 2065 as the secondary M9V spectral standard. LHS 2924 ($I_c = 15.2$; $\varpi = 91.2 \pm 0.1$ mas; Dahn et al. 2017; Gaia Collaboration et al. 2023) and LHS 2065 ($I_c = 14.4$; $\varpi = 115.49 \pm 0.07$ mas; Leggett et al. 2001;

Gaia Collaboration et al. 2023) have absolute magnitudes of $M_{Ic} = 15.0$ and 14.8 , respectively. Two other well-characterized, nearby ($d < 11$ pc) M9V stars—LP 944-20 ($I_c = 14.0$; $\varpi = 155.60 \pm 0.05$ mas; $M_{Ic} = 15.0$; Kirkpatrick et al. 1999; Henry et al. 2004; Dieterich et al. 2014; Gaia Collaboration et al. 2023) and LP 647-13 ($I_c = 14.9$; $\varpi = 94.6 \pm 0.2$ mas; $M_{Ic} = 14.7$; Cruz et al. 2003; Gaia Collaboration et al. 2023)—have similar absolute magnitudes. We therefore adopt the average absolute magnitude of the two standards LHS 2924 and LHS 2065 ($M_{Ic} \simeq 14.9$) as typical for field M9V stars (E. Mamajek, private communication). Setting $M_I = 14.9$ and $d = 15$, and solving

$$m_I - M_I = -5 + 5\log_{10}(d), \quad (1)$$

for m_I , we find that we would need to observe targets as faint as $m_I = 15.8$ in order to observe M9V stars out to 15 pc. The Gaia G_{RP} filter has a central wavelength at 797 nm, which is comparable to the I -band central wavelength at 806 nm. The faintest target in the 15 pc POKEMON sample has an apparent G_{RP} magnitude of 17.1, which is sufficiently faint to detect an M9V star at 15 pc.

Using the apparent G magnitudes from Gaia, the stellar distances, and the reference stellar properties from Pecaut & Mamajek (2013), we estimate spectral types for the POKEMON targets (Table 3). It is important to note that the original POKEMON sample was defined based on spectral types derived from colors; therefore, some of the spectral types estimated using the apparent G magnitudes are either K or L dwarfs. The fourth paper in the series will present a homogenous set of photometrically derived spectral types for the POKEMON targets, allowing for more accurate stellar characterization, and establishing the M-dwarf multiplicity rate by spectral subtype through M9V for the first time.

3. The Stellar Multiplicity Rate of M Dwarfs Within 15 pc

As noted in Winters et al. (2019a), most stellar companions to nearby M dwarfs are close in (< 50 au), and speckle interferometry—the technique used to image the targets in the POKEMON sample—is uniquely suited to detecting close-in stellar companions. In Figure 3, we plot the percent of simulated stellar companions detectable within our speckle images as a function of distance. This analysis was carried out following the procedure outlined in Section 4.2 of the previous paper in the series (Clark et al. 2023b). Briefly, the code works by first identifying the population of stellar companions that could orbit each star using the Dartmouth isochrones (Dotter et al. 2008) and the Duchêne & Kraus (2013) mass ratio and orbital period distributions for M dwarfs, and then uses the derived contrast curves to evaluate the sensitivity of each observation to these simulated companions. This plot shows that speckle imaging would allow us to recover the majority (78.1%) of simulated stellar companions to the targets in the 15 pc POKEMON sample. For simulated companions specifically within 100 au, we recover 75.5%.

Nonetheless, every detection technique only fills one particular gap in parameter space. Since the POKEMON survey used only one technique—speckle interferometry—to detect stellar companions, we carried out a literature search to ensure the inclusion of all known stellar companions to the M-dwarf primaries in our 15 pc sample. Our accompanying literature search ensured that wider ($\gtrsim 2''$) companions were not

Table 3
Spectral Types of the Targets in the 15 pc POKEMON Sample

Spectral Type	Number of Targets
K	26
M0	33
M1	35
M2	57
M3	115
M4	92
M5	69
M6	5
M7	8
M8	6
M9	1
L	8

overlooked, and ensured the accuracy of our multiplicity and companion rate calculations.

For the literature search, we mainly used data obtained via the Washington Double Star (WDS) catalog (Mason et al. 2023), and the Simbad bibliography tool (Wenger et al. 2000). However, Simbad and the WDS catalog do not provide a complete census of known companions, so we also carried out our own literature search to search for additional companions, and to ensure that the WDS companions are bound. We also used the SUPERWIDE catalog (Hartman & Lépine 2020) to identify any wide, common-proper-motion pairs.

In Table 4, we report the properties of the known stellar companions to the POKEMON primaries within 15 pc that were identified either from our speckle survey or the literature search. These are M-dwarf companions to the M-dwarf primaries in the sample; as we are calculating the stellar multiplicity rate for M dwarfs, we do not consider any substellar companions such as brown dwarfs or planets. We also do not consider M dwarfs that have more massive companions, such as higher-mass main sequence stars, evolved stars, or white dwarfs.

