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STELLAR KINEMATIC GROUPS. I. THE URSA MAJOR GROUP[1]

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ABSTRACT

The Ursa Major Group (UMaG) is studied as a test case for the authenticity of Stellar Kinematic Groups, using Coravel radial velocities, recent compilations of astrometric data, and new spectroscopic observations. Spectroscopic age indicators, particularly indices of the strength of chromospheric emission, are applied to solar-type candidate members of UMaG, and it is shown that stars that meet the spectroscopic criteria also have kinematics that agree better with the space motions of the nucleus of UMaG than does the starting sample as a whole. The primary limitation on the precision of kinematics is now parallaxes instead of radial velocities. These more restrictive kinematic criteria are then applied to other UMaG candidates and a list summarizing membership is presented. UMaG is also examined as a cluster, confirming its traditional age of 0.3 Gyr and a mean [Fe/H] of -0.08 ± 0.09 for those stars most likely to be *bona fide* members.

1. KINEMATIC GROUPS IN THE SOLAR NEIGHBORHOOD

Stars form in clusters and associations, but mostly end up in the field. Unless past star formation was very different than it is at present, stars now scattered through the Galaxy were born in Giant Molecular Clouds (GMCs). This progression from cohesion to dispersion has probably resulted from encounters of the young clusters with massive objects (perhaps the GMCs themselves), the same process that has produced the observed increase of Galactic scale height with age (disk "heating").

A disintegrating cluster must go through intermediate stages where the entire group cannot be identified, yet within some region one can find stars that are moving in nearly the same direction at nearly the same rate. Clusters dissolve on a time scale of about 0.2 Gyr (Wielen 1971), on average, so many of these groups should be young. A few old groups could conceivably be the last traces of former clusters. About a dozen stellar kinematic groups (SKGs) have been identified in the solar neighborhood (Table 1[3]). Their study goes back more than a century, and is particularly important for our understanding of the Hyades (Proctor 1869), but other groups of stars with the same proper motions (such as Praesepe and Sco-Cen) were included in the early researches (see, e.g., Rasmuson 1921) and the cluster of stars in Ursa Major was among them.

Much of the recent work in the study of SKGs is due to O. J. Eggen. SKGs are interesting in themselves as a "missing link" between clusters and field stars and their properties should offer clues into the forces that dissipate clusters. SKGs are also of interest in the study of stellar evolution because their members are nearby, thus bright; that means they can be studied in much greater spectroscopic detail than their cluster counterparts. All but three of the SKGs in Table 1 belong to the old disk or halo populations. Many of these groups have $\lesssim 10$ members, but a few have $\gtrsim 100$ members each. These objectives for the study of SKGs have not been realized in practice because of doubts about the reality of SKGs in general, and uncertainty over the membership of individual stars in particular. This paper examines this problem by using the Ursa Major Group (Eggen's "Sirius Group") as a case study, for reasons enumerated below.

1.1 What Constitutes a Stellar Kinematic Group?

To have astrophysical relevance, a SKG should have the same basic properties as a genuine open cluster (except for spatial compactness). Our working definition of an SKG is: (1) The stars should form a color–magnitude diagram (CMD) appropriate to stars of the same age and composition, with minimal scatter; and (2) they should be moving at the same rate and in the same direction through space, with only a modest velocity dispersion that reflects their lack of spatial cohesion. One might argue that SKGs are fundamentally different from genuine clusters because they have formed or evolved differently. For example, perhaps SKGs form over a longer period of time than a cluster

[1]Based in part on observations obtained at the Mount Wilson Observatory, at Lick Observatory, and on archival data from the *International Ultraviolet Explorer*. Also based on data from the SIMBAD retrieval system, a database of the Strasbourg, France, Astronomical Data Center.
[2]Guest Observer, *International Ultraviolet Explorer*.
[3]The velocities listed in this table are generally those of the defining star, taken from Woolley *et al.* (1970), and are meant to be indicative, not definitive. Also, this is not the place for a comprehensive review, and the references only indicate a few papers where those groups have been discussed. Many of these groups are in the catalogue of Alter *et al.* (1970) and subsequent supplements, to which the reader is referred. Individual groups are listed rather than Eggen's "superclusters," which are large-scale groupings of young open clusters and stars. Both the "Local Association" and the "Sirius Group" have been considered as superclusters by Eggen.

TABLE 1. Stellar kinematic groups.

Name	U	V	W	References
Ursa Major Group (Sirius Gr.)	+13	+1	−8	Roman (1949), Eggen (1960b)
γ Leonis Group	−78	−4	−1	Eggen (1959a, 1959b)
Hyades Group	−40	−16	−3	Eggen (1958a, 1958c)
Local Association (Pleiades Gr.)	−9	−27	−12	Eggen (1975)
Wolf 630 Group	+25	−33	+13	Eggen (1965c, 1969)
ϵ Indi Group	−78	−38	+4	Eggen (1958b, 1971a)
ζ Her Group	−52	−47	−27	Eggen (1958b, 1971a)
61 Cygni Group	−90	−53	−8	Eggen (1958b, 1964)
HR 1614 Group	−4	−58	−11	Eggen (1978, 1987)
σ Pup Group	−75	−88	−21	Eggen (1971a)
η Cephei Group	−33	−97	+10	Eggen (1964, 1971a)
Arcturus Group	+25	−115	−3	Eggen (1971b, 1987)
Groombridge 1830 Group	+277	−157	−14	Eggen and Sandage (1959)
Kapteyn's Star Group	+19	−288	−53	Eggen (1964)

does, so that its members have an appreciable spread in age. That is not inconceivable, but there seems little hope for using SKGs as probes of stellar evolution or for ascertaining their authenticity if our criteria for the genuineness of SKGs are relaxed significantly from those applied to genuine clusters.

SKGs need to have an additional criterion applied to determine their genuineness: It is mandatory that all members of an SKG have the same space motion in the direction of Galactic rotation—the V velocity.[4] The Galactic forces that dissolve clusters lead to diffusion of stars in all three directions. Motions in U and W lead to oscillations of the star about the mean motion of the group (see Binney & Tremaine 1987), but diffusion in V takes a star away from its cohort forever [see, e.g., the calculations of Woolley & Candy (1968) or Innanen & House (1970)]. For a subset of the original cluster to be in the solar neighborhood at the same time, those stars must have virtually identical V motions.

1.2 A Little Background

The study of SKGs goes back more than a century, and, like so much else in modern astrophysics, is indebted to E. Hertzsprung and H. N. Russell. The older literature is summarized in Roman (1949) for the Ursa Major Group, and in Eggen (1965a, 1970a) for moving groups in general (see also Eggen 1987, and, for an interesting discussion of the historical context of SKGs, see Eggen 1989). The recent literature is also rich and a number of authors have examined the problem of SKG membership and authenticity. This subject has not been recently reviewed, so it is worthwhile to summarize some results.

1.2.1 The Hyades Group

The Hyades Group (as opposed to the Hyades Cluster) is amenable to spectroscopic isolation because the Hyades is metal rich relative to the Sun and most other stars. Breger (1968) used the Strömgren δm_1 index, and found that only about half of the Hyades Group stars that Eggen (1958a, 1960a, 1963) listed were true members. Eggen (1970b), on the other hand, used the same technique but found that 70% to 80% of his candidates were likely members. Boyle & McClure (1975) reached the same conclusion as Breger (50% genuine membership) from DDO intermediate-band photometry of Hyades Group giants. In both cases, only about a quarter of the individual candidate stars could be reliably chosen as true members because of the overlap of the distributions of the cluster and field stars for the index used.

Williams (1971) was able to see some homogeneity among Hyades Group candidates (using narrow-band photometry to determine [Fe/H]). Wilson (1966) was the first to use chromospheric activity as a membership indicator when he applied it to some Hyades Group candidates and showed that most were probably not members of the parent cluster. Soderblom & Clements (1987) have applied some of the spectroscopic criteria discussed in the present paper to a few Hyades Group candidates, and most appeared to have the same age-related characteristics of legitimate Hyades Cluster stars. Boesgaard & Budge (1988) noted that the distribution of lithium abundances in Hyades Group candidates scattered much more than for stars of the Hyades Cluster, suggesting that the Group candidates might not be members. The Hyades Group as a whole appears to be real in a statistical sense (Ogorodnikov & Latyshev 1968).

1.2.2 The Wolf 630 Group

One may be more skeptical of older SKGs. How have they managed to stick together after many Galactic rotations when there are so few old open clusters? Most older stars—the Sun and α Centauri are good examples—have no obvious kinematic cohort. When examined photometrically and spectroscopically, the situation for old SKGs indeed appears worse.

[4]To avoid confusion, V will be used in this paper solely to designate this quantity. The apparent visual magnitude, for example, will be denoted by m_V. Also, the coordinate system used for spatial positions (X,Y,Z) and space motions (U,V,W) relative to the Sun is a right-handed one in which X and U are positive toward the Galactic center, Y and V point in the direction of Galactic rotation, and Z and W point toward the North Galactic Pole.

A good example of such a group is the Wolf 630 Group ("W630G") because it is well populated (Eggen 1969) and belongs to the old disk. Tuominen & Vilhu (1979) examined five W630G giants and found that four of them were possibly real members, because they were chemically homogeneous. Eggen (1970b) also found evidence for chemical homogeneity using Strömgren photometry. However, McDonald & Hearnshaw (1983) went through all of Eggen's proposed members of W630G, and constructed a CMD. They found that many of the stars could not be true members unless W630G is very different from the comparison sample (M67), or unless the observational errors in Eggen's photometry are much larger than he claimed. Boyle & McClure (1975) saw no difference between the distribution of the DDO $\delta_{\rm CN}$ index for W630G and a random sample of field stars. Proust & Foy (1988) determined spectroscopic metallicities for a number of SKG candidates. In particular, they derived $\langle[\mathrm{Fe/H}]\rangle = +0.23$ for three W630G candidates and set an upper limit of ~ 1 Gyr to the age of the group, based on estimated masses of $\sim 2\mathscr{M}_\odot$ for these stars. This conflicts markedly with Eggen's (1983b, 1986b) results, which suggest that W630G is very similar to M67 in age (about 5 Gyr) and has $\langle[\mathrm{Fe/H}]\rangle = -0.25$. Finally, Williams (1971) also studied the metallicities of giants in W630G with narrow-band photometry and could see no consistency.

1.2.3 Other groups

Zielke (1970) looked at five stars of the γ Leonis Group in spectroscopic detail, and found them inhomogeneous. Kovacs & Foy (1978) examined three stars in the ϵ Indi Group, and found that two were similar, but that one was distinctly metal deficient. Smith (1983) obtained DDO photometry of giants and dwarfs in Eggen's (1978) HR 1614 Group, and found a consistent pattern of high metal abundance that suggested group authenticity. Porto de Mello & da Silva (1991) compared the star ϕ^2 Pav to other ζ Her group members for consistency of composition and to examine the group CMD and drew no firm conclusion: they could not tell if the stars had much in common or not.

Common-proper-motion groups have also been studied. The Yale groups are inhomogeneous (Lü 1982, Lü & Tsay 1983, Lü & Lee 1983) in that they have similar proper motions but are spread out in distance, and therefore do not have parallel motions. Hanson & Vasilevskis (1983) observed subluminous stars in the region of the Hyades Cluster that share the Cluster's proper motion, and found them to be just background field stars.

There are also more positive results. Recently, Sommer-Larsen & Christensen (1987) discovered a sparse cluster in the Galactic halo that may be unbound (that cluster is less subject to tidal forces, however). Lodén (1973, 1980) has seen evidence for loose aggregates of very young stars in the southern Milky Way. Pavlovskaya & Filippova (1988) applied statistical tests to kinematic groups of Cepheids that they identified, and go on (Pavlovskaya & Filippova 1989) to associate open clusters with one another. This latter effort is not credible, however, since at least one of their "real" groups contains clusters that differ in age by nearly a dozen Galactic rotation periods, which is much too long for them to maintain kinematic cohesion.

Mention should also be made here of Ratnatunga (1988), who searched without success for members of the Hyades and Ursa Major Groups using the data in the *Bright Star Catalog* (Hoffleit & Jaschek 1982). This may be particularly telling for the Hyades Group, since so many bright stars have been nominated as its members, but is not so serious a problem for the Ursa Major Group (UMAG). Also, by looking at individual stars the present study is complementary to the work of Méndez & Ruiz (1992) and Méndez *et al.* (1992), who present statistical analyses of UMaG and the Hyades SKG.

1.2.4 Wide binaries

There is also a rich literature on the subject of wide binaries, which are no more than minimalistic SKGs. Lü & Upgren (1973) found that 60% of a sample of nearby K and M dwarfs were members of wide binaries, although their tolerance for differences in space velocities was generous (5 km s^{-1}). Beavers *et al.* (1983) have also examined nearby late-type dwarfs for pairings and found many possible duads. Brosche *et al.* (1992) find that about half of an initial sample of wide binaries are physical pairs. A summary of other recent research can be found in Dommanget *et al.* (1988).

Particularly interesting among the wide binary work is the effort by Lindroos (1986) to identify G- and K-type companions to O and B stars in the hope of finding pre-main-sequence stars in the field. Some of the Lindroos stars appear to be real post-T Tauris, but a number turn out to be nonphysical pairs once they are examined in detail (Pallavicini *et al.* 1992; Martín *et al.* 1992). We will also examine the Lindroos stars in the context of SKGs in a future paper.

1.3 Why the Ursa Major Group?

Given this generally bleak history, and the way in which membership lists for SKGs seem to change constantly, the subject being addressed seems more like "moving targets" than "moving groups." Nevertheless there are valid reasons for proceeding to examine the UMaG in detail.

(1) A tangible nucleus exists in Ursa Major. It is sparse, but provides a point of reference that is lacking for many of the SKGs of Table 1.

(2) The group at least appears to be real in a statistical sense (Ogorodnikov & Latyshev 1970).

(3) UMaG's propinquity (most of the stars considered here are within 25 pc) means that the kinematics of its stars are well determined in all three components of velocity, not just on the plane of the sky. Even low-mass members of UMaG are relatively bright, and so are often well observed.

(4) UMaG is believed to be only 0.3 Gyr old (von Hoerner 1957; Levato & Abt 1978; Giannuzzi 1979; Eggen 1983a; Tomkin & Popper 1986), which means that its age is about the same as the time scale for cluster dissolution

(0.2 Gyr; Wielen 1971), and so it should not have been torn apart as much as older SKGs.

(5) Reliable spectroscopic indicators exist to estimate the ages of young solar-type stars (Soderblom *et al.* 1991), in particular indices of chromospheric emission provide a means of assessing the likelihood of membership of an individual star that is independent of its kinematics.

(6) UMaG's space velocity is distinct from those of other young field stars (Soderblom 1990), so that there should be few interlopers to contaminate the sample. By comparison, the space velocity of the Pleiades is near the LSR, so that the contamination level is high, although the Hyades is well removed from the LSR.

