BANYAN. XIII. A First Look at Nearby Young Associations with Gaia Data Release 2

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Abstract

In this paper, we examine the nearest 100 pc entries in Data Release 2 of Gaia to identify previously unrecognized candidate members in young associations. We analyze 695,952 stars with the BANYAN \( \Sigma \) Bayesian classification software and discover 898 new high-likelihood candidate members that span a wide range of properties, from spectral types B9 to L2, including 104 comoving systems, 111 brown dwarfs, and 31 new bona fide members. Our sample is mostly composed of highly active M dwarfs and will be crucial in examining the low-mass end of the initial mass function of young associations. We also include new candidate members near the Galactic plane where previous surveys suffered from a high rate of contamination. This paper represents the first step toward a full reassessment of young associations in the solar neighborhood with the second data release of the Gaia mission.

Key words: methods: data analysis – proper motions – stars: kinematics and dynamics

Supporting material: machine-readable tables

1. Introduction

The recent Data Release 2 of the Gaia mission (hereafter Gaia DR2; Gaia Collaboration et al. 2018; Lindegren et al. 2018)4 on 2018 April 25 presented a catalog of \(~1.3\) billion trigonometric distances to stars in the Milky Way, a more than 600-fold improvement over the number of sources in the Tycho–Gaia Astrometric Solution (Gaia Collaboration et al. 2016) that came out less than a year ago, and a more than 10,000-fold improvement over that of the Hipparcos mission (Perryman et al. 1997), which shaped our understanding of the solar neighborhood for the past few decades. Gaia DR2 revolutionizes the quantity and quality of stellar kinematics data that are immediately available, and it will have a profound impact on our understanding of Galactic kinematics, among many other things.

In this paper, we examine the 27 nearest known young associations within 150 pc of the Sun (e.g., the AB Doradus and \( \beta \) Pictoris moving groups, the TW Hya and Hyades associations; Zackerman & Song 2004; Torres et al. 2008). These associations and their global properties are listed in Table 1 and are described in more detail in Gagné et al. (2018)3. A detailed analysis of their properties and known members based on Gaia DR2 will be the subject of separate papers. The ages of these associations span a few Myr to more than 1 Gyr, and they thus provide a window into the star formation history of the solar neighborhood as well as important astrophysical laboratories to understand how the properties of stars, substellar objects, and exoplanets evolve with time. Previous searches for new low-mass members in these young associations (e.g., Rodriguez et al. 2011; Shkolnik et al. 2012, 2017; Malo et al. 2013; Kraus et al. 2014) identified only a fraction of the mid-to-late-M dwarfs because of their faintness and the need to obtain follow-up trigonometric parallaxes and radial velocities for a large number of objects (the initial mass function peaks around \( \sim \)M3). Gaia DR2 now opens the door to a search down to the substellar domain (spectral type \( \sim \)L2) with an unprecedented efficiency, as the immediate availability of trigonometric parallaxes makes it possible to cut down the number of contaminants (mostly unrelated background field stars) by an order of magnitude (e.g., see Gagné et al. 2018).

In this work, we use the 100 pc sample of Gaia DR2 to recover 898 new candidate members (mostly mid-M dwarfs) that were never identified as such in the literature. In Section 2, we describe the sample selection based on the nearest 100 pc entries of Gaia DR2 and the BANYAN \( \Sigma \) Bayesian classifier, and we describe our further validation of the targets as well as our literature search in Section 3. The general properties of the resulting set of new candidate members are described in Section 4, along with those of the comoving systems that we identified. We conclude in Section 5.

2. Sample Selection

We selected all Gaia DR2 sources within 100 pc of the Sun with a parallax measurement at least three times as large as its measurement error so as to identify new candidate members in young associations based on robust parallax measurements. We used a generous criterion on the parallax quality to avoid rejecting faint candidate members that may correspond to young brown dwarfs. This sample was downloaded from the Gaia DR2 archive6 with the following SQL query:

PARALLAX>10 AND PARALLAX/PARALLAX_ERROR>=3,

which returned 695,952 entries. All entries were analyzed with the BANYAN \( \Sigma \) Bayesian classification algorithm (Gagné et al. 2018) to identify those for which the proper motion and trigonometric parallax are consistent with membership in a known young association. BANYAN \( \Sigma \) uses spatial and kinematic models of the 27 young associations within 150 pc as well as field stars within 300 pc to derive membership probabilities in each young

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3 NASA Sagan Fellow.
4 See also Luri et al. (2018), Mignard et al. (2018), Babusiaux et al. (2018), Sartoretti et al. (2018), Soubiran et al. (2018), Cropper et al. (2018), Evans et al. (2018), Hamblly et al. (2018), and Riello et al. (2018) for relevant calibration.
5 We list only the 20/27 associations that will be relevant to this paper.
6 https://archives.esac.esa.int/gaia
association based on the sky position, proper motion, radial velocity, and trigonometric distances of the targets using Bayesian inference. Radial velocities and trigonometric distances are optional, and BANYAN $\Sigma$ can calculate probabilities in their absence by taking a marginalization integral of the membership probability density over all possible values. BANYAN $\Sigma$ is computationally efficient and achieves a more accurate classification performance than previous tools in the literature in part because it is based on an analytical solution of the marginalization integrals (see Gagné et al. 2018 for more details).

