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A Pre-Gaia Census of Nearby Stellar Groups

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Abstract. The nearest, youngest groups of stars to the Sun provide important samples of age-dated stars for studying circumstellar disk evolution, imaged exoplanets, and brown dwarfs. I briefly comment on the status of the known stellar groups within 100 pc: β Pic, AB Dor, UMa, Car-Near, Tuc-Hor and β Tuc nucleus, Hyades, Col, TW Hya, Car, Coma Ber, 32 Ori, η Cha, and χ^1 For. I also discuss some poorly characterized groups and "non-groups." Grades for 2015 of *Pass*, *Satisfactory*, or *Fail* are assigned to the groups for the purposes of age-dating stars and brown dwarfs. I speculate that Tuc-Hor could have provided a supernova ~60 pc away ~2.2 Myr ago which showered the Earth with traces of ^{60}Fe-bearing dust.

Keywords. open clusters and associations: general — solar neighborhood — stars: distances

1. Introduction

The stellar groups within 100 pc offer unique samples to investigate the results of the star and planet formation process at ages $\sim10^7$-10^9 yr. Members of these groups have provided some of the first and best examples of imaged dusty debris disks, imaged extra-solar planets, and young substellar objects. Given the page limits, I will just summarize some under-appreciated and new aspects of these groups (and apologize for the lack of figures). Recent discussions on these groups can be found in Zuckerman & Song (2004), Torres *et al.* (2008), Riedel *et al.* (2014), Malo *et al.* (2014), and Gagne *et al.* (2014). **Table 1** is a compilation of the stellar clusters and associations within 100 pc (with best estimates of velocities and ages). For those interested in adopting ages to stars based on their membership to one of these kinematic groups (and assuming the star exhibits some secondary indicators hinting at coevality with the group), I assign grades of *Pass* (§2), *Satisfactory* (§3), or *Fail* (§4). Table 1 only contains the *Pass* and *Satisfactory* groups.

2. Physical Groups (Grade: Pass)

The **Ursa Major**, **Hyades**, **Coma Ber**, and η **Cha** groups are clearly real *clusters.* The young (~10 Myr) η Cha cluster's density is roughly ~30 $M_\odot\,pc^{-3}$ - the densest of any cluster within 100 pc - while the older clusters (~0.5 Gyr) are lower density (~0.3-3 $M_\odot\,pc^{-3}$), but all exceed the local disk density (~0.1 $M_\odot\,pc^{-3}$). The ~10 Myr-old **TW Hya** *association* is a well-characterized group of ~3 dozen stars (Kastner *et al.* 1997, Mamajek 2005, Weinberger et al. 2013, Ducourant *et al.* 2014), and will not be discussed further. The β **Pic** *association* was recently reviewed by Mamajek & Bell (2014, and references therein). Ages of <20 Myr can be discounted as the 6 A-type members plus the F0 member 51 Eri are all on the ZAMS. For the "classic" age of 12 Myr adopted for β Pic for most of the past decade, *all* isochrones would predict that late A- and early F-type members should be very much pre-MS (alas, they are not). MS turn-on ages and Li depletion boundary ages appear to be in agreement with a mean age of 23 ± 3 Myr.

Table 1 lists the mean distance to the **AB Dor** *nucleus* based on revised Hipparcos parallaxes (van Leeuwen 2007) for nuclear members listed by Zuckerman et al. (2004).