(7) There are enough candidate members to make a study feasible and interesting. Thus UMaG offers an excellent test case for the study of SKGs (Soderblom 1983b), and, in turn, offers the potential of providing a sample of stars of an age not otherwise found in nearby open clusters.

This paper begins in Sec. 2 by discussing how spectroscopic data can be used to estimate ages for solar-type stars and describes the observations to be analyzed. Section 3 then examines what the spectroscopic data indicate about UMaG membership for the candidate solar-type stars. The kinematics of the cluster nucleus are examined in Sec. 4, and the solar-type stars compared to it in Sec. 5. If these selection criteria are valid, they should preferentially weed out the most kinematically discrepant stars, leaving a tighter group, which is what is seen. The membership of non-solar-type stars is assessed in Sec. 6, and UMaG is examined as a cluster. Section 7 summarizes the results.

Before proceeding, we need to establish two fundamental properties for UMaG. The first is that UMaG stars have about the same composition as the Sun. This is not a critical characteristic, but it makes it easier to determine temperatures and to compare the Group to calculated isochrones. At any rate it is borne out by observations (Boesgaard 1989) to the extent that UMaG stars may be slightly metal deficient ($\langle[\mathrm{Fe/H}]\rangle = -0.1$), but not by enough to matter in the present context. Later (Sec. 6), the metallicity of UMaG is shown to be probably within 20% of solar, even after substantially changing the stars used to determine $\langle[\mathrm{Fe/H}]\rangle$.

The other essential property for UMaG is its age, which we take to be 0.3 Gyr, the value consistently found over the years. Recent recalculations of the evolution of massive stars that incorporate core convective overshooting lead to consistently greater ages for young clusters than the traditional values, by about a factor of 2. That controversy is ignored here because these UMaG stars are compared directly to stars in other young clusters. A recent paper (Schaller *et al.* 1992) uses the same physics as that which lead to the revised ages, but corrections have brought the new cluster ages into line with the traditional ones, making the issue moot. The age of UMaG is also reexamined in Sec. 7.

2. AGE-DATING SOLAR-TYPE STARS

2.1 Spectroscopic Indicators of Age

UMaG was chosen for this study because it appears to form a genuine cluster consisting of a loose nucleus surrounded by a number of group stars corotating in the Galaxy. But the legitimacy of the group as a whole cannot confirm the membership of individual stars; additional information is needed. The virtue of treating a young SKG such as UMaG is that several related criteria exist to discriminate young solar-type stars from other field stars. At an age of only 0.3 Gyr, one expects only a small fraction of solar neighborhood stars to exhibit comparable age-related characteristics just by chance ($\lesssim 5\%$ if the characteristic changes monotonically with age), and for far fewer to do so that also possess the group's kinematics.

Solar-type stars evolve too slowly to be dated by evolutionary brightening, as high mass stars are, but they exhibit several other age-related properties. Most of these are connected in some way to the star's rotation. In a star like the Sun (by which is meant one with a convective envelope), the interaction of rotation (especially differential rotation) with convection leads to generation of magnetic fields through the dynamo mechanism. If this magnetic field is combined with an ionized wind, the star can lose angular momentum because the magnetic field forces corotation of the wind beyond the stellar surface, a process we witness on the Sun. Although the details of the dynamo mechanism are not well understood, this picture appears to account for the age-related behavior of low-mass stars. It implies that the decline of rotation with age is an inexorable consequence of the evolution of a star possessing a convective envelope. Such a statement cannot be proved, but there are no clear exceptions that disprove it and it provides an excellent paradigm for understanding much of the behavior of solar-type stars.

There are several observable manifestations of the magnetic field of a solar-type star: chromospheric emission reversals in deep absorption lines (such as Ca II H and K, Hα, or the Ca II infrared triplet), overt emission lines from the chromosphere and transition region observed in the ultraviolet, and x-ray emission from stellar coronae. There are direct correlations between rotation and the strengths of these emissions for field stars (Hartmann & Noyes 1987). The emissions are easier to observe than the rotation itself (less spectroscopic resolution is needed) and are not as mass sensitive, making them easier to interpret.

All of these emissions will be used here as indicators of age—hence UMaG membership—to the extent that data are available. How reliable are ages determined from chromospheric emission (CE)? A recent study by Soderblom *et al.* (1991) shows that there is a deterministic CE–age relation, so that CE is a reliable indicator of youth. Among very young stars (roughly younger than the Hyades) the relation breaks down because a broad range of activity is seen among stars of the same age within a cluster (Simon 1990), but young stars appear to always be active so that the qualitative character of activity is not lost.

The CE criteria are here applied conservatively, in the sense that a star is allowed to be at least a possible UMaG member unless the CE is so low as to certainly rule that out. One should not be too restrictive in applying CE as an age indicator among the youngest solar-type stars. For example, in the Hyades the intrinsic dispersions seen in CE, rotation, and Li abundance are all low (Soderblom 1985a; Radick *et al.* 1987; Soderblom *et al.* 1990), but the younger Pleiades shows appreciable scatter in all three quantities (Duncan & Jones 1983; Stauffer & Hartmann 1987; Soderblom *et al.* 1993a). UMaG is intermediate in age to these two clusters, and until its membership is better refined (or another cluster of similar age is observed) it is not possible to rule out the possibility of some intrinsic scatter in these quantities for stars of the same mass and age. Also, the CE criteria are applied only to the extent needed to refine Group membership so that those properties can themselves be examined in the context of UMaG as a cluster.

Eggen (1989) and Schmitt *et al.* (1990) have criticized the use of stellar activity as a membership criterion for UMaG because that forces assumptions about the levels of activity expected. However, well-studied cases like the Hyades and Pleiades show that activity is not just correlated with age in a rough statistical sense, but is an inexorable consequence of age as a star loses angular momentum. As pointed out in the introduction, if SKGs are to have validity then they must meet the same criteria that are applied to open clusters. It seems premature to consider the degree to which SKGs exhibit a range of ages among their members before that phenomenon is understood for well-defined clusters.

There are well-known exceptions to the CE–age relation, namely close binaries (those with periods $\lesssim 10$ days) where tidal interaction forces synchronization of the rotation with the orbit. Even though the orbital angular momentum provides a deep reservoir, such systems still tend to be relatively young (Soderblom 1990). Sufficient radial velocity data exist for this sample to weed out such systems. Some candidate UMaG members are indeed close binaries, which is noted in the next section.

The abundance of lithium in the atmospheres of solar-type stars has also been used to estimate their ages (Duncan 1981, Soderblom 1983a) and in an attempt to assess UMaG membership (Soderblom 1985b). More recently, it has become obvious that we really do not understand Li depletion in solar-type stars (Soderblom 1988), and that the situation is confusing, both observationally and theoretically. It is at least clear, however, that a large relative Li abundance is a necessary condition for youth in a solar-type star, even if it is not a sufficient condition. In particular, at $\mathscr{M} \lesssim 0.9\mathscr{M}_{\odot}$ stars deplete Li quickly ($\tau \lesssim 0.1$ Gyr; Soderblom *et al.* 1990) so that any detectable Li can be taken as a sign of youth. The Li abundances of UMaG stars will be discussed in detail in a forthcoming paper (Soderblom *et al.* 1993b), and will not be used here as a membership indicator.

This idea of identifying *bona fide* UMaG members by means of spectroscopic signatures of youth is not new. Wilson (1966) may first have suggested it but it has not been done systematically nor comprehensively. Indeed, Roman's (1949) work noted that most of the late-type dwarfs in UMaG showed emission in the cores of the Ca II H and K lines. More recently, Walter *et al.* (1984) examined the chromospheric and x-ray emission strengths of 18 UMaG candidates and estimated that 13 were real group members. Soderblom & Clements (1987) broadened the sample to 32 UMaG candidates and examined chromospheric emission to show that 14 were probable or possible members, 12 were probable nonmembers, and 6 were ambiguous cases. The probable and possible members were more concentrated in velocity space than the sample as a whole, and especially in the V motion, indicating that the spectroscopic criteria were helping to segregate genuine group members. Boesgaard *et al.* (1988) have considered evidence for UMaG membership of some F dwarfs, which is discussed later.

2.2 New and Used Observations

Our goal is to assess the likelihood of UMaG membership of solar-type stars, independent of their kinematics, by using the strength of CE as an indicator of age. Some of the data analyzed here was described and presented in Soderblom & Clements (1987; hereafter referred to as SC87). That consisted of indices of CE. The use and interpretation of those indices will be described in the next two sections; here the observations are just presented. To the SC87 data are added some new *IUE* observations, some echelle spectroscopy, and additional data from the literature.

The SC87 data are of two kinds. The first is Ca II H and K observations made at Mount Wilson. That instrument measures 1 Å bandpasses at the centers of the H and K lines relative to 20 Å "continuum" bands at about 3900 and 4000 Å, yielding an instrumental equivalent width S. The color dependency of S is then removed and a correction made for photospheric light in the line-center bandpasses. Finally this flux is divided by the stellar bolometric flux to produce the index $R'_{\rm HK}$. The Mount Wilson observations have now been tabulated in Duncan *et al.* (1991), and details of the calibration and transformation of S to the flux ratio are provided in Noyes *et al.* (1984). A few additional observations from Mount Wilson have been provided by Baliunas (1992); these are mentioned in the notes of the next section. The calibration of the Ca II H and K lines presented by Noyes *et al.* is used here for consistency with previous papers and because it is adequate for the comparison of stars made here. Alternative calibrations may possibly be more precise.

The second type of observations in SC87 is from the *IUE* satellite. Short-wavelength, low-dispersion spectra from *IUE* show a number of emission features in active stars, and three of the stronger ones (N I 1240 Å, Si IV 1400 Å, and C IV 1550 Å) were combined to produce an index of emission from the star's transition region (TR), viz., $R_{\rm TR}$, analogous to $R'_{\rm HK}$. Long-wavelength spectra were also obtained to measure fluxes in the Mg II h and k features, which arise under conditions similar to those for the Ca II H and K lines. Most of the stars were observed at

TABLE 2. Journal of *IUE* observations.

HD/HDE[a]	LWP no.	HJD (2440000+)	exp. (min.)	F_h (Mergs cm^{-2} s^{-1})	F_k	log R_{hk}	I(Mg II)
13959	21925L	8594.6	20		1.16	−4.29	—
26913	2218H	5644.4	120	1.86	1.78	−4.19	—
41593	19938H	8333.3	80	2.63	2.21	−3.91	—
+63°965	19939L	8333.4	5		0.19	−4.84	—
109647	19940L	8333.5	4.5		1.32	−4.33	—
238179	19941L	8333.5	20	—	—	—	0.75
	21926L	8594.7	30	—	—	—	0.75
238208	19942L	8333.5	20	—	—	—	0.66
120528	21927L	8594.7	20	—	—	—	0.86
147513	5675H	6162.2	16	2.58	2.34	−4.14	—
	5724H	6169.0	16	1.90	1.61	−4.28	—
	5726H	6169.2	20	2.01	1.49	−4.29	—
	19943H	8333.5	24	3.00	2.13	−4.10	—

[a]Listed in order of right ascension.

high resolution, in which case measuring the line fluxes was straightforward. A few of the cooler, fainter stars were observed at low resolution, but their Mg II features were assertive and easily measured. In both cases the line fluxes were divided by the bolometric flux to yield a R_{hk} index.

2.2.1 *New IUE observations*

The *IUE* satellite and its spectrographs are described in Boggess *et al.* (1978a,b). All of the new observations were obtained with the long-wavelength spectrograph, both at high and low dispersion. A journal of the new observations is presented in Table 2. Much of the data in Table 2 is from a program to study UMaG candidates but some additional spectra were taken from the *IUE* archive. The high-dispersion spectra were integrated between the h_1 and k_1 minima, counting everything above zero flux, as done by Hartmann *et al.* (1984). A reseau occasionally falls on the short-wavelength side of the k line but does not significantly affect the measured fluxes. Stellar surface fluxes were calculated using φ, the stellar angular diameter, which was determined from the $(B-V)$ color (given below in Table 5), using the relations in Barnes *et al.* (1976).

As in SC87, a few of the cooler and fainter stars could only be observed at low resolution. For stars later than about K0 V, the ultraviolet continuum is sufficiently weak that a Mg II feature is obvious and easy to measure. In hotter stars the continuum is not weak and any emission is superposed on a broad Mg II absorption feature. Instead of determining fluxes, an I(Mg II) index for those stars was calculated, as defined in Fanelli *et al.* (1990). I(Mg II) is essentially an equivalent width.

All of the stars observed are close (within ~30 pc). No interstellar absorption is anticipated and no correction has been made.

2.2.2 *Echelle spectroscopy*

High-dispersion echelle spectra were obtained for some of the UMaG candidates at Lick Observatory. The Hamilton spectrograph (Vogt 1987) was used with both the 3 m Shane telescope and the 0.6 m Coudé Auxiliary Telescope. These Hamilton spectra were imaged onto a TI 800×800 CCD and the design of the spectrograph allowed wavelengths from about Hβ to the Ca II infrared triplet (IRT) to be recorded. The resolving power of the Hamilton is about 50 000. For a few stars, a Loral 2048×2048 CCD was used; it also has 15 μ pixels and no distinction is made between the two sets of data.

The details of data reduction and analysis are given in Soderblom *et al.* (1993a; hereafter referred to as SSHJ), so only a summary is needed here. First, the orders near 6000 and 6100 Å were cross correlated against narrow-lined template spectra to yield rotation rates ($v \sin i$) and radial velocities (v_{rad}). A comparison was made of v_{rad} values from these echelle spectra to those of Duquennoy & Mayor (1991) and Coravel velocities from the present study. For 14 stars that appear to be single and which are common to the two datasets (Coravel and echelle), the rms difference is only 0.55 km s^{-1}. (This computation was done after adding 0.4 km s^{-1} to the Coravel v_{rad} values—see Sec. 5.) A value of 0.6 km s^{-1} has therefore been adopted for the accuracy of these Hamilton v_{rad} values. In several cases these velocities supplement the Coravel data and improve on values in the literature. The detection limit for $v \sin i$ values is approximately 7 km s^{-1} (SSHJ).

From these spectra, indices of CE were calculated for Hα and the IRT. This was done by taking a profile of one of these lines for the UMaG candidate and then subtracting the profile of an inactive field star. For Hα, a set of observations was obtained of stars of various colors known to have weak chromospheres, to be used as comparisons because the wings of Hα are temperature sensitive. For the IRT a solar profile was used throughout because the profiles are effectively temperature independent. The 8542 Å line of the IRT provides the best measure of CE because it shows the strongest effect, but the other IRT features at 8498 and 8662 Å were also measured, especially when the 8542 Å feature was not fully recorded on the CCD. In all cases the index generated will be referred to as R_{IRT}.