Table 4 includes the 2MASS ID or name of the primary, component configuration for each row, year of the measurement, position angle (θ), angular separation (ρ), projected separation (a), detection technique, reference for the detection technique, magnitude difference (Δm), filter of the magnitude difference, and reference for the magnitude difference. We also list the uncertainties of the position angle, angular separation, and magnitude difference when available.

There are $n - 1$ lines for each system, where n is the number of components in the system. For instance, the quintuple system 2MASS J16552880-0820103 has four lines in Table 4. For the higher-order multiples, the component configuration indicates the components used to measure the listed magnitude difference. For instance, in the case of the 2MASS J00244419-2708242 triple system, the first line lists the magnitude difference between the primary and the photocenter of the companions (A – BaBb), while the second line lists the magnitude difference between the two stars that make up the B component (Ba – Bb).

For the astrometric and spectroscopic binaries, the projected separations listed in Table 4 were either taken from the reference given, or were calculated from the orbital periods and the estimated masses of the components via Kepler’s third law. We were able to calculate a projected separation for all multiples other than 2MASS J19352922+3746082—which

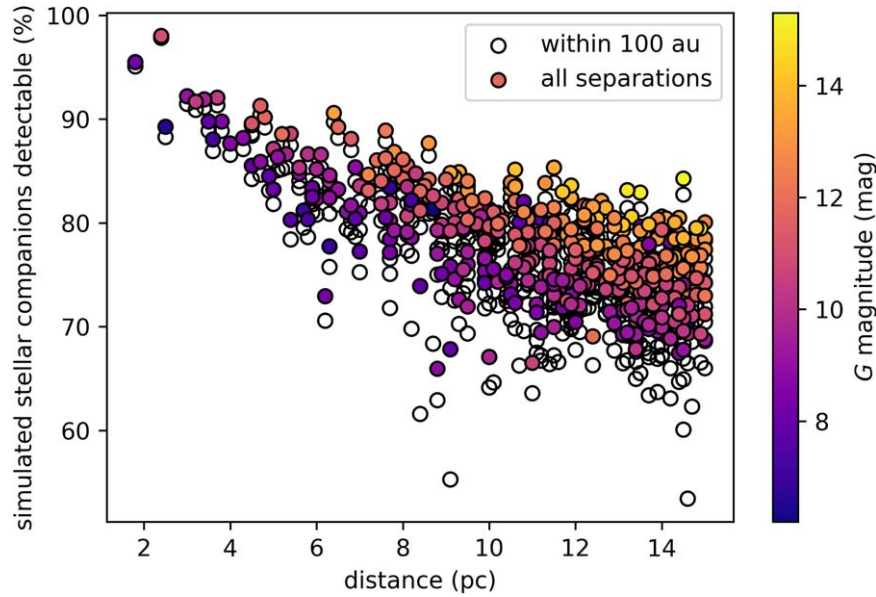


Figure 3. Percentage of stellar companions detectable within our speckle images vs. distance. Circles color coded by G magnitude represent the detectability of simulated companions at all separations. Open black circles represent the detectability of simulated companions specifically within 100 au. We find that the majority of potential stellar companions would be detectable, particularly for the nearby targets, with a median value of 78.1%. Specifically within 100 au, we find that 75.5% of simulated companions are recovered.

Table 4
Summary of Known Stellar Companions to POKEMON Primaries within 15 pc

ID	Component	Epoch (yr)	θ ($^\circ$)	Error ($^\circ$)	ρ ($''$)	Error ($''$)	a (au)	Technique	References	Δm (mag)	Error (mag)	Filter	References
00152799-1608008	A–B	1985	130	...	0.22	...	1.0945	micdet	(31)	0.4	...	V	(31)
00182256+4401222	A–B	1907	57	...	38.83	...	138.33	micdet	(11)	3.02	...	V	(89)
00244419-2708242	A–BaBb	1993	353	0.4	1.07	0.4	8.2743	spkdet	(56)	1.2	...	K	(56)
	Ba–Bb	1993	330	0.4	0.267	0.4	2.0647	spkdet	(56)	0.35	...	K	(56)
00322970+6714080	AaAb–B	1923	99	...	2.26	...	22.511	phodet	(87)	2.5	...	V	(21)
	Aa–Ab	1989	43	3	0.451	0.02	4.4922	spkdet	(67)	1.94	0.06	K	(67)
LTT 10301	A–B	1960	315	...	1	...	14.986	phodet	(59)	0.3	...	B	(59)
00582789-2751251	A–B	...	...	...	...	...	0.2381	SB1	(23)	...	...	...	...
01023895+6220422	A–B	1999	76	...	293.05	...	2889.4	visdet	(76)	2.35	0.03	K	(76)
01053732+2829339	A–B	...	...	...	...	...	0.133	SB2	(3)	...	...	...	...