Table 1. Catalog of Stellar Groups Within 100 pc

Group	Dist	Ref.	U	V	W	$\sigma_U, \sigma_V, \sigma_W$	σ_v	Ref.	Age	Ref.
...	pc	...	km/s	km/s	km/s	km/s	km/s	...	Myr	...
β Pic	$\sim15^a$	1	-10.9	-16.0	-9.2	0.3, 0.3, 0.3	1.5	2	23 ± 3	2
AB Dor	20.1 ± 1.6	3	-7.6	-27.3	-14.9	0.4, 1.1, 0.3	1.0	3	150^{+50}_{-30}	4
UMa	25.2 ± 0.3	5	14.6	1.8	-8.6	0.4, 0.7, 1.0	1.4	5	530 ± 40	6
Car-Near	33 ± 1	5	-24.8	-18.2	-2.3	0.7, 0.7, 0.4	1.3	5	~200	7
β Tuc	43 ± 1	5	-9.6	-21.6	-0.7	1.0, 1.3, 0.6	1.1	5	45 ± 4	4
Tuc-Hor	~48	9	-10.6	-21.0	-2.1	0.2, 0.2, 0.2	1.1	8	45 ± 4	4
Hyades	46.5 ± 0.5	10	-42.3	-19.1	-1.5	0.1, 0.1, 0.2	0.3	11	750 ± 150	6
Columba	~50	1	-12.2	-21.3	-5.6	1.1, 1.2, 0.9	...	...	42 ± 5	4
TW Hya	53 ± 2	12	-11.2	-18.2	-5.1	0.4, 0.4, 0.4	0.8	12	10 ± 3	4
Carina	~65	1	-10.5	-22.4	-5.8	1.0, 0.6, 0.1	...	...	45 ± 10	4
Coma Ber	87 ± 1	10	-2.4	-5.5	-0.6	0.1, 0.1, 0.1	0.4	13	560 ± 90	14
32 Ori	92 ± 2	4	-11.8	-18.5	-8.9	0.4, 0.4, 0.3	~1	5	22 ± 4	4
η Cha	94 ± 1	15	-10.2	-20.7	-11.2	0.2, 0.1, 0.1	1.5	15	11 ± 3	4
χ^1 For	99 ± 6	5	-13.1	-22.1	-3.7	0.4, 0.5, 1.1	...	5	$\sim50?$	5

Notes: Velocities are quoted on the standard Galactic coordinate system where U is towards the Galactic center, V is towards Galactic rotation ($\ell = 90°$), and W is towards the north Galactic pole (e.g. Johnson & Soderblom 1987). σ_U, σ_V, σ_W are uncertainties in the mean velocities, not velocity dispersion (σ_v is an estimate of the intrinsic 1D velocity dispersion). **References and Notes:** 1) Does not have well-defined concentration. Distance is to centroid estimated by Malo *et al.* (2014). 2) Mamajek & Bell (2014). 3) Barenfeld *et al.* (2013). 4) Bell, Mamajek, & Naylor (2015), see also Bell (this volume). 5) This work or Mamajek (unpublished). 6) Brandt & Huang (2015). Brandt & Huang (2015) have recently revised the Hyades age upward, however the -1σ uncertainty quoted encapsulates recent younger (~650 Myr) estimates e.g. de Bruijne et al. (2001). 7) Zuckerman *et al.* (2006). 8) Kraus *et al.* (2014). 9) mean kinematic distance to 120 Tuc-Hor members from Kraus et al. (2014) calculated using UCAC4 proper motions and space motion from Kraus. 10) van Leeuwen (2009). 11) de Bruijne *et al.*(2001). 12) Mean distance and velocity using astrometry from Ducourant *et al.* (2014), but omitting interlopers TWA 14, 15, 19, & 22. Velocity agrees well with Weinberger et al. (2013). Velocity dispersion from Ducourant *et al.* (2014) and Mamajek (2005). 13) Calculated using astrometry from van Leeuwen (2009) and radial velocity from Mermilliod et al. (2009), and velocity dispersion from Mermilliod *et al.* (2009). 14) Silaj & Landstreet (2014). 15) Murphy *et al.* (2013).