We found all 3510 entries with a total young association Bayesian membership probability above 90% that are separated by less than 5 km s$^{-1}$ from their best-matching young association in UVW space (727 of which have a Gaia DR2 radial velocity measurement). In the absence of a radial velocity measurement, BANYAN $\Sigma$ provides the optimal value that would minimize the distance between a target and its most probable young association in spatial–kinematic XYZ/UVW space. The 90% probability threshold is associated with a recovery rate of only 50% of the bona fide members (Gagné et al. 2018) and was selected as a first pass to identify only the most unambiguous members of young associations in Gaia DR2 while minimizing the rate of contamination from random field interlopers.

3. Literature Search and Target Validation

Gagné et al. (2018) compiled a list of candidate or bona fide members of young associations. Before our sample was analyzed in more detail, we cross-matched it with this list and removed from our sample the 1399 that were found on both lists. The known young brown dwarfs will be discussed in J. K. Faherty et al. (2018, in preparation), and the known stellar members will be discussed in J. Gagné et al. (2018, in preparation) along with an update of the spatial–kinematic models of the young associations and the field used in BANYAN $\Sigma$. We also ignored 12 K-type stars that will be discussed by M. Chalifour et al. (2018, in preparation).

Several parallax solutions near the Galactic plane in Gaia DR2 suffer from cross-matching confusion, especially for faint targets (Lindgren et al. 2018; see also Faherty et al. 2018). In order to assess which Gaia entries corresponded to physical objects, we built finder charts with all available data from the Digitized Sky Survey, SDSS (Alam et al. 2015), 2MASS (Skrutskie et al. 2006), WISE (Wright et al. 2010), Pan-STARRS (Chambers et al. 2016), VHS (McMahon et al. 2013), and UKIDSS (Lawrence et al. 2007) with the finder_charts.py Python package (Gagné et al. 2018).

We visually examined the 2195 charts to confirm the nonzero

Table 1

| Group Name | $\langle \varpi \rangle$ | $\langle \nu \rangle$ | $S_{\nu,0}$ | $S_{\nu,1}$ | Age | Reference |
|------------|----------------|----------------|-----------|-----------|-----|-----------|
| 118TAU     | 100 ± 10   | 14 ± 2        | 3.4       | 2.1       | ~10 | 1         |
| ABDMG     | 30 ± 10   | 10 ± 2        | 19.0      | 1.4       | 149 ± 51 | 2       |
| /PMG      | 30 ± 10   | 10 ± 2        | 14.8      | 1.4       | 24 ± 3 | 2       |
| CAR       | 60 ± 20   | 20 ± 2        | 11.8      | 0.8       | 45 ± 71 | 2       |
| CARN      | 30 ± 20   | 15 ± 7.2      | 14.0      | 2.1       | ~200 | 3       |
| CBER      | 85 ± 0.1  | −0.1 ± 0.8    | 3.6       | 0.5       | 562 ± 84 | 4       |
| COL       | 50 ± 20   | 21 ± 0.8      | 15.8      | 0.9       | 42 ± 4 | 2       |
| EPSC      | 102 ± 4   | 14 ± 3        | 2.8       | 1.8       | 3.7 ± 14 | 5       |
| HYA       | 42 ± 7    | 39 ± 3        | 4.5       | 1.2       | 750 ± 100 | 6       |
| LCC       | 110 ± 10  | 14 ± 5        | 11.6      | 2.2       | 15 ± 3 | 7       |
| OCT       | 130 ± 20  | 8 ± 8         | 22.4      | 1.3       | 35 ± 5 | 8       |
| PLS       | 130 ± 10  | 22 ± 2        | 5.0       | 1.1       | ~60  | 9       |
| TAU       | 120 ± 10  | 16 ± 3        | 10.7      | 3.6       | 1–2  | 10       |
| THA       | 46 ± 8   | 9 ± 5         | 9.1       | 0.8       | 45 ± 4 | 2       |
| THOR      | 96 ± 2    | 19 ± 3        | 3.9       | 2.1       | 22 ± 4 | 2       |
| TWA       | 60 ± 10   | 10 ± 3        | 6.6       | 1.5       | 10 ± 3 | 2       |
| UCL       | 130 ± 20  | 5 ± 5         | 17.4      | 2.5       | 16 ± 2 | 7       |
| UMA       | 25.4 ± 0.8 | −12 ± 3      | 1.2       | 1.3       | 414 ± 23 | 11    
| USCO      | 130 ± 20  | −5 ± 4        | 9.9       | 2.8       | 10 ± 3 | 7       |
| XFOR      | 100 ± 6   | 19 ± 2        | 2.6       | 1.3       | ~500 | 12       |