Note. The codes for the techniques and instruments used to detect and resolve systems are: AO det—detection via adaptive optics; astdet—detection via astrometric perturbation, companion often not detected directly; astorb—orbit from astrometric measurements; CCDdet—detection via CCD or other two-dimensional electronic imaging; lkydet—detection via lucky imaging; micdet—detection via a micrometry technique; occdet—detection via occultation; phodet—detection via a photographic technique; radvel—detection via radial velocity, but no SB type indicated; SB (1, 2, 3)—spectroscopic multiple, either single-lined, double-lined, or triple-lined; spcdet—detection via space-based technique; spkdet—detection via speckle interferometry; visdet—detection via wide-field CCD or other two-dimensional electronic imaging.

References. (1) Aitken (1899); (2) Balega et al. (1999); (3) Baroch et al. (2018); (4) Benedict et al. (2000); (5) Beuzit et al. (2004); (6) Blazit et al. (1987); (7) Bowler et al. (2015); (8) Burnham (1891a); (9) Burnham (1891b); (10) Burnham (1894); (11) Burnham (1913); (12) Clark et al. (2022b); (13) Clark et al. (2023a); (14) Cortés-Contreras et al. (2017); (15) Dahn et al. (1976); (16) Delfosse et al. (1999a); (17) Delfosse et al. (1999b); (18) Duquennoy & Mayor (1988); (19) ESA (1997); (20) Espin (1920); (21) Espin & Milburn (1926); (22) Forrest et al. (1988); (23) Fouqué et al. (2018); (24) Franz et al. (1998); (25) Gaia Collaboration et al. (2023); (26) Giclas et al. (1971); (27) Gili et al. (2022); (28) Gizis & Reid (1996); Hartkopf et al. (1994); (30) Heintz (1987); (31) Heintz (1993); (32) Henry et al. (1997); (33) Henry et al. (1999); (34) Herbig & Moorhead (1965); (35) Hertzsprung (1909); (36) Horch et al. (2004); (37) Horch et al. (2010); (38) Horch et al. (2012); (39) Hough (1999); (40) Hussey (1904); (41) Janson et al. (2012); (42) Janson et al. (2014); (43) Jeffers et al. (2018); (44) Jódar et al. (2013); (45) Joy (1942); (46) Joy (1947); (47) Kuiper (1934); (48) Kuiper (1936a); (49) Kuiper (1936b); (50) Kuiper (1942); (51) Kuiper (1943); (52) Lamman et al. (2020); (53) Lau (1911); (54) Leinert & Jahreis (1986); (55) Leinert et al. (1994); (56) Luyten (1969); (57) Luyten (1972); (58) Luyten (1977); (59) Luyten (1979); (60) Luyten (1997); (61) Luyten (1998); (62) Malo et al. (2014); (63) Martín et al. (2000); (64) McCarthy & Henry (1987); (65) McCarthy et al. (1988); (66) McCarthy et al. (1991); (67) Montagnier et al. (2006); (68) Osvalds & Osvalds (1959); (69) Reid & Gizis (1997); (70) Reiners & Basri (2010); (71) Reuyl (1941); (72) Richichi et al. (1996); (73) Riedel et al. (2010); (74) Rossiter (1955); (75) Skrutskie et al. (2006); (76) Sperauskas et al. (2019); (77) Struve (1837); (78) Tokovinin et al. (2010); (79) Tomkin & Pettersen (1986); (80) van Biesbroeck (1961); (81) van Biesbroeck (1974); (82) van den Bos (1937); (83) van den Bos (1950); (84) van den Bos (1951); (85) Vrijmoet et al. (2022); (86) Vyssotsky (1927); (87) Ward-Duong et al. (2015); (88) Wendell (1913); (89) Wilson (1954); (90) Winters et al. (2017); (91) Winters et al. (2020); (92) Wirtanen (1941); and (93) Worley (1962).

(This table is available in its entirety in machine-readable form.)