Omitting HIP 26369 due to large parallax uncertainty, the mean distance to the rest of the nuclear members is $20.1^{+1.7}_{-1.4}$ pc, with intrinsic 1σ dispersion of $\pm$4 pc. Barenfeld *et al.* (2013) showed that the group must be >120 Myr old, and the new analysis by Bell *et al.* (2015) estimates an isochronal age of roughly 150^{+50}_{-30} Myr. *There is no astrophysical support for ages as young as ~50-100 Myr that are commonly cited.* While the nuclear stars show remarkably coherent motions (1D dispersion ~1 km s^{-1}), and are obviously concentrated, the status of the rest of the AB Dor membership (i.e. the "*stream*") is unfortunately murkier (grade: S/F?). A spectroscopic analysis by Barenfeld et al. (2013) showed that only roughly half of purported AB Dor members sampled outside the nucleus were consistent with being co-chemical (i.e. possibly co-natal), hence the AB Dor group may share motions with other young stars of similar ages from different birthsites.

Zuckerman *et al.* (2006) discovered a nearby ~200 Myr-old group dubbed **Car-Near**. The mean distance to the Zuckerman nuclear members using revised Hipparcos astrometry is 32.7 ± 1.2 pc, with median RV = $+17.5\pm0.8$ km s^{-1}. The intrinsic velocity dispersion is only 1.3 ± 0.5 km s^{-1}. The group is puny (~8 $M_\odot$), but its inferred density is just below the local disk density. No objects are hotter than F1, and a thorough search of the Hipparcos catalog finds no plausible B/A members.

Kraus *et al.* (2014) have shown the **Tuc-Hor** group to be a much larger entity (>10^2 stars) than previously appreciated. Projections of the total stellar population based on the members found so far range from ∼200-400 (A. Kraus, priv. comm., Gagne et al. 2014, and calculation by author). The distribution of stars in Tuc-Hor appears somewhat filamentary and sheet-like over tens of parsecs - even at age ∼40 Myr. While the kinematic data are consistent with a velocity dispersion of only ∼1 km s^{-1}, the small extent of the group in Z suggests a dispersion of <0.2 km s^{-1}, analogous to that seen for small scale structures in the Taurus clouds. Combining the membership lists of Malo *et al.* (2014) and Kraus *et al.* (2014), one starts to see substructure in Tuc-Hor (see also Fig. 4 of Zuckerman et al. 2001). Tuc-Hor is draped across the southern sky, with several ill-defined clumps which may constitute subgroups: 1) a small clump of members in Pavo associated with the massive star Peacock (α Pav; B2.5; ∼6 $M_\odot$; $\alpha, \delta \simeq$ 306°, -57°; ∼55 pc); 2) another small clump in Indus associated with HR 8352 (HIP 108195; F1; α, δ $\simeq$ 329°, -62°; ∼46 pc); 3) another small clump associated with DS Tuc (HIP 116748; G5; $\alpha, \delta \simeq$ 355°, -69°; ∼46 pc); 4) the original β **Tuc** nucleus (discovered by Zuckerman & Webb 2000, listed separately in Table 1; $\alpha, \delta \simeq$ 8°, -63°; ∼43 pc); 5) to the heart of the **Horologium** subgroup centered on Achernar (B3; α, δ $\simeq$ 24°, -57°; ∼43 pc)†; 6) a small clump centered on η Hor (A6; α, δ $\simeq$ 39°, -52°.5; ∼46 pc); and 7) a small, diffuse clump near ϵ Hyi (B9; α, δ $\simeq$ 40°, -70°; ∼47 pc). Tuc-Hor does not appear so much as one large group as an ensemble of evaporating subgroups, with many of the low-mass members in the immediate vicinity of more massive stars (indeed, likely within the tidal radii, constituting unstable "trapezia"). Precise astrometry and further characterization of the membership of the Tuc-Hor complex with Gaia should yield a remarkable picture of a dynamical "missing link" between star-forming regions and the field population.