Notes. The full names of young associations are 118 Tau (118TAU), AB Doradus (ABDMG), β Pictoris (βPMG), Carina (CAR), Carina-Near (CARN), Coma Berenices (CBER), Columbia (COL), ε Chamaeleontis (EPSC), the Hyades cluster (HYA), Lower Centaurus Crux (LCC), Octans (OCT), Platais 8 (PL8), the Tucana-Horologium association (THA), 32 Orionis (THOR), TW Hya (TWA), Upper Centaurus Lupus (UCL), the core of the Ursa Major cluster (UMA), Upper Scorpius (USCO), Taurus (TAU), and $\Sigma$ For XFOR.

a Peak of distance distribution and ±1σ range.
b Peak of radial velocity distribution and ±1σ range.
c Characteristic spatial scale in XYZ space.
d Characteristic kinematic scale in UVW space.

References. (1) Mamajek (2016), (2) Bell et al. (2015), (3) Zackerman et al. (2006), (4) Silaj & Landstreet (2014), (5) Murphy et al. (2013), (6) Brandt & Huang (2015), (7) Pecaut & Mamajek (2016), (8) Murphy & Lawson (2015), (9) Platais et al. (1998), (10) Kenyon & Hartmann (1995), (11) Jones et al. (2015), (12) Pöhli & Paunzen (2010).
proper motion of the targets and to verify that their colors were consistent with their absolute Gaia G-band magnitudes (e.g., see Figures 1 and 2). This step allowed us to remove 504 contaminants that corresponded to unphysical entries in the Gaia catalog. Their distribution in relative G-band magnitude versus Galactic latitude is displayed in Figure 3 compared to the full input sample, which demonstrates that most of the unphysical Gaia DR2 parallax solutions are caused by cross-match confusion of faint objects near the Galactic plane. Most of them can also be rejected from an inspection of the ASTROMETRIC_SIGMA5D_MAX and VISIBILITY_PERIODS_USED flags in the Gaia DR2 catalog, which respectively correspond to the maximal measurement error of all astrometric solution parameters (in mas) and to the number of epochs that were used in the solution (see Figure 4). However, a simple rejection filter based on these criteria would also inevitably reject some good solutions.

A total of 250/261 initial entries with Gaia DR2 parallax measurements in the range 3–8 times larger than the measurement error were rejected by our visual inspection of the finder charts. A large fraction of low-precision parallaxes thus corresponded to unphysical Gaia DR2 entries, but we keep the remaining 11 low-precision entries because they likely correspond to valid late-M or early-L candidate members.

Our literature search revealed that 36 of our new candidate members without a Gaia DR2 radial velocity have such measurements in the literature, 6 of which rejected the membership hypothesis.

There are four high-probability candidate members of βPMG and ABDMG in our sample that appear in the literature as candidates of the more distant PLE and HYA associations and the TAU and Sco–Cen star-forming regions. These objects were rejected from our sample as a consequence of this, but we provide below a short discussion of their membership.

Both 2MASS J17513421–4854558 (≈M1) and 2MASS J17194204–4615275 (M2; Galicher et al. 2016) were identified as young candidate members of USCO with Li absorption (290 mÅ and 520 mÅ, respectively) by Song et al. (2012). However, their Gaia DR2 trigonometric distances (66.5 ± 1.2 pc and 53.0 ± 0.2 pc, respectively) preclude membership in USCO and strongly favors membership in the βPMG. In both cases, radial velocity measurements are still needed to confirm their membership, but the Gaia DR2 parallax measurements safely reject membership in USCO.

2MASS J04203904+2355502 was identified as a L1 candidate member of the TAU star-forming region by Luhan (2006), but he noted that its with weak spectroscopic signatures of low surface gravity were indicative of an age between that of TAU and field brown dwarfs. Its trigonometric distance from Gaia DR2 (38.7 ± 1.3 pc) makes it a candidate member of the
members compiled by Gagné et al. or their respective young associations. The list of consistent with the known young members and candidate color

Figure 4. Maximum measurement error on all parameters of the Gaia DR2 astrometric solution (ASTROMETRIC_SIGMA5D_MAX) vs. the number of visibility windows used in the solution (VISIBILITY_PERIODS_USED) for the full sample (black circles) and those rejected as unphysical entries by a visual examination of the finder charts (red crosses). As expected, entries with fewer epochs and larger error bars are more prone to corresponding to unphysical objects, but a simple rejection criterion based on these parameters would also reject some good solutions. See Section 3 for further details.