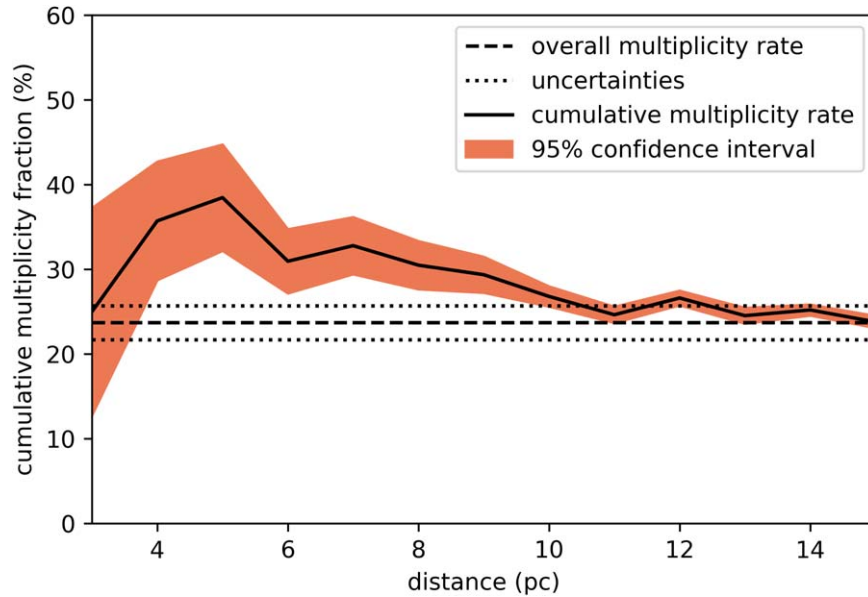


Figure 4. Cumulative stellar multiplicity rate as a function of distance, binned by 1 pc. The 95% Poisson confidence interval is shown. We also show the overall stellar multiplicity rate (and uncertainties) for comparison. No corrections have been applied for undetected companions. Although the cumulative multiplicity rate is higher at smaller distances due to a smaller number of stars in those bins, we do find that the cumulative multiplicity rate stays roughly flat from 11 pc onwards; the drop-off from 11 to 15 pc is 0.6%, which we consider negligible. Since the cumulative multiplicity rate remains roughly flat in these bins, this indicates that we are not missing multiples at these distances.

was first identified as a radial velocity variable by Shkolnik et al. (2012) and confirmed as an SB1 by Jeffers et al. (2018)—as no orbital elements or stellar properties have been published in the literature.

In total, we find that 107 of the 455 POKEMON primaries within 15 pc host M-dwarf companions known to the literature. Of these, 85 are double (N_D), 21 are triple (N_T), zero are quadruple (N_{Qd}), and one is quintuple (N_{Qn}). 348 of the POKEMON primaries within 15 pc are therefore not known to host stellar companions (N_S). We can calculate the multiplicity and companion rates using these values and the equations defined in Winters et al. (2019a)

$$MR = 100 * \frac{N_D + N_T + N_{Qd} + N_{Qn}}{N_S + N_D + N_T + N_{Qd} + N_{Qn}}, \quad (2)$$

$$CR = 100 * \frac{N_D + 2N_T + 3N_{Qd} + 4N_{Qn}}{N_S + N_D + N_T + N_{Qd} + N_{Qn}}. \quad (3)$$

The multiplicity rate is simply defined as the percentage of systems that are multiple. In comparison, the companion rate is defined as the average number of companions per primary in the sample, so it takes into account whether the systems are binary, trinary, or of even higher orders.

We calculate the uncertainty on our rates using the analytic formula for the sample standard deviation of a binomial distribution

$$\sigma_n = \sqrt{\frac{p(1-p)}{n}}, \quad (4)$$

where n is the number of experiments (the number of primaries) and p is the probability of success (the number of multiples divided by the number of primaries).

Using these equations, we find a stellar multiplicity rate of $23.5\% \pm 2.0\%$ and a stellar companion rate of $28.8\% \pm 2.1\%$. We also find that the ratios of singles:doubles:triples:higher-order systems is 348:85:21:1, corresponding to 76.5:18.7:4.6:0.2%. For

comparison, Winters et al. (2019a) found ratios of 76:20:3:0.3% for their sample of M dwarfs within 25 pc. 104 of the targets in the 15 pc POKEMON sample are not in the Winters et al. (2019a) sample, and yet the ratios are quite similar. In contrast, Raghavan et al. (2010) found ratios of 56:33:8:3% for singles:doubles:triples:higher-order systems for companions (including brown dwarfs) in a sample of 454 solar-type stars. This result reemphasizes that more massive stars are more likely to be higher-order systems than our less-massive neighbors.

In Figure 4, we plot the cumulative stellar multiplicity rate as a function of distance. Although the cumulative multiplicity rate is higher at smaller distances due to a smaller number of stars in those 1 pc bins, we do find that the cumulative multiplicity fraction stays within the uncertainties of the overall multiplicity rate from 11 pc onwards; the dropoff from 11 to 15 pc is 0.6%, which we consider negligible. Since the cumulative multiplicity function remains roughly flat in these bins, this indicates that we are likely not missing multiples.

As noted previously, these multiplicity rates are restricted to include only stellar companions, and not brown dwarfs. It is therefore important to explore whether this exclusion of substellar companions may impact our calculated multiplicity rate. We note that lower-mass binaries tend to have mass ratios closer to unity, and surveys to date have found few brown dwarfs around small stars using radial velocity measurements (Tokovinin 1992; Pass et al. 2023), high-resolution imaging (Dieterich et al. 2012), or astrometry (e.g., Henry et al. 2018). Furthermore, Winters et al. (2019a) and Raghavan et al. (2010) find quite low brown dwarf companion rates of $1.3\% \pm 0.3\%$ and $1.5\% \pm 0.6\%$, respectively. We therefore conclude that the exclusion of brown dwarf companions has little impact on our multiplicity rate calculations.