The equivalent widths for Hα and the IRT were corrected for scattered light (mostly due to some order overlap) by 5% and 10%, respectively, and then increased slightly (by 0.03 Å for Hα and 0.05 Å for the IRT) to

TABLE 3. Echelle spectroscopy of UMaG candidates.

HD	$v \sin i$ (km s^{-1})	W_λ^{em} (Å) in core				log $R_{H\alpha}$	log R_{8498}	log R_{8542}	log R_{8662}
		Hα	λ8498	λ8542	λ8662				
4813	<7	<0.05	<0.07	—	<0.07	<−5.3	<−5.3	—	<−5.3
6920	10	<0.05	<0.07	—	<0.07	<−5.3	<−5.3	—	<−5.3
11131	<7	0.11	0.12	—	0.13	−4.95	−5.07	—	−5.04
13959	<7	0.11	0.16	—	0.17	−4.94	−4.85	—	−4.83
26913	<7	0.09	0.19	0.22	0.19	−4.90	−4.85	−4.79	−4.84
26923	<7	0.11	0.13	0.14	0.15	−5.01	−5.05	−5.01	−5.00
39587	8	0.12	0.16	0.19	0.18	−4.95	−4.96	−4.89	−4.91
41593	<7	0.13	0.21	0.26	0.23	−4.90	−4.78	−4.68	−4.74
43318	<7	0.04	<0.07	<0.07	<0.07	−5.38	<−5.3	<−5.3	<−5.3
48682	<7	0.09	<0.13	—	<0.07	−5.10	<−5.1	—	<−5.3
50692	<7	0.03	<0.07	<0.07	0.10	−5.48	<−5.3	—	<−5.2
72905	—	0.19	0.17	—	0.18	−4.73	−4.93	—	−4.90
72905	—	0.17	0.17	—	0.19	−4.79	−4.93	—	−4.89
79028	<7	<0.04	<0.08	—	<0.06	<−5.4	<−5.3		<−5.4
81858	<7	<0.05	<0.07	<0.07	<0.07	<−5.3	<−5.3	<−5.3	<−5.3
88355	15.6	—	<0.08	<0.08	<0.07	—	≤−5.3	≤−5.3	<−5.3
109011	<7	0.20	0.19	—	0.20	−4.69	−4.80	—	−4.77
109011	<7	0.18	0.15	—	0.17	−4.72	−4.89	—	−4.83
109647	<7	0.22	0.17	—	0.19	−4.65	−4.85	—	−4.79
110463	<7	0.12	0.13	—	0.16	−4.93	−4.94	—	−4.87
111456	53	0.13	0.26	—	0.28	−4.92	−4.80	—	−4.77
114260	<7	<0.04	<0.07	—	<0.10	<−5.4	<−5.2	—	<−5.1
115043	9	0.09	0.18	—	0.18	−5.05	−4.90	—	−4.91
120528	<7	<0.05	0.07	0.14	0.22	<−5.3	−5.30	−5.00	−4.82
124752	<7	0.06	0.10	—	<0.08	−5.19	−5.10	—	−5.18
134083	47	<0.07	0.22	—	0.22	<−5.2	−4.88	—	−4.89
137107/8	<7	<0.05	<0.07	—	<0.07	<−5.3	<−5.3	—	<−5.3
141003B	<7	0.23	—	—	0.36	−4.6 :	—	—	−4.55
147513	<7	0.11	0.13	—	0.16	−4.97	−5.05	—	−4.96
151044	<7	<0.05	<0.07	—	<0.07	<−5.3	<−5.3	—	<−5.3
160269	<7	0.07	0.09	—	<0.07	−5.15	−5.22	—	<−5.3
173667	17	—	<0.07	—	<0.07	—	<−5.3	—	<−5.3
178428	<7	<0.05	<0.07	—	<0.07	<−5.4	<−5.3	—	<−5.3
184960	<7	<0.05	<0.07	—	<0.07	<−5.3	<−5.3	—	<−5.3
203454	16	0.26	0.17	—	0.14	−4.60	−4.96	—	−5.04

approximate the zero-point offset of Herbig (1985). Rotational effects were corrected for using Herbig's prescription. After all this, the present chromospheric equivalent widths are slightly higher than Herbig's—by about 10 mÅ at Hα and 20 mÅ at the IRT for those stars common to the two samples—but no further corrections are made.

The equivalent widths were converted to fluxes using $(V-R)_K$ and $(V-I)_J$ colors determined from Eqs. (1) and (2) in SSHJ, and those fluxes were transformed to a stellar surface flux by using a stellar angular diameter calculated with the relations in Barnes *et al.* (1976) and Lacy (1977). The surface flux was divided by the star's bolometric flux to obtain the chromospheric flux ratios $R_{H\alpha}$ and R_{IRT}. (The derivation of temperatures is discussed below.) The Lick observations are summarized in Table 3 and examples of the subtraction procedure are illustrated in SSHJ. Stellar surface fluxes are not listed in Table 3 but they can be recovered from the flux ratios and the temperatures given below (Table 5).

2.2.3 *Additional information*

X-ray observations (Walter *et al.* 1984; Schmitt *et al.* 1990) are listed for a few UMaG candidates in Table 4. This provides additional grounds for rejecting membership of some stars.

Other observational indicators of youth are available for some of these stars, but they are detailed in the comments of the next section.

3. SELECTION AND SEGREGATION OF SOLAR-TYPE STARS

3.1 Candidates for Membership

Candidate UMaG members were taken from the lists of Roman (1949), Krisciunas (1979), and Eggen (1983a, 1984, 1985, 1986a, 1989). These were selected in various ways, mostly astrometric. In particular, Krisciunas searched the Gliese (1969) and Woolley *et al.* (1970) catalogues of nearby stars for objects with appropriate motions, and that ensures that our candidate list is virtually complete to 25 pc, at least for the G dwarfs. All stars with spectral types between about F5 V and K5 V were included if spectroscopic observations were available. One dM0 star was also included because an *IUE* spectrum was obtained.

TABLE 4. X-ray luminosities of UMaG candidates.

HD	log L_x	HD	log L_x
38392	28.4	88355	28.4
38393	27.6	111456	29.2
39587	28.8	124752	< 27.9
45088	29.0	131156	28.8
64096	27.5	137107/8	27.9
72905	28.9		

TABLE 5. Spectroscopic membership indicators for UMaG solar-type stars.

RGO (1)	HD/HDE (2)	HR (3)	Name (4)	Sp. (5)	$(B-V)$ (6)	$T_{\rm eff}$ (7)	log $R'_{\rm HK}$ (8)	log $R^{hk}_{\rm HK}$ (9)	log $R^{\rm TR}_{\rm HK}$ (10)	log $R^{\rm H\alpha}_{\rm HK}$ (11)	log $R^{\rm IRT}_{\rm HK}$ (12)	$v \sin i$ (13)
a) Probable Spectroscopic Members												
9061B	11131	—	χ Cet B	dG1	0.62	5800	−4.37	−4.47	—	−4.46	−4.33	3.4±2
9076	13959	—	—	K4V	1.05	4480	−4.35	−4.47	—	−4.45	−4.17	5.0±1
—	26913	1321	V891 Tau	G8V	0.70	5500	−4.39	−4.39	—	−4.42	−4.26	4.4±1
—	26923	1322	V774 Tau	G0V	0.59	5920	−4.49	—	—	−4.51	−4.34	3.7±1
222	39587	2047	χ^1 Ori	G0V	0.59	5920	−4.44	−4.42	−4.49	−4.45	−4.33	9.4±0.4
227	41593	—	—	K0Ve	0.81	5140	−4.42	−4.17	—	−4.42	−4.11	4.0±1
311	72905	3391	π^1 UMa	G1V	0.62	5800	−4.33	−4.37	−4.39	−4.32	−4.40	9.5±0.6
—	109011	—	—	K2V	0.93	4780	−4.35	−4.55	—	−4.24	−4.18	5.2±1
—	109647	—	—	K0	0.95	4740	—	−4.46	—	−4.18	−4.15	2.3±2
—	110463	—	—	K3V	0.95	4740	—	−4.46	—	−4.44	−4.22	2.1±1
9417	111456	4867	—	F6V	0.46	6480	−4.39	−4.43	−4.40	−4.43	−4.33	35
9434	115043	—	—	G2V	0.60	5880	−4.43	−4.32	—	−4.44	−4.42	7.7±0.8
566AB	131156AB	5544AB	ξ Boo AB	G8V	0.77	—	−4.36	−4.39	−4.42	—	—	2.5
—	141003B	5867B	β Ser B	K3V:	0.9:	4900	—	−4.38	—	−4.3 :	−3.97	3.3±2
9559A	147513A	6094A	—	G5V	0.62	5800	−4.40	−4.43	—	−4.48	−4.30	3.3±1
702.1	165185	6748	—	G3V	0.62	5800	—	−4.39	−4.42	—	—	7.5±1.0
b) Possible Spectroscopic Members												
216B	38392	1982	γ Lep B	K2V	0.95	4740	−4.52	−4.43	—	—	—	1.8±1
216A	38393	1983	γ Lep A	F6V	0.48	6380	−4.95	−5.05	< −4.8	—	—	8.7±0.8
233	45088	—	OU Gem	K2Ve	0.94	4760	−4.36	−4.26	−4.30	—	—	4.4±1
—	238179	—	—	G8V	—	5500:	—	I = 0.75	—	—	—	1.5±1.5
—	238208	—	—	K2V	—	5000:	—	I = 0.66	—	—	—	1.5±1.5
—	120528	—	—	G5V	0.66	5660	—	I = 0.86	—	< −4.7	−4.34	< 2
578	134083	5634	45 Boo	F5V	0.44	6560	−4.66	−4.67	−4.46	—	−4.40	45±2
624	147584	6098	ζ TrA	G0V	0.55	6080	−4.4 :	−4.66	−4.44	—	—	≤3.0
632	150706	—	—	G3V	0.61	5840	−4.59	−4.39	—	—	—	4.5±1.0
659A	155674A	—	—	K8V	1.16	4260	HK=+3	—	—	—	—	3.7±1
659B	155674B	—	—	K8V	1.26	4080	HK=+3	—	—	—	—	—
—	203454	8170	—	F8V	0.53	6180	−4.15	−4.35	—	−4.13	−4.29	18.0±1.3
c) Probable Spectroscopic Non-members												
37	4813	235	ϕ^2 Cet	F8V	0.50	6300	—	−4.87	—	< −4.7	< −4.7	3.5±0.7
53.4	6920	340	44 And	F8V	0.60	5880	−4.81	—	—	< −4.7	< −4.7	11.0±1
—	43318	2233	→	F6V	0.50	6300	—	—	—	−4.83	< −4.5	4.1±1
245	48682A	2483	ψ^5 Aur	G0V	0.57	6000	−4.96	—	—	−4.57	< −4.6	4.0±1
252	50692	2569	37 Gem	G0V	0.58	5960	−4.57	—	—	−4.90	< −4.4	2.7±1
291	64096	3064	9 Pup	G1V	0.57	6000	—	−5.06	< −4.7	< −4.7	—	2.0±1
337.1	79028	3648	16 UMa	dF9	0.58	5960	—	—	—	< −4.8	< −4.7	4.6±1
—	81858	3754	ω Leo	dF8	0.60	5880	—	—	—	< −4.8	< −4.4	< 7
—	88355	3998	34 Leo	F7V	0.46	6480	—	−5.05	—	—	≤ −4.4	18.1±1
—	94686	—	—	F8V	0.55	6080	—	−4.77	—	—	—	4.4±1.2
500	114260	—	—	G7V	0.73	5400	< −4.6	—	—	< −4.8	< −4.4	1.2±1
—	124752	—	—	K1V	0.81	5140	—	−5.26	—	−4.67	−4.4	< 7
584	137107/8	5727/8	η CrB	G2V	0.58	5960	—	−4.77	−4.77	< −4.8	< −4.4	2.8±0.7
—	151044	—	—	F8V	0.54	6140	—	−4.90	—	< −4.8	< −4.4	5.7±1.0
684	160269A	6573	26 Dra	G1V	0.61	5840	—	—	—	−4.62	≤ −4.4	4.3±1
9635	173667	7061	110 Her	F6V	0.46	6480	−4.72	—	—	—	< −4.7	18.9±1
746	178428	7260	—	dG4	0.70	5520	—	—	—	< −4.9	< −4.4	1.6±1
—	184960	7451	—	F8V	0.48	6380	—	−5.07	—	< −4.7	< −4.7	6.5±0.8

HD 176303 = 11 Aql is sometimes listed as an UMaG member but is not included here because its parallax (van Altena *et al.* 1992) and spectral type indicate that it is a subgiant, which places it beyond the domain of this study. It is, at any rate, a likely nonmember because of its low activity [Baliunas (1992) reports $S = 0.194$, equivalent to $R'_{\rm HK} = -4.76$], which is confirmed by the kinematics presented in Sec. 6.

Cross-referencing objects between different papers is sometimes difficult because of use of a number of designations, but all possible aliases for these stars cannot be provided here. Virtually all the stars considered are brighter than $m_V \approx 9$, for which Henry Draper numbers are the most convenient and generally used appellation. Thus HD numbers, in right ascension order, are the primary designation, with a couple of BD numbers too. Some of these candidates may be unlikely members from the start since improved astrometry has placed them beyond the likely kinematic bounds of the group, but as many candidates as possible have been included in the interests of completeness and to examine that part of velocity space that surrounds UMaG itself.

3.2 Spectroscopic Membership Analysis

Table 5 lists the solar-type stars here analyzed. All the stars that were listed in SC87 are tabulated, even if they are binaries for which CE may not be a valid age indicator;

remarks on those stars are given below. The colors are from Nicolet (1978) whenever possible, otherwise Woolley *et al.* (1970) was used. Spectral types are from the *Bright Star Catalog* (Hoffleit & Jaschek 1982), Levato & Abt (1978), Hoffleit *et al.* (1983), and Woolley *et al.* (1970), except for HD 26913/23 (see the remarks below). Temperatures were calculated from the listed $(B-V)$ value using the relation in SSHJ. Some of the stars listed are unresolved doubles, but no attempt has been made to correct for the photometric effects of a secondary because that is inconsequential for these purposes. ξ Boo is an exception because it is well studied and the $T_{\rm eff}$ values of its components are given below in the remarks.