ABDMG in the foreground of TAU. A radial velocity measurement is still needed to fully confirm its membership in the ABDMG.

2MASS J04254357+1616214 was identified by Bouvier et al. (2008) as a low-probability candidate member of the HYA; however, its nearby distance (67.0 ± 0.3 pc) makes it a candidate member of the βPMG instead. The same is true of 2MASS J04341301+1510569 (van Altena 1966), but its distance (49.1 ± 0.2 pc) makes it a viable candidate member of the ABDMG.

We used Gaia absolute G-band magnitude versus $G - G_{RP}$ color–magnitude diagrams to further reject any candidates not consistent with the known young members and candidate members or their respective young associations. The list of members compiled by Gagné et al. (2018) was compared to our candidates one group at a time (e.g., see Figure 5) and any candidates significantly fainter than the young sequences were rejected from our sample. This step rejected an additional 327 candidates, most of them in ABDMG (114), βPMG (79), and COL (37). This is consistent with the determination of Gagné et al. (2018) that these associations are the ones most likely subject to contamination by unrelated field interlopers in kinematic-based searches, mostly because of their proximity (i.e., their members cover a larger fraction of the sky).

4. Discussion

Our sample of new candidate members is the first step toward filling a gap in the current census of low-mass stars in young associations. Until now, obtaining trigonometric parallax measurements for a large number of low-mass stars has prevented completing the census of young associations, particularly in the M spectral class, which are fainter and much more numerous than the more massive members. Previous works have been successful at identifying a large fraction of the early M-type members (e.g., Shkolnik et al. 2012, 2017; Malo et al. 2013, 2014a; Kraus et al. 2014; Gagné et al. 2018b), but there remains a dearth of late-M type members. In Figure 6, we show a color–magnitude diagram of the current census of bona fide members (Gagné et al. 2018), compared with the sample discussed here. This figure demonstrates how Gaia DR2 is particularly powerful at completing the faint, low-mass end of the color–magnitude diagram.

An advantage of Gaia DR2–based searches is that trigonometric distances make it possible to cover the Galactic plane with significantly less contamination than searches based on only proper motion. In Figure 7, we show the distribution in sky positions of the new candidate members identified here. This figure demonstrates how our search is not biased away from the Galactic plane like most previous all-sky searches (e.g., Gagné et al. 2015b). Confirming membership still requires a spectroscopic follow-up to assess their youth and measure their radial velocities. In this section, we estimate the basic properties of the new candidates uncovered here in order to guide future telescope observations.

4.1. Photometric Spectral-type Estimates

In this section, we build an absolute G-band magnitude versus spectral-type sequence in order to estimate the spectral types of the new young association candidates discovered here. We preferentially include young stars and brown dwarfs with ages $\sim$5–200 Myr, which are more representative of our sample, but we do not build separate sequences at different ages because only approximate spectral types will be calculated.

We cross-matched the lists of bona fide members of young associations compiled by Gagné et al. (2018) with Gaia DR2 to build the bulk of the sequence across the stellar domain. Because the current list of bona fide members is incomplete for spectral types later than $\approx$K0, we added the lists of candidate members compiled by Gagné et al. (2018b) and Gagné et al. (2018a), which cover spectral types down to $\approx$M5, and the known young brown dwarfs compiled by Faherty et al. (2016) and Gagné et al. (2015a). The resulting list of young objects contains a small number of objects in the ranges of spectral types M6–M9 and L5–T0, and we therefore completed these spectral ranges with the compilations of Hawley et al. (2002), Cruz et al. (2007), West et al. (2008), and Smart et al. (2017). These data likely do not represent the full spread in absolute G-band magnitudes that are due to young ages, but they remain useful to estimate spectral type.

We calculated the median absolute G-band magnitude and the corresponding standard deviation for each spectral type in the range B5–L9 with bins of 0.5 subtypes using the compilation described above. A 3σ outlier rejection step was then applied, and the median and standard deviation across the full sequence was re-calculated. The resulting sequence is displayed in Figure 8 and was used to estimate the spectral types of the new candidates identified here unless they already had a measured spectral type in the literature. The average standard deviation around the resulting sequence is $\approx$0.6 mag, which corresponds to a spectral-type uncertainty of 3–5 subtypes, depending on spectral class. The resulting spectral-type estimates are listed in Table 2 with our compilation of new candidate members. We compare the distribution of estimated spectral types in the current sample with the known members and candidate members of young associations in Figure 9.
4.2. Chromospheric Activity