4. The Separation Gap

As expected, close-in stellar companions affect multiple facets of planet formation, as well as the dynamics and

Table 5
POKEMON Primaries within 15 pc that Host Both Planetary and Stellar Companions

Planet	Discovery Technique	Reference	Stellar Companion Separation (au)
GJ 15 A b	Radial Velocity	Howard et al. (2014)	138.33
GJ 15 A c	Radial Velocity	Pinamonti et al. (2018)	138.33
GJ 49 b	Radial Velocity	Perger et al. (2019)	2889.4
LTT 1445 A b	Transit	Winters et al. (2019b)	22.563
LTT 1445 A c	Transit	Winters et al. (2022)	22.563
Ross 458 c	Imaging	Burgasser et al. (2010)	5.466
HD 147379 b	Radial Velocity	Reiners et al. (2018)	691.99
HD 180617 b	Radial Velocity	Kaminski et al. (2018)	437.71
GJ 896 A b	Astrometry	Curiel et al. (2022)	21.921

architectures of planetary systems. Cieza et al. (2009) analyzed young stars with protoplanetary disks, and showed that disk-hosting multiples have a very different projected separation distribution as compared to non-disk-hosting multiples. Systems with close-in stellar multiples ($a < 40$ au) are half as likely to retain a disk than more widely separated multiples.

More recently, studies of data from Kepler, K2, and TESS have shown that when we detect stellar companions to planet-hosting FGK stars, the companions have projected separation distributions that peak at larger values than what have been found for field stars (e.g., Kraus et al. 2012; Bergfors et al. 2013; Wang et al. 2014; Kraus et al. 2016; Ziegler et al. 2020; Howell et al. 2021; Moe & Kratter 2021).

Complementing these works, a survey combining radial velocity and imaging observations of nearby FGK stars found that the frequency of giant planets around single stars and in wide ($\gtrsim 100$ au) binaries was nearly identical ($\approx 20\%$), while the frequency of giant planets in close ($\lesssim 100$ au) binaries was nearly 0% (Hirsch et al. 2021). This is likely the result of the close-in stellar companions affecting and perhaps inhibiting the planet formation process (e.g., Dupuy et al. 2016). While these works focused on solar-type (FGK) stars, Clark et al. (2022a) saw this in a sample of M-dwarf TESS Objects of Interest (TOIs) as well. In that work, the frequency of stellar companions around TOI-hosting M dwarfs was found to be similar to the companion rate for field stars, but the stellar companions were found at much larger separations.

The volume-limited, 15 pc POKEMON sample enables an exploration of this idea for the M dwarfs in a systematic manner. The projected separation distribution for the multiples in the 15 pc POKEMON sample is roughly Gaussian with a peak at 6.57 au ($\sigma_{\log a} = 1.3$, $SE_{\log a} = 0.11$). Specifically within 10 pc, we find a peak at 4.95 au ($\sigma_{\log a} = 1.4$, $SE_{\log a} = 0.18$). This is in good agreement with the recent survey of M dwarfs for wide ($\gtrsim 2''$) companions (Winters et al. 2019a), which found a peak at 20 au for their sample within 25 pc, and at 4 au for their sample within 10 pc. However, when we explore the projected separation distribution for the POKEMON multiples that host planets, we find that it is quite different from the Winters et al. (2019a) distribution.

There are seven POKEMON primaries within 15 pc that are known to host both stellar and planetary companions (Table 5). GJ 15 A and LTT 1445 A host two planets each, so in total there are eight known planets. These systems were identified via a search of the Exoplanet Archive¹⁰ for known planets in multistar systems and a cross-match with our sample.

Interestingly, only one planetary system was detected via the transit method, which has been used to identify the vast majority of known planets. 419 of the 455 targets in the 15 pc POKEMON sample have been observed by TESS, and of these, 397 have a TESS magnitude brighter than 13, meaning they have been searched by the TESS project’s quick-look pipeline for planets. This means that in total, 87% of the 15 pc POKEMON sample has been searched for transiting planets. There are eight TOIs in the 15 pc POKEMON sample: 256, 455, 562, 1796, 1827, 4481, 4599, and 6251. However, only one of these TOIs (455, or LTT 1445 A) was discovered in a system with stellar companions.

We note that the presence of a blended stellar companion can prevent the detection of transiting small planets by diluting the transit depth below the detection threshold of TESS (Lester et al. 2021). The approximate transit depth limit for TESS is ~ 100 ppm; after correction for an equal-brightness companion, the minimum transit depth would be ~ 200 ppm, translating to a planet that is $1.4\times$ larger than originally thought. At 200 ppm, the minimal detectable planet would be $0.9 R_{\oplus}$ around an M0V star, and $0.2 R_{\oplus}$ around an M9V star (E. Mamajek, private communication). Thus, there could be very small planets hidden in the sample beyond the detection limits of TESS.