Column (7) lists the $R'_{\rm HK}$ value for a star. Since the purpose of the present paper is to compare levels of chromospheric activity in stars and not to determine absolute flux levels or to study the chromospheres themselves, the other flux ratios have been transformed to the equivalent of $R'_{\rm HK}$ by using mean relations between quantities. Table VII of SC87 provides R_{hk}–$R'_{\rm HK}$ and $R_{\rm TR}$–$R'_{\rm HK}$ relations, Herbig (1985) illustrates a mean $R_{{\rm H}\alpha}$–$R'_{\rm HK}$ relation and the dependence of the IRT flux ratios on $R'_{\rm HK}$. These rescaled quantities are denoted as $R^{hk}_{\rm HK}$, $R^{\rm TR}_{\rm HK}$, $R^{{\rm H}\alpha}_{\rm HK}$, and $R^{\rm IRT}_{\rm HK}$, (columns 8 to 11). The $R^{\rm IRT}_{\rm HK}$ ratio calculated from Herbig's relations was consistently higher than the other ratios and so was reduced by 0.2 dex to agree in the mean with $R'_{\rm HK}$.

Some of the numbers in column (7) are eye estimates of H and K emission strength from Wilson & Woolley (1970). They give values for three UMaG candidates for which little quantitative information is available. Some of the numbers in column (8) are I(Mg II) values. The last column of Table 5 lists rotational velocities, from Kraft (1967); Soderblom (1982); Vogt *et al.* (1983); Gray & Nagar (1985); Soderblom *et al.* (1989); Marcy & Basri (1989); Pallavicini & Soderblom (1993); the present study (Lick echelle spectra); and from Coravel (see Benz & Mayor 1984 for a description). A $v \sin i$ can be a less reliable indicator of age than CE because of the ambiguity introduced by an individual star's aspect. Also, many of the $v \sin i$ values are only upper limits. Rotation is not used directly as an age indicator, but none of the known rotation rates conflicts with the membership judgments presented below.

A simple rule is employed in applying these indices to the problem of UMaG membership: an index indicates membership if it is consistent with the star being younger than the Hyades. The Hyades provides a convenient comparison, both because good data are available for it and because it is about twice the age of UMaG. Allowing that degree of latitude in the chromospheric indices is an appropriately conservative criterion, but in fact it matters little since the likely members and nonmembers do not generally have overlapping ranges of $R_{\rm HK}$ indices. What this means is that the $R_{\rm HK}$ indices must exceed -4.6, algebraically. For the x-ray data, $\log L_x > 28.7$ indicates membership by placing those stars more than a factor of two above the rest [Fig. 9(a) of Micela *et al.* (1988) shows the $\log L_x$ distribution for the Hyades]. I(Mg II) should be less than 0.75 (see Fig. 3 of Smith *et al.* 1991), if that index is known. The Wilson & Woolley eye estimates cannot be compared directly to the other Ca II observations, but a star with HK $= +4$ is clearly very young because the emission is so overt [their scale ranges from $+8$ for the most active to -5, with only 12% of stars having an index of $+3$ or greater (Wielen 1974)]. For HK $= +3$, the star is probably also young, but it is not possible to be very exact. Wielen (1977) estimated that the average age of the Wilson & Woolley stars with HK $\geqslant +3$ is 0.3 Gyr if the star formation rate has been constant over the age of the Galactic disk. To be conservative, an HK value of $+3$ or greater has been taken to suggest UMaG membership until more quantitative data are available for these stars.

The various flux ratio indices are illustrated as a function of $(B-V)$ color in Fig. 1. Vertical lines join different indices for the same star. By these means each index or datum is evaluated to provide a "vote" that is either positive (indicating UMaG membership), negative, or neutral. Based on these votes, the stars have been put into one of three classes:

Probable spectroscopic members (PrS): These are stars for which more than one indicator is available, and for which all the votes favor membership. These are the best-defined members of UMaG in spectroscopic terms, although some of these stars may yet fail the kinematic test.

Possible spectroscopic members (PoS): For these stars there is generally not enough information to clearly indicate membership or nonmembership, or some of the data conflict to an extent that a decision cannot be made. For example, the $R_{\rm HK}$ values might sometimes lie in the range of probable members and sometimes not. Some PoS stars are close binaries for which CE cannot measure age.

Probable spectroscopic nonmembers (SNM): For these stars all, or nearly all, of the available data conflict with the object being as young as a UMaG member.

3.3 Comments on Individual Stars

For some additional remarks on many of these stars, see SC87. Details on and references to the orbits of the many visual binaries among these stars can be found in Worley & Heintz (1983). No comments are made if the data in Table 5 seem self-evident.

HD 4813 = ϕ^2 Cet: Listed as a possible spectroscopic binary by Duquennoy & Mayor (1991; hereafter referred to as DM).

HD 11131 = χ Cet B: This is a common-proper-motion companion to χ Cet A (HD 11171), an F2 IV star.

HD 13959: This is a visual binary (ADS 1729) consisting of two K4 V stars (Christy & Walker 1969). The orbital period is 35.52 yr and the eccentricity is 0.66 (Worley & Heintz 1983). Wilson and Wooley (1970) list an eye-estimated HK strength of $+4$, which is substantiated by a Mount Wilson measurement of $\langle S\rangle = 1.056$. Strictly speaking, $R'_{\rm HK}$ is not defined for $(B-V) > 1.00$, but the relations of Noyes *et al.* (1984) were nevertheless used. The S value of this star lies along the upper bound of the distribution of S values for the nearby stars (see Fig. 1 of

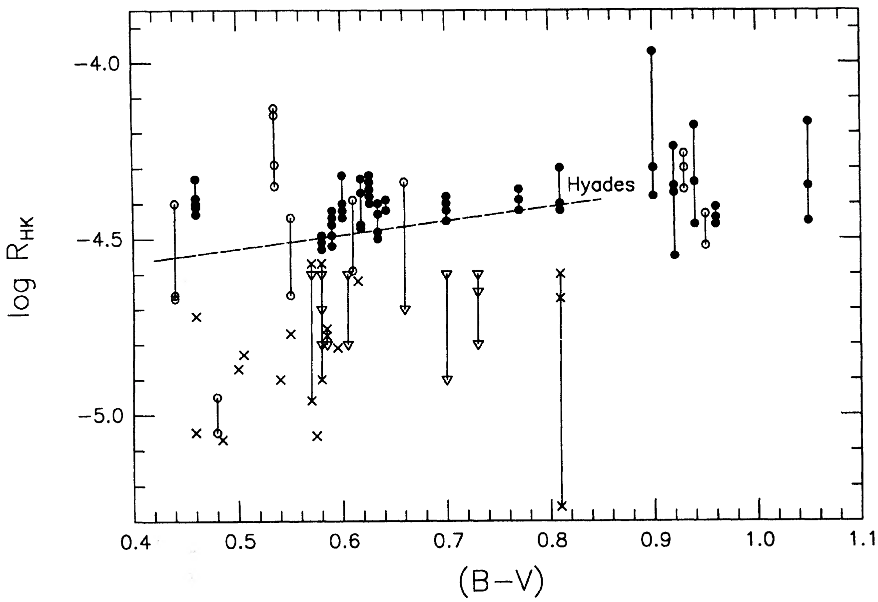

FIG. 1. The $R_{\rm HK}$ indices ($R'_{\rm HK}$, $R^{hk}_{\rm HK}$, $R^{\rm TR}_{\rm HK}$, $R^{\rm H\alpha}_{\rm HK}$, and $R^{\rm IRT}_{\rm HK}$) for the stars of Table 5 are shown against $(B-V)$ color. Vertical lines join different indices for the same star, and some stars have been shifted slightly in $(B-V)$ to avoid overlap. The line indicates the mean relation for Hyades stars (Soderblom 1985). Stars judged to be Probable Spectroscopic Members on the basis of these indices are shown as filled circles, Possible Spectroscopic Members are open circles, and Probable Spectroscopic Nonmembers are crosses. Triangles denote upper limits to the observed quantity, but are not shown if they exceed a measured value from another index.

Vaughan & Preston 1980) which, with the Wilson & Wooley observation, fully confirms this star's high level of activity.

HD 26913/23 = HR 1321/2 = V891 and V774 Tau: Are these stars dwarfs or subgiants? The distinction is important because no trigonometric parallaxes are available for them, forcing their distances to be estimated from their absolute magnitudes. Stephenson (1960) classified the pair as G5 IV+G0 IV (in the sense of 26913+26923), which seem to be the spectral types adopted in the *Bright Star Catalog* and elsewhere. However, Wilson & Skumanich (1964) state positively that both stars are dwarfs on the basis of the ratio of Fe I λ4071 to Sr II λ4077. Likewise, Kraft's (1967) analysis of Strömgren photometry places these stars squarely on the ZAMS, and Barry (1971) also found them to be dwarfs. Slettebak (1963) found these stars to be dwarfs, classifying them as G8 V+G0 V. More recently, Abt (1981) classified the pair as G3 V+G0 IV, but the relative magnitudes and colors of these two stars mean that both have to be either subgiants or dwarfs; the system cannot contain one of each. Finally, Hauck & Philip (1981) find these stars to lie on the main sequence based on their analysis of Geneva photometry. The weight of the above evidence favors dwarfhood for these two stars, but the parallaxes that will be provided by *Hipparcos* will resolve the issue. The spectral types of Slettebak have been adopted.

Unfortunately, *IUE* observations are available for only one of these stars; details are given in Table 2. These two stars form the visual binary ADS 3085, but an orbit is not available (Worley & Heintz 1983). The high levels of chromospheric emission for these two stars is substantiated by many observations at Mount Wilson, and the echelle spectra show it too. A rotation period of 7.2 days has been determined as well for HD 26913 (Baliunas *et al.* 1983) that leads to $\Omega_*/\Omega_\odot = 3.5$, which suggests $v \sin i \leqslant 6.3$ km s^{-1}. Gray & Nagar (1985) have measured $v \sin i = 1.0$ km s^{-1} for HD 26923, which is extraordinary because the high level of CE emission for both stars indicates rapid rotation, so that a small $v \sin i$ means that HD 26923 must be oriented nearly pole on, even if it is a subgiant. However, the Coravel $v \sin i$ is 3.7 ± 1 km s^{-1}, and was determined from seven observations. A careful attempt should be made to detect rotational modulation in HD 26923. Both HD 26913 and 26923 have strong lithium features (Wilson *et al.* 1965; Kraft & Wilson 1965; Duncan 1981), reinforcing their youth. Ziegler *et al.* (1984) and Cutispoto (1991) report m_V variations in HD 26913 with an amplitude of about 0.06 mag and a period of 6.8 days.

HD 38392/3 = γ Lep: The high level of CE in the K2 V secondary of this visual binary (ADS 4334) is suggestive of membership, but the low activity in the F6 V primary as well as the L_x of that star are contraindications. SC87 judged the membership of this system to be ambiguous and it is left as a possible member here. There are two additional components to this system (Woolley *et al.* 1970) that could also be observed. Baliunas (1992) gives $S(38392) = 0.519$ and $S(38393) = 0.152$. Cayrel de Strobel *et al.* (1989) report on the IRT line in γ Lep B, concluding that it is a young, active star.

HD 39587=χ^1 Ori: This is a single-lined spectroscopic binary with an orbital period of 14.2 yr (DM; Irwin *et al.* 1992) and is also an astrometric double (Lippincott & Worth 1978). The secondary is small (0.15 $\mathscr{M}_\odot$) and remote (about 6 au) and so cannot influence the primary, which has a rotation period of 5.1 days (Stimets & Giles 1980).

HD 45088=OU Gem: This is both a visual binary (ADS 5054) and a spectroscopic double. Its high levels of Ca II and Mg II emission and x-ray flux can be attributed to this system being a close binary with a 6.99 day orbital period and for this reason SC87 judged this to be an ambiguous case. Tomkin (1980) estimates the secondary to have spectral-type K5.

HD 48682=ψ^5 Aur: The echelle spectrum is for the primary of this well-separated (36 arcsec) visual binary (ADS 5425).

HD 50692=37 Gem: SC87 judged this star to be a possible member because of relatively strong Ca II H and K emission. But that emission is significantly weaker than in most UMaG candidates of similar color, and the Hα and Ca II IRT fluxes are also weak, indicating nonmembership.

HD 64096=9 Pup: This is a visual binary (ADS 6420) and double lines can be seen at high resolution [Pallavicini & Soderblom (1993) determine $v \sin i < 2.5$ km s^{-1} for both components]. Although Boesgaard *et al.* (1988) did not resolve the two components, their lithium abundance for this system is well below other UMaG stars of similar temperature. Abt & Levy (1976) determined a spectroscopic orbit, but Batten *et al.* (1978) suggest that that may be spurious because of the low velocity amplitude. The low x-ray flux confirms nonmembership. DM measure a period for the orbit of 23.5 yr. The $R_{\rm HK}^{\rm H\alpha}$ value in Table 5 has been estimated from the observations of Herbig (1985), but is taken as an upper limit because light from the secondary probably accounts for some filling in of the core of Hα. Grossenbacher & Mesrobian (1969) provide an astrometric orbit and masses for the pair.

HD 79028=16 UMa: A spectroscopic binary with a period of 16.24 days (DM).

HD 81858=ω Leo: Visual binary (ADS 7390) with a period of 116.85 yr and an eccentricity of 0.56 (Batten *et al.* 1978).

HD 94686: A visual binary (ADS 7992) also seen to be an SB2 (Soderblom 1982; Boesgaard *et al.* 1988). The Mg II flux is low, indicating nonmembership.

BD+63°965: This star's low Mg II *h* and *k* flux indicates nonmembership, but its spectral type of dM0 places it well beyond the range of other stars considered here and it will not be discussed further.

HD 109011, HD 109647, and HD 110463: All three of these K dwarfs lie in the region of the cluster nucleus and have proper motions appropriate to that. They also have high levels of Mg II *h* and *k*, Hα, and IRT emission. Roman (1949) reported seeing Ca II H and K emission in HD 109011 and HD 110463, but there is insufficient information to quantify that statement. Joy and Wilson (1949) mention a visual estimate of H and K emission for HD 110463 that is high. Thus all three appear to be highly probable members. No MK spectra type is available for HD 109647—see SC87—but Bidelman (1985) has indicated that the star is definitely a dwarf and is at K0. The Coravel traces show that HD 109011 is a spectroscopic binary, and Baliunas (1992) gives $S=0.707$.

HD 114260: SC87 had only a poorly determined Ca II H and K equivalent width from a photographic spectrogram, but an echelle spectrum shows that this star is definitely a nonmember. This is also a spectroscopic binary (DM), with a period of 20.5 days.

HD 120528: Our Hamilton spectra show this star to have CE greater than the Sun's but less than that of HD 11131. For the present we regard it as a possible member.

HD 124752: Although this star is supposed to be part of the nucleus of UMaG, its consistently low CE levels indicate this star is a nonmember, and that is substantiated by its low L_x.

HD 131156=ξ Boo: A visual binary (ADS 9413) observed as a single object with *IUE*. Both stars have consistently high CE levels in all indices. Temperatures are not given in Table 5 because the photometry is for both stars together, but Popper (1980) lists 0.71 and 1.10 as the $(B-V)$ values for the two components, corresponding to $T_{\rm eff}=5480$ and 4380 K, respectively.