One of the well-known signs of youth for early- and mid-type M dwarfs is their chromospheric activity compared (e.g., Rodriguez et al. 2011; Shkolnik et al. 2011; Malo et al. 2014a; Schmidt et al. 2015). Signatures of high chromospheric activity include overluminosity at X-ray and ultraviolet wavelengths, as well as strong Hα emission (e.g., West et al. 2008; Schmidt et al. 2015) and a high rate of flares (e.g., Schmidt et al. 2007; Davenport et al. 2012). While assessing the latter two characteristics in our sample will require follow-up at the telescope in spectroscopy and imaging, the X-ray and ultraviolet properties of several new candidates presented here can already be obtained from the ROSAT all-sky survey (Boller et al. 2016) and the GALEX catalog (Martin et al. 2005).

We cross-matched our sample of candidates with the second ROSAT all-sky catalog to obtain their X-ray luminosity and compare them with the young and field samples of early- to mid-M dwarfs of Malo et al. (2014a). We used the Gaia DR2 proper motions and positions to project back positions to epoch 1994.5 and used a cross-match radius of 30″, yielding 194 matches. The resulting X-ray luminosities are compared with the field objects and the ABDMG and βPMG candidate members of Malo et al. (2014a) in Figure 10. Most of our candidates demonstrate a clear X-ray overluminosity compared to the field sample of Malo et al. (2014a) and are consistent with ages younger than ∼200 Myr, which is expected based on the ages of the young associations considered here (see Table 1).

A similar cross-match was performed with the data release 5 of GALEX (at epoch 2007.5 and a cross-match radius of 10″) and yielded 180 matches. The NUV − G GALEX–Gaia color of our sample versus its G − R Gaia color (which traces the spectral type) are compared to a sample of field stars and recovered known candidates or bona fide members in Figure 11. Most of the new candidate members identified here have unusually blue NUV − G colors compared to field stars, which is a signature of high chromospheric activity.

4.3. Comoving Systems

We searched the Gaia DR2 catalog for comoving systems by examining a 2′ radius around each source in our sample of new candidate members. We searched for objects with proper motions within 10 mas yr⁻¹ and a trigonometric parallax within 5 mas of each other. We chose these very conservative limits to identify only the most likely comoving systems while

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**Figure 5.** Color–magnitude diagrams of known bona fide members (blue circles) and candidate members (filled red circles) of young associations of similar ages (Gagné et al. 2018) compared to the new candidate members identified in this work (filled red circles). All candidates too faint to be consistent with their respective association (orange crosses) were rejected from our sample. See Section 3 for further details.

**Figure 6.** Gaia DR2 color–magnitude diagram of known bona fide members in young associations (black open circles) compiled in Gagné et al. (2018). We choose G − G_Gaia as a comparison color because photometric quality in Gaia DR2 remains good down to the substellar regime. New candidate members identified in this work are displayed as red open circles. These data include pre-main-sequence as well as main-sequence objects, depending on their masses and ages, which explains the large scatter especially at low masses (red color). Some of the slightly older and more massive objects have also started to depart from the main sequence. See Section 4 for further details.
minimizing contamination from chance alignments. Deriving false-contamination probabilities at larger spatial or kinematic separations will require a careful examination of chance alignments within the members of a young association (e.g., see Gagné et al. 2017).

Our conservative criteria identified 104 comoving systems, 82 of which are comoving with an object outside of our sample. Sixteen of the latter cases are new companions to known bona fide or candidate members of young associations. In 40 cases, we identified a comoving system that had a radial velocity measurement in the literature. Including this measurement in BANYAN $\Sigma$ allowed us to reject 12 candidate members from our sample and strengthen the membership of 28 others. All comoving systems identified here are listed in Table 3.

### 4.4. Isochrone Ages

We compared the absolute Gaia G-band magnitudes versus $G - R$ color of our new mid- to late-M-type candidates ($G - G_{RP} > 1.3$ mag) with those of the MIST solar-metallicity tracks v1.1 (Choi et al. 2016). We used the Bayesian method described by Gagné et al. (2018b) to verify if we find relative
differences in the distribution of isochrone ages in our candidate members of associations with different ages. The resulting isochrone age distributions for our targets are displayed in Figure 12. We note that the MIST isochrone age estimations ignore the contribution of magnetic fields and are therefore expected to be systematically too low, but the relative differences in age distribution between candidates in associations of different ages can already be seen clearly. See Section 4.4 for further details.