Additionally, we note that short-period transiting planets discovered by TESS do not represent the entire range of planets that may exist in the 15 pc POKEMON sample. While 87% of the 15 pc sample was observed by TESS, transiting planets represent only about 10% of the expected total number of planets. However, radial velocity searches for planets orbiting these stars are substantially less complete and/or systematic. Many of these systems have not been searched via the radial velocity method due to the faintness of the host star and/or the presence of a stellar companion. A full completeness and reliability analysis of the radial velocity surveys is beyond the scope of this work, but we note that non-transiting planets could be hidden in the sample. Nonetheless, the lack of planets we find in the 15 pc POKEMON sample is consistent with the radial velocity + imaging survey of nearby (within 300 pc) FGK stars, where Neptune-sized and larger planets in short orbital periods were rarely found in systems with close-in stellar companions (Hirsch et al. 2021).

With these caveats noted, in Figure 5 we plot the histogram of projected separations for the multiples in the 15 pc POKEMON sample, as well as Gaussian fits to the planet-hosting and non-planet-hosting distributions, and TOI distributions from Clark et al. (2022a). When the non-planet-hosting and planet-hosting samples are assessed separately, the non-planet-hosting POKEMON multiples have a projected

¹⁰ <https://exoplanetarchive.ipac.caltech.edu>

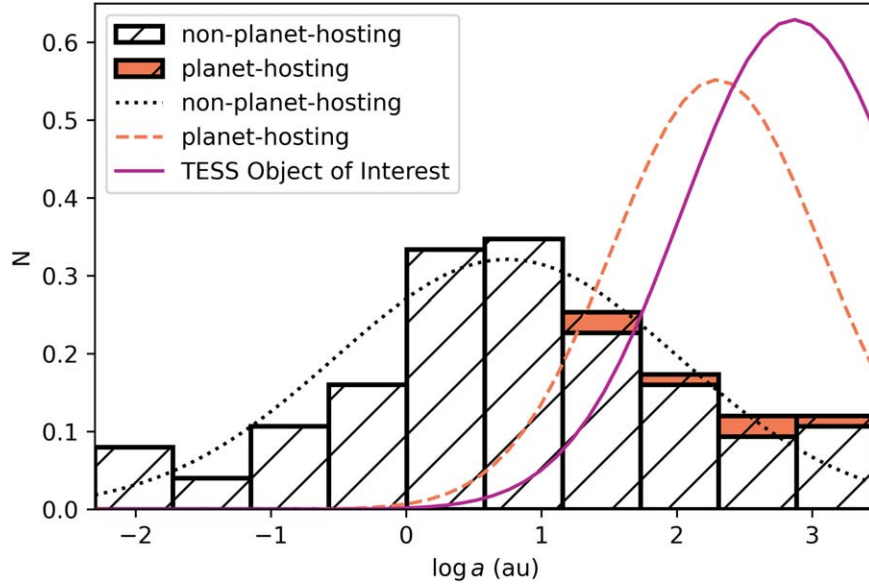


Figure 5. Projected separation distributions for various populations of M-dwarf multiples. The histogram shows the distribution of projected separations for the targets in the 15 pc POKEMON sample that are known to be multiple, separated by planet-hosting (orange) and non-planet-hosting (white) status. The dotted, black line is a Gaussian fit to the projected separations of the non-planet-hosting POKEMON multiples, with a peak at 5.57 au ($\sigma_{\log a} = 1.3$, $SE_{\log a} = 0.11$). The dashed, orange line is a Gaussian fit to the projected separations of the planet-hosting POKEMON multiples, with a peak at 198 au ($\sigma_{\log a} = 0.77$, $SE_{\log a} = 0.32$). The solid, yellow line is a Gaussian fit to the projected separations of the M-dwarf TOIs from Clark et al. (2022a), with a peak at 735 au ($\sigma_{\log a} = 0.83$, $SE_{\log a} = 0.25$). We note that we use Gaussian fits to compare our distribution of projected separations with other studies of multiplicity (e.g., Raghavan et al. 2010; Winters et al. 2019a); we do not use this to indicate that the distribution of stellar multiples is Gaussian, but rather to show that the peaks of the distributions are shifted. The two planet-hosting distributions have peaks at relatively consistent values, whereas the peaks of the planet-hosting and non-planet-hosting distributions differ by more than an order of magnitude. This result indicates that the presence of a stellar companion impacts the formation and long-term stability of any planets in the system.

separation distribution that peaks at 5.57 au ($\sigma_{\log a} = 1.3$, $SE_{\log a} = 0.11$), while the planet-hosting POKEMON multiples have a peak at 198 au ($\sigma_{\log a} = 0.77$, $SE_{\log a} = 0.32$). These peaks and standard deviations are determined when the $\log_{10}$ separations are fit with a normal Gaussian distribution, and are taken to be the means of the distributions. We note that we consider the Ross 458 system as non-planet-hosting, as its “planet” is a circumbinary T dwarf located $\sim 100''$ from the M-dwarf pair.