Given the number of 2-8 $M_\odot$ Tuc-Hor members known (∼7), a Salpeter IMF would predict ∼1 star with mass >8 $M_\odot$. Tuc-Hor may have eked out forming a star hotter than B2 which would have undergone supernova in the recent past. *It is possible that Tuc-Hor, and not Sco-Cen, was responsible for the supernova which produced the 2.2 Myr-old* ^{60}*Fe signal in sea floor ferromanganese crusts, and contributed to sweeping out the Local Bubble* (e.g. Fry *et al.* 2015). Tucana was only slightly further away (∼60 pc) from the Sun 2.2 Myr ago, well positioned to provide a ∼8 $M_\odot$ supernova close enough to Earth for its ^{60}Fe-enriched dust to pollute the Earth.

3. Likely Physical Groups; More Work Needed (Grade: Satisfactory)

The **Carina** and **Columba** groups are reported to be of similar ages and kinematics to Tuc-Hor (Torres et al. 2008). Bell *et al.* (2015) estimate new consistent isochronal ages of 45^{+11}_{-7} and 42^{+6}_{-4} Myr for Car and Col, respectively. I have tentatively included these in Table 1, however they clearly require further study.

32 Ori: This is a new group from Mamajek (2007) that will be discussed further in Bell et al. (2015) and Shvonski *et al.* (in prep.). Bell *et al.* was able to find a consistent age for a preliminary membership list ‡, of 22 ± 4 Myr.

† The ∼8.7 $M_\odot$ Achernar binary has *7(!)* K7-M5 Tuc-Hor members from Kraus *et al.* (2014) projected within its estimated tidal radius 2.8 pc $\simeq$ ∼3°.7: 2MASS J01344601-5707564, J01375879-5645447, J01504543-5716488, J01380311-5904042, J01505688-5844032, J01521830-5950168, J01275875-6032243. They display a clear Li-depletion boundary between ∼M4-M4.5 which could be used to independently age-date Achernar.

‡ 32 Ori, HD 35656, HD 35714, HD 36338, HD 35499, HD 35695, HD 245059, 2MASS J05200029+0613036, 2MASS J05203182+0616115, 2MASS J05234246+0651581, V1874 Ori, 2MASS J05253253+0625336, 2MASS J05194398+0535021. Group is centered near α, δ $\simeq$ 82°, +6°, with proper motion $\mu_\alpha, \mu_\delta \simeq$ +9, -35 mas yr^{-1} and mean radial velocity $+18.5 \pm 0.4$ km s^{-1}.

The **Alessi 13 (χ^1 For)** cluster (Dias et al. 2002) appears to consists of at least a dozen stars with masses in the range 0.9-2.4 $M_\odot$ (total mass ∼18 $M_\odot$) - anchored by the A1 stars χ^1 For and χ^3 For A ($\alpha, \delta \simeq 51°$, -36°; μ_α, $\mu_\delta \simeq$ +37, -4 mas yr^{-1}). Within a volume of ∼100 pc^3, these stars have a density of ∼0.2 $M_\odot$ pc^{-3} - roughly double the local disk density. Kharchenko *et al.* (2013) estimated an isochronal age of ∼525 Myr, but the MS turn-off is ill-defined. However, the X-ray emitting stars¶ *all* appear to have saturated emission (log(L_X/L_{bol} ≃ -3.4), more suggestive of an age more like ∼$10^{7.5}$ yr. Indeed, Alessi 13's velocity and position are suggestive that it may be part of the Tuc-Hor/Col/Car complex, which itself may be related to the Cas-Tau association.

4. Unphysical Groups or Streams (Grade: Fail)

While there are convincing cases of ∼40 Myr-old stars in **Argus** membership lists, Bell *et al.* (2015) were unable to assign an ambiguous isochronal age to the group. The scatter in HR diagram positions is highly suggestive that Argus is either seriously contaminated by interlopers, and/or may not constitute a coeval group (i.e. is a *stream*).

Zuckerman *et al.* (2013) proposed a new group of ∼14 systems dubbed **Oct-Near** with age ∼30-100 Myr. The group has a wide range in velocity, most importantly V and W (>5 km s^{-1}). The members do not appear to clump on the sky. The uniqueness of the velocities of these young stars is pointed out by Zuckerman *et al.*, however it probably warrants *stream* status at this point, and further investigation is needed.