HD 134083=45 Boo: SC87 list this star as a possible member and that verdict is repeated here. The various chromospheric indices for this star are contradictory. Perhaps $R'_{\rm HK}$ is in error because this star is much bluer than most stars observed at Mount Wilson, but the Mg II lines are also relatively weak. The far-UV emissions are relatively strong (SC87), and the IRT profiles show clear evidence of filling into the same extent as seen for HD 111456. At the same time, the Hα profile showed little evidence of activity, although that is a difficult assessment because no spectrum of an inactive star of the same color was available to which to compare this star; it was instead compared to HD 88355. Finally, the $v \sin i$ of 45 Boo is high, even for an F dwarf. This star remains as only a possible member until better data resolve the discrepancies.

HD 137107/8=η CrB: A visual binary (ADS 9617) and SB2 (DM) with a period of about 42 yr.

HD 141003B=β Ser B: The association of this star with β Ser A, which has a spectral type of A2 IV, as part of the visual binary ADS 9778 reinforces the probable youth of this star. That is substantiated by the CE indices. The nominal $(B-V)$ color of this star is 0.99 but Lutz & Lutz (1977) report 0.84. Our own comparison of the spectrum of HD 141003B to other Probable Members in the 6700 Å region suggests $(B-V)\approx 0.9$, and hence $T_{\rm eff}\approx 4900$ K.

HD 147513=HR 6094: Zarro (1983) has shown that this star is relatively active on the basis of its Hα and Ca II K profiles. The K line profile illustrated in Zarro & Rodgers (1983) indicates that HD 147513 has about the same level of activity as κ^1 Ceti, so that its S value is about 0.35, which translates to $\log R'_{\rm HK} \approx -4.4$. This value is in accord with the Ca II IRT observations of HD 147513 reported in Foing *et al.* (1989) and the Hamilton echelle observations too. Some *IUE* observations of the Mg II lines have become available since SC87 was published and they

TABLE 6. Kinematics of Ursa Major nucleus stars.

HD	Name	π (mas)	μ_α^{FK5} (mas yr^{-1})	μ_δ^{FK5} (mas yr^{-1})	v_{rad} (km s^{-1})	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	for π = 46 ± 4 mas: U (km s^{-1})	V (km s^{-1})	W (km s^{-1})
91480	37 UMa	34.4 ± 10.5	+ 67 ± 0.5	+39 ± 0.6	−10.4 ± 0.5	+13.2 ± 2.3	+ 4.2 ± 2.2	− 5.5 ± 0.9	+11.3 ± 0.6	+2.3 ± 0.5	− 6.2 ± 0.4
95418	β UMa	46.3 ± 8.5	+ 82 ± 0.4	+34 ± 0.4	−12.0 ± 0.5	+12.7 ± 1.3	+ 2.2 ± 1.1	− 7.8 ± 0.6	+12.7 ± 0.6	+2.2 ± 0.5	− 7.8 ± 0.4
103287	γ UMa	17.6 ± 8.4	+ 94 ± 0.3	+12 ± 0.3	−12.6 ± 0.5	+25.8 ± 10.1	+ 9.9 ± 6.5	− 6.8 ± 2.1	+12.8 ± 0.7	+1.4 ± 0.5	− 9.4 ± 0.5
106591	δ UMa	56.5 ± 8.0	+103 ± 0.4	+ 9 ± 0.4	−13.4 ± 0.5	+11.8 ± 1.0	− 0.3 ± 0.7	−10.7 ± 0.4	+13.5 ± 0.8	+0.8 ± 0.5	−10.5 ± 0.4
109011	—	42	+111 ± 3.6	+ 7 ± 3.8	−13.1 ± 0.6	+14.4 ± 2.1	+ 2.2 ± 1.5	−10.9 ± 0.6	+13.5 ± 0.9	+1.6 ± 0.7	−11.0 ± 0.6
109647	—	35	+117 ± 3.8	− 3 ± 3.9	− 9.0 ± 0.3	+16.1 ± 2.8	+ 5.0 ± 1.7	− 7.1 ± 0.4	+12.8 ± 1.0	+3.1 ± 0.7	− 7.3 ± 0.3
110463	—	39	+124 ± 4.7	− 6 ± 4.5	− 9.7 ± 0.3	+15.2 ± 2.6	+ 4.7 ± 1.8	− 8.3 ± 0.4	+13.3 ± 1.0	+3.4 ± 0.8	− 8.3 ± 0.3
111456	HR 4867	40.8 ± 13.8	+109 ± 3.8	− 3 ± 3.6	−12.0 ± 1.5	+14.5 ± 3.7	+ 1.1 ± 2.4	− 9.7 ± 1.3	+13.2 ± 1.0	+0.4 ± 0.9	− 9.8 ± 1.3
112185	ϵ UMa	8.6 ± 11.9	+111 ± 0.4	− 6 ± 0.4	− 9.3 ± 0.5	+55.2 ± 73	+27.3 ± 43	− 7.2 ± 1.4	+12.3 ± 0.9	+2.0 ± 0.5	− 8.0 ± 0.4
113139	78 UMa	23.5 ± 4.7	+122 ± 5.3	− 2 ± 4.9	− 9.8 ± 0.5	+23.0 ± 4.2	+ 9.3 ± 2.9	− 9.2 ± 0.7	+12.9 ± 1.0	+2.7 ± 0.8	− 8.9 ± 0.5
115043	—	48.4 ± 15.3	+112 ± 2.7	−11 ± 2.6	− 8.5 ± 0.1	+11.4 ± 3.0	+ 1.8 ± 1.8	− 7.8 ± 0.2	+11.9 ± 0.9	+2.1 ± 0.6	− 7.8 ± 0.2
116656/7	ζ UMa	41.4 ± 6.1	+121 ± 0.4	−20 ± 0.4	− 5.6 ± 0.5	+13.4 ± 1.8	+ 4.2 ± 1.0	− 5.6 ± 0.5	+12.2 ± 1.0	+3.5 ± 0.6	− 5.5 ± 0.4
116842	80 UMa	41.0 ± 7.5	+118 ± 5.8	− 9 ± 5.3	− 8.9 ± 0.5	+13.1 ± 2.2	+ 3.5 ± 1.5	− 9.1 ± 0.6	+11.9 ± 1.1	+2.7 ± 0.8	− 8.9 ± 0.5
							average[a]		+12.6 ± 0.7	+2.2 ± 0.9	−8.4 ± 1.6
							Palouš and Hauck		+12.4 ± 2.1	+1.6 ± 1.2	−8.8 ± 0.9
							Eggen		+13.9 ± 1.0	+1.5 ± 0.9	−9.4 ± 1.9

[a] Indicated uncertainties are dispersions about the mean, not the error of the mean.

confirm membership. Note that one available spectrum (LWP 5847) was not used because the cores of the Mg II lines were saturated.

Petit (1977) found HD 147513 to exhibit variability of about 0.07 mag in m_V. Also, this star has a DA white dwarf companion that is more than 5 mag fainter (Wegner 1973). Finally, Laird (1985) found this star to have [Fe/H] = +0.13, essentially the same as Wegner (1973) found. That is a higher metallicity than other UMaG members (Boesgaard *et al.* 1988), but not by a significant margin.

HD 147584 = ζ TrA: The R'_{HK} index has been estimated from the flux for the Ca II H line listed in Rebolo *et al.* (1989) by assuming $F_K \approx F_H$. This is a close spectroscopic binary (Batten *et al.* 1978), with a period of about 13 days. The available data for this system are not as clear cut as for the highly probable members. The emissions are consistently too weak (see illustrations in SC87 and Rebolo *et al.* 1989) to place this star in the same league as a χ^1 Ori or π^1 UMa, but they are nonetheless relatively strong. Perhaps ζ TrA is as young as other UMaG stars but has relatively weak emission because it is in a close binary, which forces it to rotate more slowly than single stars of its age. On the other hand, it is not impossible for ζ TrA to be older because Hyades stars with even shorter orbital periods have yet to achieve synchronization (Mathieu & Mazeh 1988). ζ TrA is unlikely to be as young as UMaG, but that possibility cannot be completely ruled out, and so this star is retained as a possible member.

HD 150706: This is an ambiguous case because the Mg II flux is high but Ca II H and K, Hα, and the IRT indices are relatively low. It is left as a possible member.

HD 151044: Eggen (1989) points out that the high lithium abundance of this star conflicts with its low CE level if both are age indicators. Such a situation is not unusual,

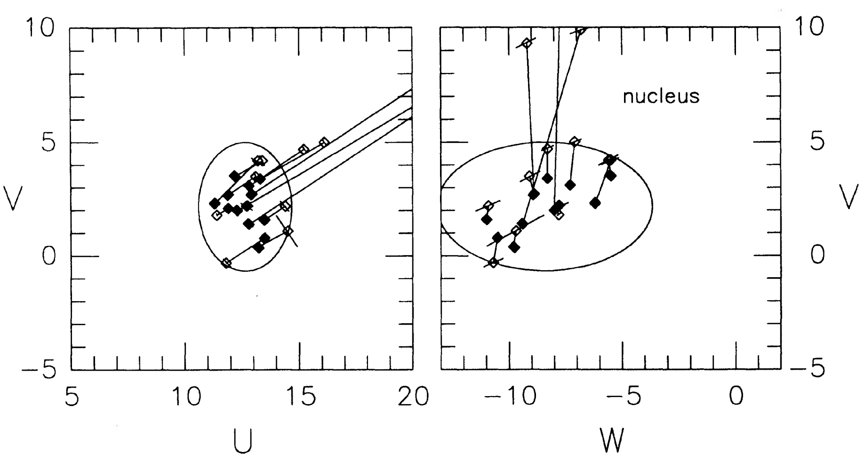

FIG. 2. Space motions of stars of the nucleus of the Ursa Major cluster (Table 6). The open diamonds are plotted at the velocities that result from using the measured parallax for a star, while the filled diamonds were calculated using a parallax of 46 mas for all the stars. Lines join points for the same star. The short lines across the diamonds show the effect of varying only the radial velocity by one standard deviation.

however, for a F8 V star because lithium depletion is very slow at that mass.

HD 155674: The separation of the two components of this visual binary (ADS 10386) is 22 arcsec.

HD 160269=26 Dra: A photographic spectrogram of the Ca II K line taken with the Soviet 6 m telescope (Beskin 1991) shows a moderate central reversal that corresponds to log $R'_{HK} \approx -4.7$. This is confirmed by the echelle spectrum of Hα and the IRT. This visual binary (ADS 10660) is also a spectroscopic double (DM) with a period of about 74 yr. Upgren (1962) has published an astrometric orbit.

HD 173667=110 Her: This star is sufficiently hot and evolved to be dated via Strömgren photometry; the result is 4 Gyr (Soderblom *et al.* 1991).

HD 178428: This is a spectroscopic binary with a period of 21.96 days (DM; Lu 1990).

HD 203454=HR 8170: A double-lined spectroscopic binary with a 3.2 day period (Batten *et al.* 1978). Stockton & Fekel (1992) have just published an orbit for this system and estimate the companion to have a spectral type of about K6 V. They also infer that both components are synchronously rotating.

4. KINEMATICS OF THE NUCLEUS STARS

Before studying the motions of the solar-type stars and how they relate to membership, the kinematics of the stars that define this SKG—the nucleus of the Ursa Major cluster—are reexamined. Eggen has used Sirius, a single star, to define the group motion (and as eponym) because that star's propinquity leads to very precise and accurate motions for it, but that advantage is offset by deviations that individual stars can show from the group motion.

The kinematics of 13 stars generally associated with the nucleus of UMaG are listed in Table 6. Levato & Abt (1978) list 14 nucleus stars; all are retained here except HD 124752, and ζ UMa has been treated as one object.

TABLE 7. Kinematics of UMaG solar-type candidates.