4.5. Brown Dwarfs

We used the bolometric luminosity versus spectral-type relations of Faherty et al. (2016) combined with the Saumon & Marley (2008) evolutionary tracks to obtain a rough estimate of the spectral types that correspond to the substellar regime at the age of each young association considered here. We used these estimates to identify a total of 111 objects in our sample that are new brown dwarf candidate members in young associations with spectral types later than M6–L2, depending on the age of the young association they likely belong to. Obtaining near-infrared spectra yield gravity-sensitive spectroscopic indices (e.g., Allers & Liu 2013) and will provide valuable data for interpreting atmospheres similar to those of gaseous giant planets (e.g., Marois et al. 2008; Rameau et al. 2013). Ultimately, this sample will place constraints on the very low mass end of the initial mass function (e.g., Gagné et al. 2015a).

There are 19 brown dwarfs in our sample with estimated spectral types in the L class. Their parallax measurements are 7–90 times larger than the measurement errors, with a median of 25. They are listed in Table 4.

4.6. Tentative Indications of Spatial Extension

It can be expected that the current census of the nearby young associations is biased toward nearby distances because our knowledge of their spatial distribution is still based on members bright enough to have been detected by the Hipparcos mission (Perryman et al. 1997). Recent discoveries (Bowler et al. 2017; Desrochers et al. 2018) suggested, for example, that the ABDMG might be larger than previously thought, and its very similar kinematics and age to the more distant Pleiades association (e.g., see Luhman et al. 2005; Soderblom et al. 2014; Gagné et al. 2018) raises the question of whether the two associations may be related. In its default setting,
Table 2
New Candidates Identified in This Work

| Name          | Spectral Type | Assoc. | R.A. | Decl. | $\mu_x \cos \theta$ | $\mu_y$ | Parallax | Rad. Vel. | Ambiguous | Reference |
|---------------|---------------|--------|------|-------|---------------------|---------|----------|-----------|-----------|-----------|
| J0644−4137    | (M4)          | ABDMG  | 06:44:54.065 | −41:37:27.38 | $-5.17 \pm 0.07$ | $-20.89 \pm 0.07$ | 20.37 ± 0.04 | ...       | ...       |          |
| J0646+1015    | (M6)          | ABDMG  | 06:46:05.803 | +10:15:37.96  | $-19.38 \pm 0.38$ | $-98.25 \pm 0.44$ | 16.95 ± 0.14 | ...       | ...       |          |
| J0650−3203    | (M5)          | ABDMG  | 06:50:27.278 | −32:03:19.11  | $-26.22 \pm 0.08$ | $-54.64 \pm 0.09$ | 31.70 ± 0.05 | ...       | ...       |          |
| J0700−4447    | (M6)          | ABDMG  | 07:00:34.277 | −44:47:13.56  | $-43.50 \pm 0.25$ | $-14.42 \pm 0.25$ | 45.22 ± 0.13 | ...       | ...       |          |
| J0703−4152    | (M9)          | ABDMG  | 07:03:02.270 | −41:52:22.686 | $-11.7 \pm 1.2$ | $-20.2 \pm 2.5$ | 20.72 ± 0.86 | ...       | ...       |          |

Notes.
- Spectral types between parentheses were estimated from the absolute Gaia G-band magnitude.
- J2000 position at epoch 2015 from the Gaia DR2 catalog.
- List of associations in ambiguous cases with their relative probabilities (%) between parentheses.
- References for spectral type and radial velocity, respectively.

References. (1) West et al. (2011), (2) Bardalez Gagliuffi et al. (2014), (3) Cruz & Reid (2002), (4) Lindegren et al. (2018), (5) Comoving star; (6) Gray et al. (2006), (7) Phan Bao et al. (2008), (8) Alonso-Floriano et al. (2015), (9) Stephenson (1986), (10) Reid et al. (1995), (11) Abt & Cardona (1984), (12) Wilson (1953), (13) Abt & Morrell (1995), (14) Newton et al. (2014), (15) Scholz et al. (2005), (16) Malo et al. (2014a), (17) Wright et al. (2003), (18) Reid et al. (2004), (19) Jeffries (1995), (20) Houk (1982), (21) Riaz et al. (2006), (22) Herbig et al. (1986), (23) Houk & Smith-Moore (1988), (24) Reid et al. (2007), (25) Kunder et al. (2017), (26) Desidera et al. (2015), (27) Gray et al. (2003), (28) Fleming et al. (1988), (29) Schlieder et al. (2012), (30) Gaidos et al. (2014), (31) Lépine et al. (2013), (32) Kirkpatrick et al. (2008), (33) Koen et al. (2010), (34) van Belle & von Braun (2009), (35) Faherty et al. (2009), (36) Cook et al. (2016), (37) Kirkpatrick et al. (1991), (38) Evans et al. (1964), (39) Duflot et al. (1995), (40) Allen et al. (2007), (41) Dieterich et al. (2014), (42) Law et al. (2008), (43) Deshpande et al. (2013), (44) Bowler et al. (2015), (45) Shkolnik et al. (2012), (46) Pesch (1968), (47) Guieu et al. (2006), (48) Luhman (2006), (49) Jones & West (2016), (50) Rodriguez et al. (2013), (51) Roiter et al. (2007), (52) Evans (1967), (53) Gontcharov (2006), (54) Cruz et al. (2003), (55) Houk & Cowley (1975), (56) Upgren (1962), (57) Gagné et al. (2015a), (58) Torres et al. (2006), (59) Comerón et al. (2013), (60) Krautter et al. (1997).