Her-Lyr was defined by Gaidos (1998) and Fuhrmann (2004), with more recent adjustments by Lopez-Santiago *et al.* (2006) and Eisenbeiss *et al.* (2013). Fuhrmann has demonstrated that there is a clump in velocity space of young-ish stars within 25 pc, however given the large velocity dispersion (variously quoted at ∼3-4 km/s), the stars in most of these lists would not stay within each other's vicinity for very long. Lopez-Santiago *et al.* (2006) said their Her-Lyr members were *"chosen by their kinematics assuming a total dispersion of ±6 km s^{-1} in U and V, respectively... [t]he value of the dispersion has been chosen equal to that of the ∼200 Myr old Castor MG... coeval with the Hercules-Lyra Association. No restriction in the W component has been imposed in this first selection."* This is a recipe for selecting stars with a wide range of ages and birthsites (and whose sample mean age is likely to be of limited utility). There is remarkably little continuity in the published Her-Lyr membership lists. Only three stars have withstood the scrutiny of Fuhrmann, Lopez-Santiago *et al.*, and Eisenbeiss *et al.* as Her-Lyr "members": HD 10008, HD 166, and HD 206860, with the latter two being the sole surviving members from the original Gaidos study! Eisenbeiss *et al.* (2013) does show that the gyrochronology ages for these three stars are somewhat clustered (231, 315, 296 Myr, respectively). Extrapolation of the mass function for Her-Lyr by Eisenbeiss et al. (2013) predicts a population of ∼25 ∼200-300 Myr Her-Lyr M dwarf members within 25 pc. The spectroscopic and kinematic survey of local (<25 pc) X-ray-bright M dwarfs by Shkolnik *et al.* (2012) was designed to discover just such young M dwarfs. Their survey yielded only a *single* candidate Her-Lyr M dwarf. Thus far, Her-Lyr may constitute a *stream*, but I concur with Brandt *et al.* (2014) that membership to Her-Lyr should not be used for age-dating stars.

Mamajek *et al.* (2013) and Zuckerman et al. (2013) independently argued that the **Castor Moving Group** is unphysical. Purported Castor "members" have a wide velocity dispersion (∼3-6 km/s). The velocities of the key members (e.g. Fomalhaut, Vega, etc.) are sufficiently well-constrained that one can confidently conclude that they were

¶ TYC 7027-715-1, TYC 7027-852-1, TYC 7026-185-1.

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not near each other as recently as 10 Myr ago, let alone hundreds of Myr ago. The group should probably be considered the *Castor Stream*. The **IC 2391 Supercluster** and **Local Association** are streams that suffer from the same problems as Her-Lyr and Castor. Membership to these groups and adoption of group ages is unhelpful for age-dating stars.

The nearest Cepheid is the famous F8 supergiant **Polaris**, which is at least a triple system along with two F dwarfs. Turner (2004) proposed that Polaris belonged to a larger group†, and I've included it here as there are a range of distance estimates between ∼90-130 pc (Turner 2009). However, the recent trig parallax from van Leeuwen (2007) places it at ∼129 pc. Turner (2009) presented a CMD for Polaris's neighbors, but no kinematic analysis. If one adopts the Polaris space motion of Wielen et al. (2000) (U, V, W) = (-14.2 $\pm$ 1.2, -28.0 $\pm$ 0.8, -5.4 $\pm$ 1.0) $\mathrm{km\,s^{-1}}$, and convert it to a convergent point solution of α, δ = 107°, -31°, S_{tot} = 31.9 $\mathrm{km\,s^{-1}}$, one finds that Turner's stars are clearly not sharing motion (peculiar velocities of typically ∼5-10 km/s; too large to stay near Polaris over tens of Myr.). I have seen no evidence for a "Polaris cluster".