HD/HDE	π (mas)	μ_α^{FK5} (mas yr^{-1})	μ_δ^{FK5} (mas yr^{-1})	v_{rad} (km s^{-1})	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	for V ≡ +2.0 km s^{-1} π	M_V	v_{rad}	U	W
4813	61.8 ± 7.2	−231 ± 1.4	−222 ± 1.5	+ 8.5 ± 0.1	+22.5 ± 2.8	− 2.1 ± 0.5	−12.9 ± 0.6	—	—	+25.4	+20.0	−29.1
6920	50	−132 ± 2.3	− 40 ± 2.5	−13.9 ± 0.1	+18.6 ± 2.2	− 4.5 ± 1.2	+ 0.4 ± 0.9	23.9	2.50	− 5.3	+13.8	− 2.6
11131	44.2 ± 7.5	−146 ± 3.4	− 88 ± 3.2	− 4.2 ± 0.2	+18.5 ± 2.9	+ 2.0 ± 0.5	− 2.3 ± 1.1	44.5	4.97	− 4.4	+18.6	− 2.1
13959	32.2 ± 8.4	−104 ± 4.6	− 53 ± 4.6	+ 0.2 ± 0.1	+13.8 ± 3.7	+ 4.3 ± 1.3	− 9.3 ± 2.4	69.8	8.13	− 9.1	+19.2	− 2.2
26913	56	− 98 ± 2.2	−109 ± 2.1	− 7.0 ± 0.3	+12.4 ± 1.3	− 1.0 ± 0.4	− 7.0 ± 2.1	—	—	−37.1	+38.2	+ 8.3
26923	43	−108 ± 2.5	−104 ± 2.3	− 7.1 ± 0.1	+14.6 ± 1.7	− 0.4 ± 0.3	−10.5 ± 2.8	—	—	−31.2	+35.2	+ 1.7
38392	124.9 ± 4.7	−305 ± 3.2	−355 ± 3.4	− 9.9 ± 0.2	+16.8 ± 0.4	+ 5.4 ± 0.2	−10.2 ± 0.6	31.1	0.94	− 4.7	+13.5	−12.3
38393	124.9 ± 4.7	−287 ± 1.3	−371 ± 1.4	− 9.1 ± 0.1	+16.7 ± 0.4	+ 4.2 ± 0.1	−10.1 ± 0.5	56.1	4.75	− 5.7	+14.6	−11.5
39587	111.0 ± 1.5	−188 ± 2.3	− 92 ± 2.2	−13.5 ± 0.4	+13.7 ± 0.4	+ 2.7 ± 0.1	− 8.3 ± 0.2	—	—	− 8.7	+ 8.9	− 8.5
41593	65.3 ± 10.2	−126 ± 2.9	−107 ± 3.0	− 9.8 ± 0.1	+10.6 ± 0.2	+ 0.2 ± 0.4	−11.3 ± 1.8	377.9	9.15	−17.2	+17.7	−11.0
43318	34.5 ± 6.2	−160 ± 2.2	−222 ± 2.3	−39.6 ± 0.2	+46.5 ± 2.2	+ 5.9 ± 2.3	−27.9 ± 6.0	26.4	2.73	−31.3	+39.3	−29.1
45088	67.2 ± 3.0	−124 ± 2.0	−166 ± 2.1	− 8.4 ± 0.2	+ 8.9 ± 0.1	− 4.4 ± 0.3	−13.6 ± 0.6	—	—	−35.9	+35.7	−15.1
48682A	66.2 ± 8.5	+ 2 ± 1.5	+160 ± 1.2	−23.6 ± 0.1	+25.0 ± 0.4	+ 7.8 ± 1.4	− 3.2 ± 0.5	143.4	6.03	−69.5	+68.4	−17.0
50692	52.7 ± 11.5	− 46 ± 3.1	+ 27 ± 2.7	−14.7 ± 0.1	+12.9 ± 0.3	+ 6.4 ± 0.9	− 5.8 ± 0.6	—	—	+10.0	−10.8	− 0.6
64096	61.3 ± 2.5	− 60 ± 1.4	−340 ± 1.3	−21.1 ± 0.1	+27.8 ± 0.6	+ 2.5 ± 0.6	−19.5 ± 0.7	59.2	3.98	−20.4	+27.4	−19.4
72905	72.2 ± 5.5	− 24 ± 2.8	+ 87 ± 2.9	−12.3 ± 0.2	+ 9.9 ± 0.2	+ 0.4 ± 0.5	− 9.4 ± 0.3	56.0	4.33	− 8.4	+ 7.1	− 7.1
79028	43.7 ± 7.8	− 17 ± 3.6	− 26 ± 3.2	−14.2 ± 0.5	+ 7.6 ± 0.6	− 7.4 ± 0.6	− 9.8 ± 0.5	—	—	+13.8	−11.4	+ 8.3
81858	20.7 ± 3.3	+53 ± 3.0	− 7 ± 2.9	− 6.9 ± 0.6	+13.4 ± 1.6	+ 2.9 ± 0.7	+ 3.5 ± 1.4	9.3	0.25	− 5.2	+12.4	+ 4.6
88355	30.3 ± 6.0	+ 28 ± 2.6	− 41 ± 2.9	−15.2 ± 0.2	+12.8 ± 1.2	+ 2.0 ± 1.0	−11.0 ± 0.3	30.3	3.17	−15.2	+12.8	−11.0
94686	15.3 ± 3.1	+ 57 ± 7.3	+ 64 + 9.5	—	—	—	—	—	—	−18.6	+24.2	−12.8
238179	21	+103 ± 5.5	− 14 ± 5.0	−44.4 ± 0.3	+31.3 ± 4.2	− 7.1 ± 2.3	−38.6 ± 0.6	11.3	4.17	−21.6	+26.0	−18.5
114260	76.3 ± 13.6	+153 ± 10.0	−350 ± 8.7	−12.0 ± 0.1	+ 9.2 ± 2.7	+ 0.3 ± 1.3	−24.9 ± 3.1	101.2	7.30	−14.8	− 7.9	−26.8
238208	30	+ 76 ± 4.8	− 34 ± 4.5	−48.6 ± 0.3	+23.6 ± 2.6	−18.5 ± 0.9	−40.4 ± 0.5	4.2	—	− 2.9	+13.3	− 1.0
120528	22	+101 ± 4.0	− 36 ± 4.1	−22.5 ± 0.3	+24.1 ± 4.0	− 1.7 ± 1.8	−21.4 ± 0.6	15.4	4.50	−14.4	+23.1	−14.2
124752	34.1 ± 17.0	+147 ± 1.9	− 11 ± 2.0	− 5.6 ± 2.0	+16.7 ± 7.7	+ 9.0 ± 6.3	− 9.5 ± 3.1	77.2	7.98	−16.7	+19.5	−17.7
131156A	148.9 ± 1.6	+164 ± 3.9	−125 ± 4.0	+ 1.3 ± 0.1	+ 6.4 ± 0.1	+ 0.8 ± 0.1	− 1.9 ± 0.1	49.1	3.09	+ 7.6	+ 9.1	− 3.6
134083	61.3 ± 9.3	+117 ± 0.6	−165 ± 0.6	− 9.9 ± 0.6	+13.2 ± 2.6	− 2.2 ± 0.2	−17.0 ± 1.4	9.7	−0.18	+ 4.0	+18.8	− 5.0
137107/8	59.5 ± 5.1	+141 ± 5.2	−165 ± 4.7	− 6.9 ± 0.1	+14.6 ± 1.5	− 4.6 ± 0.4	−12.5 ± 0.6	—	—	+ 9.4	+20.7	+ 1.1
141003B	36.8 ± 9.6	+ 66 ± 0.4	− 45 ± 0.5	+ 1.4 ± 0.3	+ 8.5 ± 2.0	+ 2.0 ± 0.4	− 5.8 ± 1.8	37.3	7.81	+ 1.3	+ 8.4	− 5.8
147513A	67.5 ± 7.7	+ 78 ± 4.0	− 10 ± 3.6	+13.0 ± 0.1	+13.8 ± 0.2	− 1.1 ± 0.4	− 2.8 ± 0.6	33.0	3.04	+ 3.1	+ 4.5	− 4.0
147584	93.8 ± 10.2	+196 ± 2.0	+108 ± 1.2	+ 8.5 ± 1.5	+12.3 ± 1.3	+ 3.1 ± 1.3	− 5.4 ± 0.5	107.5	5.07	+10.2	+13.6	− 5.8
150706	45.2 ± 13.8	+ 95 ± 2.0	− 93 ± 2.0	−16.8 ± 0.3	+17.1 ± 3.5	− 6.0 ± 2.2	−12.2 ± 1.0	21.3	3.65	− 6.5	+13.7	− 6.6
151044	34.9 ± 8.5	+134 ± 1.9	−105 ± 2.6	−13.2 ± 0.2	+15.7 ± 4.4	− 2.6 ± 1.8	−21.4 ± 3.1	21.2	3.05	− 7.0	+16.8	−17.3
155674	50.8 ± 5.5	+ 78 ± 4.0	−110 ± 4.0	+ 3.0 ± 0.1	+11.4 ± 1.3	+ 4.9 ± 0.4	− 3.6 ± 0.7	—	—	− 0.6	+11.0	− 5.8
160269A	68.6 ± 5.8	+254 ± 3.5	−515 ± 3.1	−15.9 ± 0.5	+36.5 ± 3.1	− 4.3 ± 0.8	−21.8 ± 1.1	40.7	3.23	− 8.5	+36.4	−17.8
165185	59.0 ± 6.8	+107 ± 7.1	+ 11 ± 5.3	+15.2 ± 0.2	+14.5 ± 0.2	+ 3.9 ± 0.7	− 9.0 ± 1.0	95.3	5.87	+42.5	+41.5	−12.5
173667	50.9 ± 5.3	− 8 ± 0.4	−335 ± 0.5	+22.8 ± 0.2	+39.1 ± 2.6	+ 0.1 ± 1.8	− 9.0 ± 1.4	57.1	3.01	+25.3	+40.7	− 8.6
178428	60.6 ± 8.5	+ 63 ± 2.8	−306 ± 2.8	+14.8 ± 0.1	+24.8 ± 2.1	− 0.2 ± 1.6	−14.2 ± 2.2	74.9	5.52	+17.7	+26.6	−14.0
184960	36.5 ± 10.2	+ 30 ± 2.5	−183 ± 2.5	+ 1.0 ± 0.3	+20.2 ± 5.6	+ 2.1 ± 0.4	−13.0 ± 3.7	41.3	3.13	+ 0.9	+20.2	−13.1
203454	36.6 ± 6.8	− 16 ± 2.3	−229 ± 2.2	− 5.8 ± 1.1	+21.5 ± 4.1	− 9.8 ± 1.3	−18.9 ± 3.6	—	—	+ 6.1	+22.5	−20.3

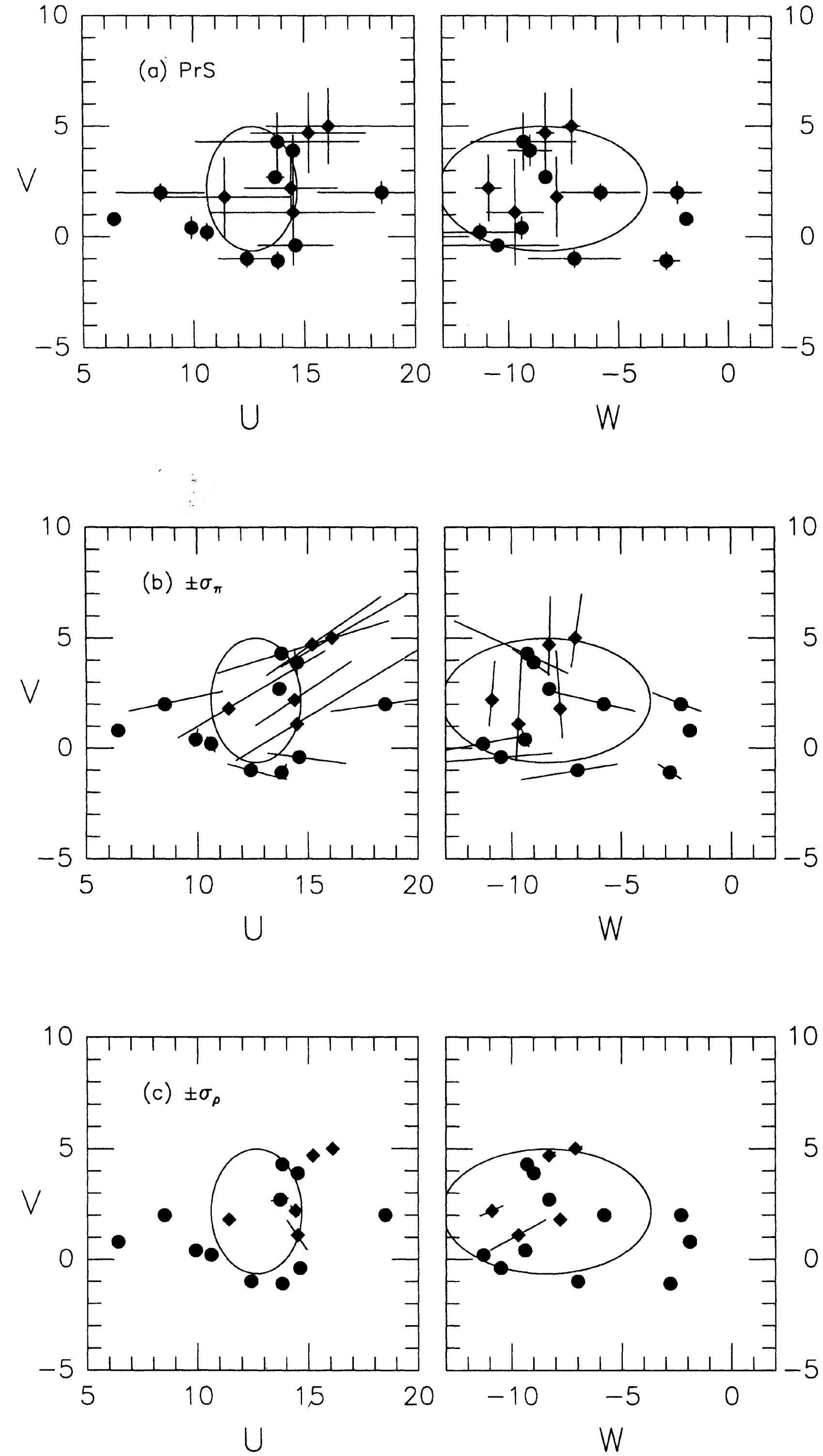

FIG. 3. Space motions of the PrS of UMaG. The ellipse is centered on the mean motion of the nucleus and has dimensions of 3 times the velocity dispersion of the nucleus stars. (a) The points are plotted with their formal error bars. The diamonds are stars of the group nucleus. (b) The lines show the effect of varying the parallax by one standard deviation in each direction. (c) The lines show the effect of varying the radial velocity by one standard deviation.

TABLE 8. Mean motions of UMaG stars.

Subset	N	$\langle U\rangle$	$\langle V\rangle$	$\langle W\rangle$	σ_U	σ_V	σ_W
Nucleus stars, unweighted	13	+12.64±0.18	+2.17±0.25	−8.42±0.42	0.65	0.91	1.52
Nucleus stars, weighted	13	+12.55±0.20	+2.09±0.23	−8.00±0.35	0.71	0.83	1.25
All HPS and PrS solar-type, unweighted	16	+13.02±0.73	+1.79±0.47	−7.59±0.72	2.93	1.90	2.89
All HPS and PrS solar-type, weighted	16	+ 9.47±0.82	+1.49±0.30	−4.69±0.80	3.28	1.20	3.21
HPS, PrS without ξ Boo, unweighted	15	+13.46±0.64	+1.85±0.50	−7.97±0.66	2.46	1.94	2.58
HPS, PrS without ξ Boo, weighted	15	+12.31±0.51	+1.96±0.35	−8.07±0.36	1.97	1.36	1.41

The parallaxes in column (3) are from the latest *Yale Parallax Catalog* (van Altena *et al.* 1992). The proper motions in columns (4) and (5) are from the *Catalog of Positions and Proper Motions* (PPM, Roeser & Bastian 1989), and are on the FK 5 system in the J2000 reference frame. The radial velocities in column (6) are from Evans (1980).

The procedures in Johnson & Soderblom (1987) were used to calculate the space motions in columns (7), (8), and (9), except that the constants needed to transform equatorial to Galactic coördinates for the J2000 reference frame were taken from Murray (1989). Some of the velocities listed in Johnson & Soderblom were bungled because of an incorrect implementation of the error computation. That error has now been rectified, and the uncertainties listed in Table 6 are believed to be accurate representations of the formal uncertainties along each of the three velocity axes. However, those formal uncertainties can be misleading because a single input parameter often introduces most of the uncertainty, and that then gets transformed into an error volume in velocity space that is asymmetric, highly prolate, and generally not aligned with the primary *UVW* axes. More can be learned by examining the influence of specific inputs on the final results, as will be illustrated.

The space velocities calculated from measured parallaxes of the nucleus stars are shown as open diamonds in Fig. 2. The individual parallaxes for these stars differ substantially, and at least one (that for ϵ UMa, whose point is off scale in Fig. 2) is likely to be spurious. Another measure of distance can be made by treating these stars as a cluster and determining a distance modulus. Mendoza (1967) did so, deriving $(m_V-M_V)=1.70$, which corresponds to $\pi=46$ millarcseconds (mas). The distance modulus of Mendoza is uncertain by $\lesssim 10\%$, leading to an adopted uncertainty of 4 mas for this inferred parallax. Use of $\pi=46\pm4$ mas results in the space velocities in the last three columns of Table 6. These velocities are shown as solid diamonds in Fig. 2, and they are joined by lines to the open points for the same stars.