(This table is available in its entirety in machine-readable form.)
BANYAN Σ compares the XYZ Galactic positions of objects to a fixed spatial model of young associations, and is therefore not designed to uncover such spatial extensions of known associations. Our search did not identify candidate members of ABDMG at larger distances, but this could be entirely caused by our bias in recovering new candidate members that are located spatially near those already known. Future work will be needed to explore this possibility. BANYAN Σ has the option to consider only UBV space velocities in its search for new candidate members, but in this case it will be important to confirm the youth of the candidate members because searches based on UBV only will suffer significant contamination from random field interlopers.

Our survey has, however, identified a possible extension of the TWA to slightly larger distances (see Figure 13) that may bridge it to the LCC region of the Sco–Cen star formation complex. Searches for new candidate members in TWA have been known to be contaminated by the LCC region of the Sco–Cen star formation complex (e.g., see Gagné et al. 2017); however, BANYAN Σ now includes a model of LCC. We uncovered five candidates at the far end of TWA that have a zero LCC membership probability, and four slightly more distant candidates that are most likely TWA candidates but have non-negligible membership probabilities in LCC. Determining the ages of these stars seemingly bridging the two associations may allow us to understand whether they are simply contaminants or whether TWA and LCC are related.

Our sample of new candidates in CAR and COL also shows slightly different spatial distributions than the currently known bona fide members (see Figure 14). Confirming the radial velocities and youth of the new candidates will be required to determine whether the spatial models of BANYAN Σ will need to be refined and to test whether the spatial distribution of the lower-mass members are distinct from those of the more massive members. The distributions of new candidate members closely followed that of known bona fide members for all other associations and spatial–kinematic projections.

4.7. New Bona Fide Members

There are 17 B9–G8 stars in our sample that have full kinematics and were not previously recognized as candidate members of young associations in the literature. We calculated MIST isochrones for them (see Section 4.4 for further details) and report them in Table 5 as new bona fide members of their respective young associations. All of them have ages consistent with their young association, except for iot Cen (7 ± 4 Myr), which is much too young to belong in CARN. The ages of the F-type stars in Table 5 cannot be constrained with isochrones, and it will be difficult to pose any age constraints for these stars. In addition to these, there are 15 stars in our sample that are comoving with a known bona fide member (see Section 4.3). They are also reported in Table 5.

5. Conclusions

We used the BANYAN Σ algorithm with the nearest 100 pc entries in the Gaia DR2 to identify 898 new candidate members with spectral types in the range B9–L2 in the 27 nearest young associations from an initial sample of 3158 candidates (1411 were already known in the literature, 504 Gaia DR2 entries were rejected from a visual examination of finder charts, and 18 were rejected with a literature radial velocity measurement). One hundred and four of these objects are comoving systems and will serve as important benchmarks for the calibration of atmosphere and evolutionary models. Spectroscopic follow-up of these targets to obtain radial velocities and signatures of youth such as lithium absorption will be needed to confirm their membership. Our search identified mostly mid-M candidate members, which contribute
most importantly to the initial mass function. The ongoing TESS mission (Ricker et al. 2015) will uncover exoplanet companions to several of these nearby M dwarfs with the transit method. Identifying age-calibrated stars among the TESS sample in 27 distinct populations with ages in the range \( \sim 2\sim 750 \) Myr will provide crucial information on the fundamental parameters of these future exoplanet discoveries and will inform how the structure of planetary systems evolve with time.