Chereul *et al.* (1999) reported the discovery of three new "loose clusters" in a Hipparcos study of density-volume inhomogeneities among nearby ($d < 125$ pc) A-F type stars. The closest of these ($d \simeq 89$ pc), was dubbed "Pegasus 2" by Chereul *et al.*, but appears as "**Chereul 3**" in WEBDA‡ and Dias et al. (2002). WEBDA currently lists Chereul 3 as the 3rd closest *open cluster*, while Dias *et al.* (2002) call it a *moving group*, and exclude it from their open cluster catalog. Despite their proximity, the Chereul cluster candidates have gone largely unstudied since their discovery. The memberships for these groups were not listed in Chereul et al. (1999), however they were kindly provided to the author by E. Chereul (priv. comm.). While Fig. 10 of Chereul *et al.* 1999 shows 8 members, the list from Chereul (priv. comm.) contained 6 Hipparcos systems¶. The revised Hipparcos parallaxes for these 6 stars indicate that they are at a range of distances (roughly ±20 pc rms about a mean distance of 95 pc). Unfortunately, their radial velocities in the compiled catalog of Gontcharov *et al.* (2006) have a large scatter (range: -38 to +16 km/s). Attempts to determine a robust convergent point solution for this sample which results in reasonable agreement between observed and predicted radial velocities, and trig and kinematic parallaxes, were unsuccessful. The HR diagram positions of the Chereul 3 stars are consistent with A/F-type main sequence stars drawn from a wide range of ages (0.4-2.5 Gyr). HIP 104338 and 104616 (54' separation) could comprise a wide physical pair (similar RVs and astrometry), but there is little to suggest any relation between the other purported members. I conclude that Chereul 3 is likely to be unphysical.

Chereul 2: Chereul *et al.* (1999) also reported a ∼800 Myr-old group dubbed "Pegasus 1", but listed as "Chereul 2" by WEBDA and Dias *et al.* (2002). E. Chereul (priv. comm.) listed 14 candidate members‖, for which I estimate mean distance 91 pc and E(B-V) = 0.04. However the parallaxes are consistent with intrinsic spread ±15 pc and the radial velocities range from -28.6 to +14.4 $\mathrm{km\,s^{-1}}$, with no obviously clumping. The HR diagram positions are consistent with isochronal ages between the ZAMS and $\sim 10^{9.4}$ yr, hence both the color-mag and kinematic data are consistent with Chereul 2 being unphysical.

Latyshev (1977) reported a candidate nearby open cluster in UMa (dubbed **Latyshev**

† Including HD 7283, 40335, 45919, 52908, 103435, 108862, & 118285.

‡ http://www.univie.ac.at/webda/

¶ Chereul 3 members: HIP 103652, 104338, 105902, 106488, 106783, 107120. One of these is resolved into two components by Hipparcos (HIP 103652) and one has an obvious wide separation companion (HIP 106781 is 39" from HIP 106783). Two A/F-type stars missing from Chereul's list which appear in Fig. 10 of Chereul *et al.* 1999 are HIP 104430 and 104616.

‖ Chereul 2 members: HIP 102299, 103261, 103652, 103813, 104771, 104884, 105478, 105608, 106362, 107585, 108389, 108439, 108441, 109349, & 110465.

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2 by Archinal & Hynes 2003) comprised of 7 A-type stars of similar proper motions and magnitudes††. With modern astrometry, it is clear that these stars have a wide range of space velocities (8 to 25 $\mathrm{km\,s^{-1}}$), and no consistent convergent point solution can be found which explains the observed range of radial velocities (-19 to -3 $\mathrm{km\,s^{-1}}$). The mean distance to the Hipparcos entries is 110 pc, but the kinematics indicate it is unphysical.

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†† SAO 28803, 28866, 28885, 28928, 28843, 28868, and 28891. SAO 28868 appears to be a typo in Latyshev (1977), as the star's properties clearly correspond to SAO 28862 instead.

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