While only a small number of POKEMON multiples host known planets, the planet-hosting distribution is in reasonable agreement with the results from the recent multiplicity survey of M-dwarf TOIs (Clark et al. 2022a). After removing false positives, the peak of the projected separation distribution for the M-dwarf TOIs is found to be 735 au ($\sigma_{\log a} = 0.83$, $SE_{\log a} = 0.25$).

We also break down the projected separations of the stellar multiples by planet-hosting status in Table 6, where we note that the breakdown of close-in and wide companions is $\sim 5:1$ for the non-planet-hosting multiples, but reversed to $\sim 1:5$ for the planet-hosting multiples.

The number of planet-hosting systems with stellar companions in both the POKEMON (6) and TOI (11) samples is relatively small, but it is telling the two planet-hosting distributions have peaks at relatively consistent values, whereas the peaks of the planet-hosting and non-planet-hosting distributions differ by more than an order of magnitude. Every planet-hosting binary—besides the circumbinary planet—has a companion separation that is larger than the peak of the non-planet-hosting separation distribution. Additionally, an Anderson–Darling test of the planet-hosting and non-planet-hosting POKEMON multiple distributions yields a p -value of 0.003, indicating that the two samples are likely drawn

Table 6
Projected Separations of Stellar Multiples by Planet-hosting Status

	$a < 100$ au	$a > 100$ au
Non-planet-hosting POKEMON targets	102	22
Planet-hosting POKEMON targets	2	4
M-dwarf TESS Objects of Interest	2	9

from different parent distributions. Furthermore, a Kolmogorov–Smirnov (K-S) test of the planet-hosting and non-planet-hosting POKEMON multiple distributions yields a p -value of 0.003. When the non-planet-hosting POKEMON multiples are compared to the M-dwarf TOIs from Clark et al. (2022a), the K-S test has the same result (p -value = 7×10^{-7}). However, a K-S test of the planet-hosting POKEMON multiples and the M-dwarf TOIs shows that the two distributions likely stem from the same parent distribution (p -value = 0.5).

In order to determine the statistical significance of the difference between the peaks of the planet-hosting and non-planet-hosting samples, we added the standard errors of the planet-hosting and non-planet-hosting samples in quadrature to estimate the uncertainty in the difference; we find a value of 2.17 au. This means that the peaks of the planet-hosting and non-planet-hosting differ by over 88σ , a highly significant result.

We also carried out a Monte Carlo analysis to investigate this result further. We drew six random samples—representing the six planet-hosting multiples—from the projected separation distribution for the POKEMON multiples 1000 times. We then fit a Gaussian distribution to each draw to calculate the mean. This mean was equal to or larger than the mean of the planet-hosting POKEMON multiple distribution in only one out of

1000 cases. This result indicates that it is very unlikely that the highly skewed peak of the planet-hosting POKEMON multiples is the result of random chance.

These results represent statistically significant evidence for a correlation between binary separation and the presence of a planetary companion in M-dwarf systems. Of course, observational biases may exist in our samples; for instance, the low-separation side of the histogram could be affected by still-missing companions. And as noted, the POKEMON sample has not been uniformly searched for planets, and there are likely (as of now) unknown planets orbiting stars in the non-planet-hosting portion of the sample. Additionally, the planetary content of the secondary stars in these systems is relatively unknown. It would therefore be of interest to search both components of systems with wider companions ($\gtrsim 100$ au) for planets to investigate whether the tail toward larger projected separations that we find in the POKEMON multiple distribution is produced by planet-hosting systems, and to investigate whether the planets that orbit secondary stars differ from those that orbit primaries.

5. Conclusions and Future Work

We have carried out the POKEMON speckle survey of nearby M dwarfs using the Differential Speckle Survey Instrument and NN-Explore Exoplanet Stellar Speckle Imager on the 4.3 m Lowell Discovery Telescope and the 3.5 m Wisconsin–Indiana–Yale–NOIRLab telescope, respectively. Using these instruments, we have imaged 1125 targets, 455 of which are in our volume-limited, 15 pc sample of M-dwarf primaries. We find that the stellar multiplicity rate of M dwarfs within 15 pc is $23.5\% \pm 2.0\%$, and that the companion rate is $28.8\% \pm 2.1\%$.