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Table 4

| Spectral Type<sup>a</sup> | Assoc. | R.A.<sup>b</sup> (hh:mm:ss.sss) | Decl.<sup>b</sup> (dd:mm:ss.ss) |
|--------------------------|--------|-------------------------------|------------------------------|
| (L0) ABDMG               | 01:38:47.53 | −34:52:32.8                   |
| (L1) HYA                 | 04:33:56.71 | +05:37:23.7                   |
| (L1) HYA                 | 04:45:43.83 | +12:46:31.2                   |
| (L2) ABDMG               | 05:08:16.60 | −14:13:49.6                   |
| (L2) ABDMG               | 05:19:28.80 | −45:06:38.1                   |
| (L1) ABDMG               | 05:44:57.42 | +37:05:00.5                   |
| (L1) COL                 | 06:16:56.25 | −25:43:55.9                   |
| (L5) CAR                 | 07:23:52.61 | −33:09:43.0                   |
| (L1) CAR                 | 09:18:56.29 | −61:01:18.7                   |
| L2 CAR                   | 09:28:39.53 | −16:03:12.4                   |
| (L2) CAR                 | 09:42:32.37 | −25:51:37.6                   |
| (L1) CAR                 | 11:50:42.86 | −29:14:48.9                   |
| L4 CAR                   | 12:13:02.96 | −04:32:44.3                   |
| (L2) BPMG               | 18:10:35.72 | −55:13:45.0                   |
| (L1) BPMG               | 18:26:46.80 | −46:02:24.5                   |
| (L1) ABDMG               | 18:40:59.39 | −09:59:17.5                   |
| (L3) BPMG               | 21:04:31.36 | −09:23:22.7                   |
| (L1) ABDMG               | 21:13:41.87 | +35:07:39.6                   |
| (L2) ABDMG               | 23:54:12.69 | +22:08:21.2                   |

Notes.

<sup>a</sup> Spectral types between parentheses were estimated from the absolute Gaia G-band magnitude.

<sup>b</sup> J2000 position at epoch 2015 from the Gaia DR2 catalog.
Table 5
New Bona Fide Members

| Name                  | Spectral Type | Assoc. | R.A.\(^a\) | Decl.\(^b\) | MIST Age (Myr) | Comoving |
|-----------------------|--------------|--------|-------------|-------------|----------------|----------|
| 2MASS J00395354–3817176 | (M4)         | THA    | 00:39:35.48 | −38:17:18.7 | ...            | 2MA039-3816\(^c\) |
| 2MASS J01484771–4831156 | (M5)         | ABDMG  | 01:48:47.90 | −48:31:16.4 | ...            | GSC 08044-00859 |
| UCAC3 222–12335       | (M5)         | HYA    | 02:58:06.06 | +20:40:01.3 | ...            | 47 Ari    |
| UCAC4 311–003056       | (M4)         | COL    | 03:07:49.18 | −27:50:47.0 | ...            | HD 19545  |
| UCAC3 262–003815       | (M2)         | THA    | 03:48:40.51 | −37:38:20.0 | ...            | C23DM J03486-3737 |
| 2MASS J03530890–1719444 | (M5)         | HYA    | 03:53:09.08 | +17:19:44.1 | ...            | HD 24357  |
| 2MASS J01495770–1402413 | (M4)      | HYA    | 04:19:57.83 | +14:02:40.8 | ...            | h Tau     |
| UCAC3 126–11943       | (M5)         | THA    | 03:48:45.73 | −27:02:02.2 | ...            | HIP 21632 |
| 2MASS J04400675–2536457 | (M4)         | HYA    | 04:40:06.89 | +25:36:44.7 | ...            | HD 283810 |
| UCAC3 12193316–6440520 | (M3)         | LCC    | 10:19:03:08 | −64:40:51.9 | ...            | C23DM J10191-6441 |
| UCAC3 12193316–6440520 | (M3)         | LCC    | 13:25:58:04 | −51:11:44.9 | ...            | HD 116651 |
| UCAC3 16572144–5343277 | (M5)         | BPGM   | 16:57:21.41 | −53:43:29.2 | ...            | 2M1657-5343\(^d\) |
| UCAC3 16183775–3839104 | (M4)         | UCL    | 16:18:37:72 | −38:39:11.0 | ...            | HIP 79908 |
| UCAC3 74–42846        | (M2)         | BPGM   | 17:48:33:74 | −53:06:12.7 | ...            | HD 161460 |
| HD 223340             | K1V          | ABDMG  | 23:48:50.61 | −28:07:17.3 | ...            | del ScI   |

Notes.

\(^a\) Spectral types between parentheses were estimated from the absolute Gaia G-band magnitude.

\(^b\) J2000 position at epoch 2015 from the Gaia DR2 catalog.

\(^c\) The full name of this object is 2MASS J00395379–3816584.

\(^d\) The full name of this object is 2MASS J16572029–5343316.

in the Gaia MultiLateral Agreement (MLA). The Gaia mission website is https://www.cosmos.esa.int/gaia. The Gaia archive website is https://archives.esac.esa.int/gaia. This research was started at the NYC Gaia DR2 Workshop at the Center for Computational Astrophysics of the Flatiron Institute in 2018 April.

J.G. wrote the codes, manuscript, generated figures, and led all analysis; J.K.F. provided help with parsing the Gaia DR2 data as well as general comments.

Software: BANYAN $\Sigma$ (Gagné et al. 2018).

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