Using a single distance for all the nucleus stars reduces the scatter in both the U and V motions. What scatter that remains can be accounted for by errors in the radial velocities and the finite spatial extent of the nucleus. For example, the short line segments in Fig. 2 show the effect of varying only the radial velocity by one standard deviation in each direction. For several of the stars such changes would be sufficient to bring the V motion into near perfect agreement with the mean value. Also, the nucleus stars are spread over more than 20° in the sky, which corresponds to about 7 pc. This means that the actual uncertainty in distance for an individual star could be as much as about 20%, which is enough to allow for additional adjustment in the final space motions.

The mean space motion of the 13 nucleus stars is listed in Table 6, together with similar means calculated by Palouš & Hauck (1986) and Eggen (1983a). [For earlier work on the nucleus of Ursa Major, see Roman (1949), Petrie & Moyls (1953), and Eggen (1965b)]. The uncer-

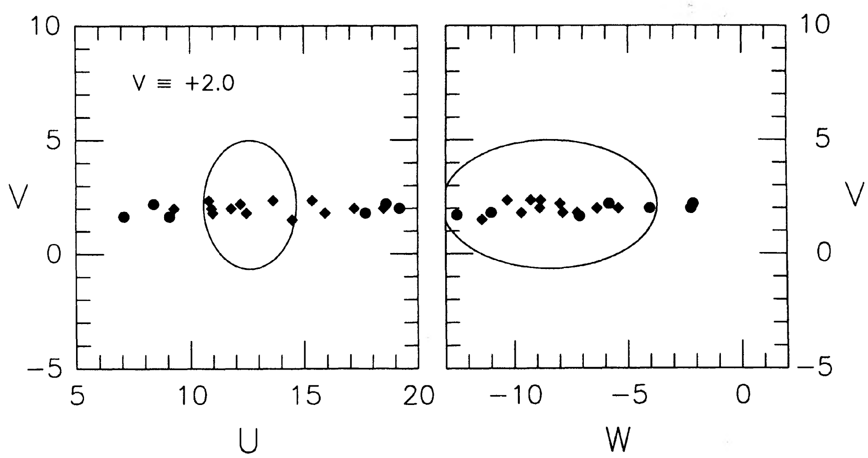

FIG. 4. Space motions of the PrS stars for the case where the V component has been forced to $+2.0$ km s^{-1} and the radial velocity has been held at the observed value. The plotted V values have been altered slightly to avoid overlap of the points.

tainties listed are dispersions about the mean, not the error of the mean, which means that not all these values agree to within the errors, although the present data do not conflict with Palouš & Hauck.

The net result is that these nucleus stars have essentially identical U and V motions to within the errors, but that they show a larger spread in W. However, Ursa Major is in the direction of the North Galactic Pole, so that the scatter in W is due primarily to differences in radial velocities. The ellipses in Fig. 2 are centered on the mean motions and have dimensions of three times the velocity dispersion in each direction. These ellipses will be repeated in subsequent illustrations to provide a comparison with the motions of field stars.

5. KINEMATICS OF THE SOLAR-TYPE CANDIDATES

Space motions of the solar-type stars of Table 5 have been computed in the same way just outlined for the nucleus stars, with the exception that stars south of declination $-2.5°$ have had proper motions taken from the *General Catalogue* of Boss (1937). The results are listed in Table 7. Coravel radial velocities (Duquennoy & Mayor 1991, present study) have been used whenever possible because of their high precision. These Coravel $v_{\rm rad}$ values have had 0.4 km s^{-1} added to them to place them on the same velocity scale as observations of minor planets at several observatories (Duquennoy *et al.* 1991; Latham & Stefanik 1992). This correction is so slight that it cannot alter any of the conclusions about kinematics reached here.

For HD 81858 the radial velocity determined from the Hamilton echelle spectrum was used because it is superior to previous observations. A few values have been taken from Griffin & Emerson (1975), or Woolley *et al.* [1970, using the quantitative errors in Gliese (1969)]. The proper motion of HD 11131 has been taken as identical to that of HD 11171, its companion, and that is from the FK 5 (Fricke *et al.* 1988). The proper motion of HD 147584 is also from the FK 5. For a few stars trigonometric parallaxes have not been measured, so an effective parallax was estimated from the spectral type and color using the relations in Gliese (1971). No uncertainties are shown for these nontrigonometric parallaxes in Table 7, but values of 20% were adopted for calculating the uncertainties in the derived quantities. As for the nucleus stars, the uncertainties listed are the formal ones from combining the uncertainties of all the input parameters.

5.1 Probable Spectroscopic Members

The space motions of those stars judged to be probable spectroscopic members (PrS), based on their age-related indicators, are shown in Fig. 3(a). Also shown are ellipses that are centered on the motion of the nucleus and have semimajor axes equal to three times the velocity dispersion in each coordinate; i.e., they represent the 3σ error ellipsoid. The solar-type stars that are also part of the nucleus itself (HD 109011, 109647, 110463, 111456, and 115043) have been shown as diamonds, and their velocities were calculated using their measured parallaxes.

The possible spectroscopic member (PoS) and probable spectroscopic nonmember (SNM) stars will be discussed further in a moment, but here an obvious yet important conclusion is noted: Using spectroscopic criteria to judge the membership of solar-type stars succeeds because the stars that meet those criteria are more tightly clustered in velocity space than was the sample before nonkinematic criteria were applied. This cohesiveness of the motions of the PrS stars also reinforces the authenticity of the Group, for it is implausible that these stars should have similar ages and just happen to lie near each other in velocity space.

The error bars in Fig. 3(a) are the formal ones. Figure 3(b) illustrates the effects of changing the parallax by one standard deviation in each direction and Fig. 3(c) shows the same for the radial velocity uncertainties. Modern observations have greatly reduced the uncertainty in space motions that used to be dominated by the radial velocities. For most of these stars, reasonable changes in the parallaxes can bring their V motions into agreement with the nucleus value of approximately $+2.0$ km s^{-1}.

As an ensemble, these PrS stars have the same components of motion as the nucleus to within the errors. The mean motions are listed in Table 8, calculated both with unweighted values and by weighting each velocity by $1/\sigma^2$. These means were calculated using all the PrS stars, including nucleus solar-type stars, as calculated with their measured parallaxes.[5]

ξ Boo, despite the clear evidence for its youth on spectroscopic grounds, must be rejected as an UMaG member on the basis of its kinematics. It does have the correct V motion, but it is so highly discrepant in U and W that it cannot plausibly belong to the group. The parallax and proper motions of this star are very precise because of its proximity, and its radial velocity is also well determined (DM). ξ Boo deviates by about 9 km s^{-1} from the motion of the nucleus, yet is $\lesssim 20$ pc from those stars, which means that if ξ Boo is truly part of UMaG it was given its deviant velocity less than about 2 Myr ago. Eggen (1989) has also considered ξ Boo to be a nonmember because of its kinematics.

These PrS stars appear more distended in U than do the stars of the nucleus, but that is mostly due to HD 131156 (ξ Boo) and HD 141003B at $U \approx 7.6$ km s^{-1}. ξ Boo especially distorts the velocity dispersions because of its small uncertainties; if it is ignored the distension decreases.

One of our requirements for the authenticity of the Group is that its members should have essentially identical V motions. The last four columns of Table 7 show the results of imposing this requirement. Column (9) lists the parallax the star must have if V is forced to a value of $+2.0$ km s^{-1}, given its observed $v_{\rm rad}$, and column (10) gives the star's M_V that follows from that parallax. If the observed parallax is held fixed instead, the $v_{\rm rad}$ value in column (11)

[5]Adopting the $+0.4$ km s^{-1} offset to the Coravel velocities mentioned above reduced the velocity dispersions of the PrS stars along all three axes. That suggests that using minor planets as $v_{\rm rad}$ standards is better than using the traditional IAU standards, at least for G dwarfs.

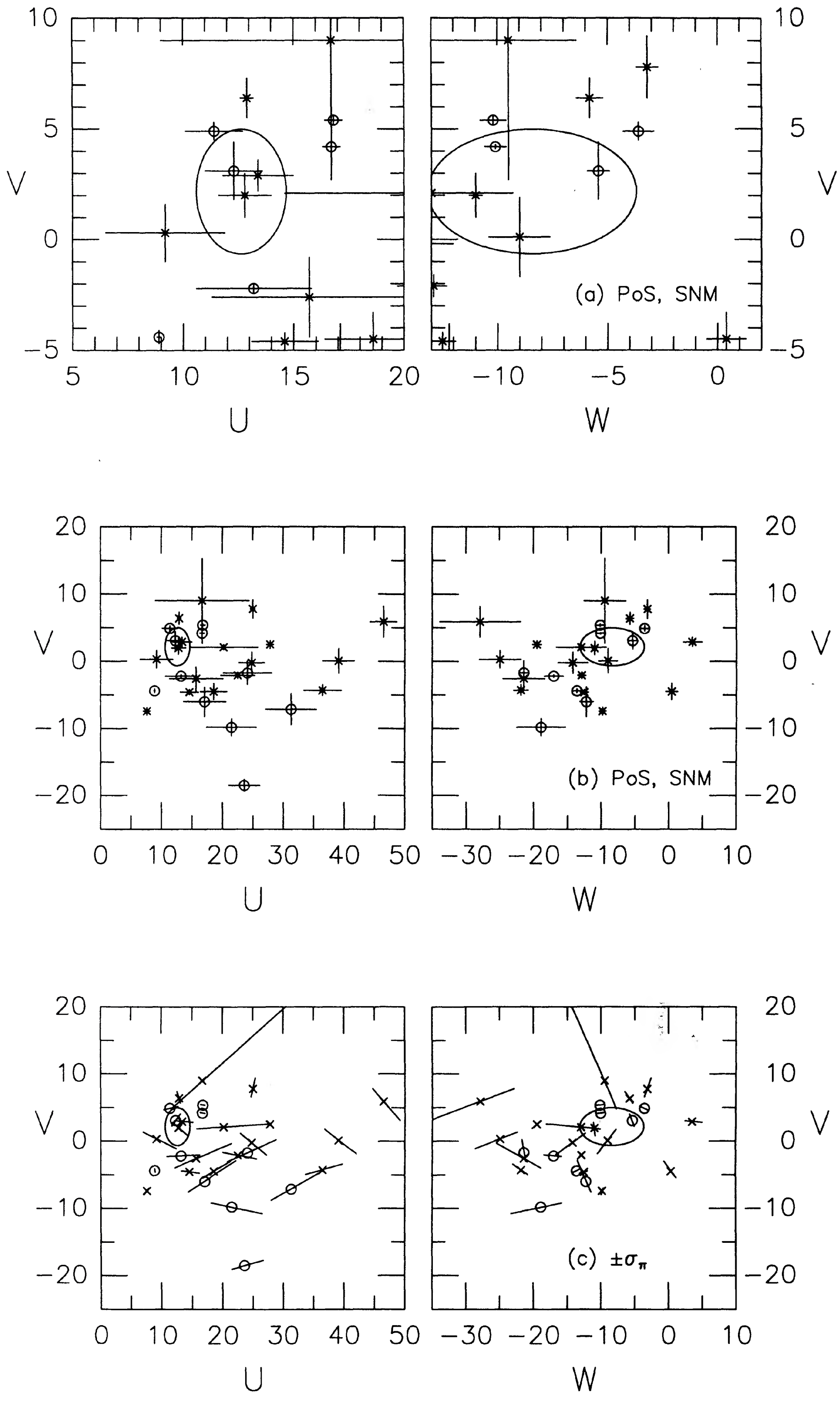

FIG. 5. Space motions of the SNM, shown as crosses, and the PoS, shown as open circles. (a) The points are shown to the same scale as Fig. 3 with the formal error bars. (b) Same as (a) at a larger scale. (c) The lines show the effect of varying the parallax by one standard deviation.

results. Finally, columns (12) and (13) list the U and W velocities that are derived from using the observed $v_{\rm rad}$ and the parallax in column (9). These derived parallaxes do not take account of the uncertainties in the other quantities used to compute them, so the fact that they often disagree with the measured parallaxes by significant amounts is probably indicative of their large error bars. The fact that one standard deviation changes in the parallax bring most stars into line with the V motion of the nucleus [Fig. 3(b)] is, we feel, more representative of the true effect of uncertainty in π.

These U and W values are shown in Fig. 4 (spread out slightly in V to avoid point overlap) for the PrS stars. Note that virtually all these PrS stars fit within the VW error ellipse of the nucleus. Stated another way, virtually all the stars chosen as likely members on spectroscopic grounds can formally have V motions identical to the Group nucleus without creating spreads in U and W that exceed the spreads that the nucleus stars themselves exhibit. The same cannot be said of the PoS and SNM stars, for only HD 88355, 124752, and 147584 even fall within the UVW domain of Fig. 4.

5.2 Possible Members and Probable Nonmembers

What about the stars that were rejected as members on purely spectroscopic grounds? Figure 5 shows the space motions of the PoS and SNM stars at two different scales. The kinematics consistently substantiate the rejection of almost all of those stars as members. Only one probable nonmember (SNM) lies fully within the 3σ error ellipsoid in all three coordinates, namely 34 Leo. Three other SNMs have large enough uncertainties in their motions to prevent their being entirely rejected for the present; these are HD 81858, 124752, and 184960. Better radial velocities may help to conclusively reject these stars. It is not surprising that one or two old field stars might occupy this region of velocity space purely by chance.

The situation for the possible members (PoS) is similar. Only HD 147584 and HD 155674 are close enough to the motion of the nucleus to remain as potential group members. The rest of the PoS category can confidently be rejected as UMaG members on kinematic grounds. It may be argued that the PoS stars exhibit a greater spread in velocity space just because they are systematically older than the PrS stars, and so form a broader Group "halo," but that begs the question of what a *bona fide* SKG really is. Even then, the PoS stars show a significant spread in the V component, too great for them to constitute a kinematic cohort.

The large uncertainties in the velocity components of many of these stars is also due mainly to poor quality parallaxes, as is shown in Fig. 5(c). This diagram also shows that parallax errors alone cannot bring the space motions of the PoS and SNM stars into agreement with the nucleus stars.

For the Ursa Major Group, spectroscopic membership criteria have been shown to strongly reinforce the kinematic criteria. The contamination is nearly nonexistent: only one PrS star failed the kinematic tests (ξ Boo) and only one kinematic member failed the spectroscopic tests (namely, 34 Leo; HD 124752 has large error bars that also allow for the possibility of it being a kinematic member). The connection between spectroscopic selection criteria and kinematic membership can be summarized with a matrix, shown in Table 9. The likelihood of kinematic membership has been assessed from the deviation of the star from the motion of the nucleus: Probable members fall within the 3σ error ellipsoid or their 1σ error bars must touch it, possible members could fall within the ellipsoid if they were moved by up to three times their own uncertainties, and unlikely kinematic members fall further away from the 3σ ellipsoid than their own uncertainties allow.