We also investigated how the presence of stellar companions may impact the properties of any planetary companions in the system. We find that peaks of the projected separation distributions for non-planet-hosting and planet-hosting multiples differ by over an order of magnitude (5.57 and 198 au, respectively). This result is consistent with the recent survey of M-dwarf TOIs, which have a peak at 735 au (Clark et al. 2022a). We therefore conclude that planet-hosting multiples have larger projected separations than non-planet-hosting multiples, indicating that the presence of a stellar companion impacts the formation and long-term stability of any planets in the system. Planets orbiting M dwarfs are favorable targets for atmospheric characterization via transmission spectroscopy, so understanding the occurrence rate and properties of stellar companions to M dwarfs is critical to current missions such as the James Webb Space Telescope (Gardner et al. 2006), as well as upcoming missions such as Ariel (Tinetti et al. 2018) and the Habitable Worlds Observatory.

We are continuing to follow up the POKEMON targets with the Quad-camera Wavefront-sensing Six-channel Speckle Interferometer (Clark et al. 2020). We are also currently obtaining homogenous spectral types for all targets in the sample, and in a forthcoming publication we will present the stellar multiplicity rate of M dwarfs within 15 pc calculated by spectral subtype through M9V for the first time.

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Erratum: “The POKEMON Speckle Survey of Nearby M Dwarfs. III. The Stellar Multiplicity Rate of M Dwarfs within 15 pc” (2024, AJ, 167, 174)

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We have discovered that the stellar companion to GJ 369, which was included in the analysis of C. A. Clark et al. (2024), was in fact a double cosmic-ray hit during one of the 5000 40 ms exposures. Our observations have now been reanalyzed and show that GJ 369 is single. We include updates to Tables 2 and 4 here. We also note that the updated stellar multiplicity and companion rates for M dwarfs within 15 pc are $23.3\% \pm 2.0\%$ and $28.6\% \pm 2.1\%$, respectively.

Table 2
Targets in the Volume-limited 15 pc POKEMON Sample of M-dwarf Primaries

2MASS ID or Name	Gaia DR3 ID	G Magnitude (mag)	G _{RP} Magnitude (mag)	Distance (pc)	References	Known Companion(s)?
00064325–0732147	2441630500517079808	11.8	10.4	4.8	(6)	N
00085512+4918561	393621524910343296	14.4	13	14.8	(6)	N
00113182+5908400	423027104407576576	13.5	12.1	9.3	(6)	N
00152799–1608008	2368293487261055488	10.3	8.9	5.0	(10)	Y
00153905+4735220	392350008432819328	10	8.9	11.5	(6)	N
00154919+1333218	2768048564768256512	11.4	10.2	12.2	(6)	N
00182256+4401222	385334230892516480	7.2	6.2	3.6	(6)	Y
00202922+3305081	2863419584886542080	13.9	12.5	12.3	(6)	N
00242463–0158201	2541756977144595712	16.6	15	12.4	(6)	N
00244419–2708242	2322561156529549440	13.2	11.6	7.7	(6)	Y

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Table 4
Summary of Known Stellar Companions to POKEMON Primaries within 15 pc

ID	Component	Epoch (yr)	θ ($^{\circ}$)	Error ($^{\circ}$)	ρ ($''$)	Error ($''$)	a (au)	Technique	References	Δm (mag)	Error (mag)	Filter	References
00152799+1608008	A-B	1985	130	...	0.22	...	1.0945	micdet	(29)	0.4	...	V	(29)
00182256+4401222	A-B	1907	57	...	38.83	...	138.33	micdet	(11)	3.02	...	V	(87)
00244419+2708242	A-BaBb	1993	353	0.4	1.07	0.4	8.2743	spkdet	(54)	1.2	...	K	(54)
	Ba-Bb	1993	330	0.4	0.267	0.4	2.0647	spkdet	(54)	0.35	...	K	(54)
00322970+6714080	AaAb-B	1923	99	...	2.26	...	22.511	phodet	(85)	2.5	...	V	(20)
	Aa-Ab	1989	43	3	0.451	0.02	4.4922	spkdet	(65)	1.94	0.06	K	(65)
LTT 10301	A-B	1960	315	...	1	...	14.986	phodet	(57)	0.3	...	B	(57)
00582789+2751251	A-B	...	...	...	...	...	0.2381	SB1	(22)	...	...	...	...
01023895+6220422	A-B	1999	76	...	293.05	...	2889.4	visdet	(74)	2.35	0.03	K	(74)
01053732+2829339	A-B	...	...	...	...	...	0.133	SB2	(3)	...	...	...	...

Note. The codes for the techniques and instruments used to detect and resolve systems are: AO det—detection via adaptive optics; astdet—detection via astrometric perturbation, companion often not detected directly; astorb—orbit from astrometric measurements; CCDdet—detection via CCD or other two-dimensional electronic imaging; lkydet—detection via lucky imaging; micdet—detection via a micrometry technique; occdet—detection via occultation; phodet—detection via a photographic technique; radvel—detection via radial velocity, but no SB type indicated; SB (1, 2, 3)—spectroscopic multiple, either single-lined, double-lined, or triple-lined; spcdet—detection via space-based technique; spkdet—detection via speckle interferometry; visdet—detection via wide-field CCD or other two-dimensional electronic imaging.

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