TABLE 9. A comparison of kinematic and spectroscopic memberships for non-nucleus solar-type stars.

Spectroscopic	Kinematic Membership		
Membership	Probable	Possible	Unlikely
PrS	6	4	1
PoS	1	1	9
SNM	2	2	15

The trend here is clear: the more a star behaves like one of the age of UMaG (in the sense of having the chromospheric activity of a young star), the more its kinematics agree with the motion of the Group nucleus. Thus application of spectroscopic criteria appears to be a valid means of winnowing solar-type stars to refine the Group membership. Is the use of CE infallible for determining membership? That may be nearly impossible to prove, but all of the considerable data amassed so far supports the contention that young stars always have high activity levels (Wilson 1966; Kraft & Greenstein 1969; Skumanich & Eddy 1981; Soderblom 1985; Simon 1990; Soderblom *et al.* 1991; Prosser *et al.* 1991; SSHJ).

6. THE URSA MAJOR GROUP AS A KINEMATIC GROUP AND AS A CLUSTER

The last section demonstrated that authentic UMaG members should fall within or near that part of velocity space that is defined by the motions of the stars of the group nucleus. Here that requirement is extended to stars other than solar type to try to better determine membership in UMaG.

Palouš & Hauck (1986) examined the space motions of nearly 1000 A stars and listed 101 that they judged to be likely UMaG members. The kinematics of those stars was calculated in the usual way, except that distances were determined from absolute magnitudes, which were calculated from Strömgren photometry (Palouš 1983). The space motions of those 101 stars (less the nucleus stars that they included) are shown in Fig. 6. The volume of velocity space from which they selected stars from is obvious from the bounds of the distribution, but within those bounds there is not a significant concentration of the stars at or near the nucleus velocity. Palouš & Hauck also illustrated all 927 of their stars in the UV plane (their Fig. 1). There

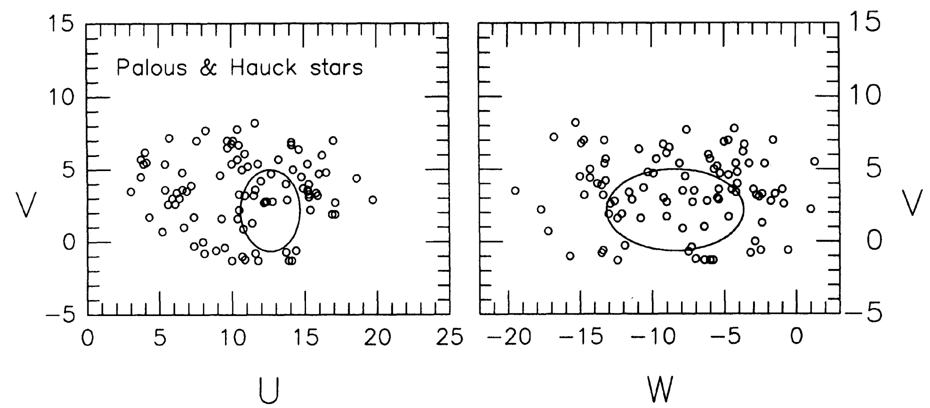

FIG. 6. Space motions of 101 A stars listed by Palouš & Hauck (1986) as UMaG members (the nucleus stars in their listing have been omitted).

is the expected ellipsoidal distribution of stars, but there is not otherwise any apparent structure in that distribution either. In particular, at the nominal velocity of the UMaG nucleus the density of stars does not exceed the density at a number of random fluctuations that occur elsewhere. The significance of the UMaG clustering within the space velocity distribution of Palouš & Hauck cannot be large if the clustering does not stand out to begin with, but a formal calculation is not justified until much more precise kinematics become available for these stars. For the present, it is not possible to reject the hypothesis that *none* of the Palouš & Hauck stars are UMaG members (except those known to belong to the nucleus).

Evolved stars are more pertinent to this study because they determine the group's age. Table 10 presents the kinematics of evolved UMaG candidates, taken from lists in Eggen (1983a, 1985, 1986, 1989). The F stars of Boesgaard *et al.* (1988) that were not part of the solar-type tabulation have also been listed. As before, proper motions are from the PPM and radial velocities are from Evans (1980). Distances have been calculated from the absolute magnitudes listed in the Eggen papers or from Strömgren photometry if good parallaxes were not available. The space motions of these additional candidates are shown in Fig. 7.

The entire analysis of this paper has been used to con-

TABLE 10. Kinematics of additional UMaG candidates.

HD	π (mas)	μ_α^{FK5} (mas yr^{-1})	μ_δ^{FK5} (mas yr^{-1})	v_{rad} (km s^{-1})	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})
4031	23.0±7.2	+ 17±0.4	− 7±5.0	−15.6±1.5	+11.2±1.3	+ 3.8±1.1	−10.9±1.4
6763	33.3±11.9	−264±1.1	−185±1.3	+ 6.7±1.3	+40.3±15.3	+ 5.5±1.1	−22.3±6.1
11171	44.2±7.5	−146±0.4	− 92±0.7	− 0.9±1.5	+17.7±3.0	+ 1.9±0.4	− 5.5±1.8
11257	20.7±4.1	− 72±4.7	− 32±4.4	+11.1±1.5	+ 9.2±3.2	+ 9.4±1.5	−16.7±2.1
13594	24.3±4.3	− 80±4.6	− 58±2.8	− 8.1±1.5	+16.0±2.2	+ 0.4±1.5	−13.5±2.8
24160	23.7±13.6	− 52±3.0	− 49±2.0	+ 2.0±1.0	+12.0±7.3	+ 0.5±1.1	− 8.0±3.8
30834	9.6±1.9	− 25±3.4	− 3±3.1	−16.5±0.5	+18.4±0.8	+ 2.8±2.0	− 9.3±2.7
33111	49.7±4.6	−100±1.0	− 79±1.1	− 9.0±1.5	+12.9±1.3	+ 3.6±0.6	− 7.0±1.2
40183	44.3±5.5	− 57±0.4	− 4±0.7	−18.2±1.5	+17.0±1.4	− 1.2±0.5	− 8.8±0.7
44691	22.8±6.8	− 29±5.1	+ 19±2.9	−59.3±1.5	+53.0±1.4	−14.5±2.0	−23.3±1.6
44762	17.5±5.9	− 30±2.9	− 56±2.3	− 2.6±1.5	+13.4±4.2	+ 0.4±1.4	−11.1±4.1
48915	380.3±2.0	−553±0.3	−1205±0.5	− 9.4±1.9	+15.4±1.3	+ 1.1±1.4	−11.1±0.3
75605	26.8±15.3	+ 5±7.0	− 50±6.0	− 7.8±1.5	+ 9.0±4.2	+ 5.1±2.0	− 5.8±3.0
85364	16.3±3.3	+ 9±1.0	− 32±1.0	−10.0±1.5	+10.6±1.5	+ 0.9±1.7	− 8.9±1.1
85444	18.5±9.0	+ 16±3.0	− 29±1.8	−13.5±1.5	+11.2±3.7	+ 7.5±2.2	− 8.5±1.3
89025	12.3±8.4	+ 17±4.0	− 13±1.0	−15.0±1.5	+14.6±5.1	+ 0.9±2.4	− 9.2±2.6
91752	23.9±4.8	+ 36±3.0	− 35±2.9	−23.7±0.6	+19.4±1.6	− 3.6±1.2	−16.5±1.0
99028	34.1±4.4	+166±2.0	− 79±0.1	−10.3±2.0	+26.9±3.3	+ 3.4±0.8	− 4.8±1.9
99648	32.7±9.8	+ 18±0.4	− 17±0.9	− 9.1±1.5	+ 4.3±1.0	+ 3.7±0.8	− 8.0±1.3
102070	28.7±11.9	+ 29±1.0	− 38±1.4	− 2.6±1.5	+ 6.7±3.0	+ 0.5±1.3	− 4.9±1.7
109799	36.3±11.9	+ 75±4.0	−100±2.5	− 0.9±1.5	+12.4±4.3	− 0.5±1.2	−10.6±3.4
124674	10.0±2.0	+ 72±5.7	− 9±5.8	−20.4±1.5	+28.2±6.1	+ 9.7±4.6	−26.9±2.6
125451	40.4±10.3	+105±0.7	− 30±0.8	− 3.0±1.5	+ 9.3±2.8	+ 5.2±1.4	− 7.7±1.9
139006	37.6±8.8	+121±0.3	− 98±0.6	+ 1.7±1.5	+17.5±4.0	+ 3.0±0.8	− 8.9±2.7
176303	39.4±11.4	+ 5±2.6	−124±2.7	+15.9±0.3	+20.8±2.8	+ 2.8±2.5	− 6.1±2.1
180777	48.0±8.5	+ 47±1.5	−121±1.7	− 4.0±1.5	+10.5±1.7	+ 2.7±1.7	− 7.9±1.3
216627	37.1±8.8	− 42±1.0	− 21±1.0	+18.0±1.5	+11.4±1.4	+ 5.9±0.6	−14.0±1.4

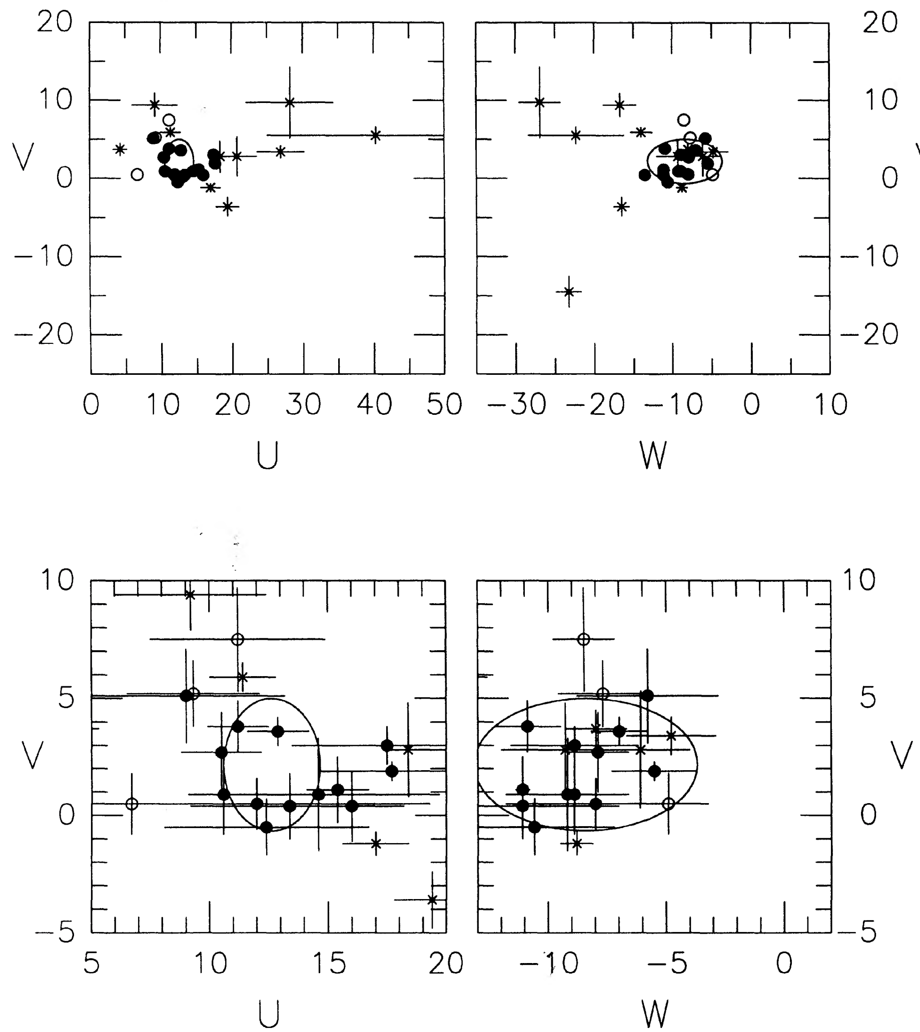

FIG. 7. (a) Space motions of the additional UMaG candidates of Table 9. These are primarily evolved stars from lists of Eggen and F dwarfs from Boesgaard *et al.* (1988). The filled circles denote probable kinematic members, the open circles possible members, and the crosses stars judged to be nonmembers. The error bars have been left off the probable and possible members in (a) to reduce clutter. Panel (b) is the same as (a), but on an enlarged scale.

struct a membership list (Table 11) for the Ursa Major Group. This is not an all-inclusive list in that there are candidates in some of Eggen's lists that are not considered, but these stars have passed all of the tests that the observations permitted. They have been classified as follows.

Probable Members: These are stars for which every indicator supports UMaG membership, which includes: (1) The stars of the nucleus. (2) The PrS solar-type stars of Sec. 5, with ξ Boo excluded. (3) Other stars, such as Sirius, that have well-defined space motions that agree (to within one standard deviation) with the mean motion of the nucleus.

Possible Members: In these cases the 3σ error ellipsoid overlaps the mean motion of the nucleus. The PoS stars of Table 5 that have kinematics in accord with the nucleus are included here.

Probable Nonmembers: Any star not listed in Table 11 has been rejected as a UMaG member.

Having created a list of *bona fide* UMaG members, let us examine them in the ways one might look at an open cluster. Critical information is missing that would be needed to do that job well, particularly a full census of UMaG members within a volume-limited sample. To date, Group membership has been anecdotal, based on whatever sample for which proper motions or other data might have been obtained. The large number of A stars proposed as Group members is evidence of that, as is the minuscule number of low-mass stars thought to be members, unless UMaG has a mass function that is radically different from those of open clusters. The type of work done by Méndez *et al.* (1992) should reveal these low-mass members of UMaG.

The fact that the A stars in the constellation of Ursa Major form a compact nucleus suggests that those stars lie

TABLE 11. Summary of UMaG membership.

HD	HR	Name	Sp.	$(B-V)$	$T_{\rm eff}$	M_V	Remarks
			Probable Members				
11131	531B	χ Cet B	dG1	0.62	5800	5.09	VB
11171	531A	χ Cet A	F3III	0.33	7140	3.00	VB
13594A	647A	—	F4V	0.40	6500	3.66	VB, $P=145$yr
13959	—	—	K4V	1.05	4480	6.50	
24160	1195	—	G9II-III	0.95	4940	0.46	
26913	1321	V891 Tau	G8V	0.70	5500	5.67	
26923	1322	V774 Tau	G0V	0.59	5920	4.48	
33111	1666	β Eri	A3III	0.13	8560	1.33	
39587A	2047A	χ^1 Ori A	G0V	0.59	5920	4.50	SB, AB
41593	—	—	K0Ve	0.81	5140	5.85	
44762A	2296A	δ Col A	G7II	0.88	5080	−0.34	SB, $P=869$d
48915A	2491A	α CMa A	A1Vm	0.00	9620	1.46	SB, $P=50.04$yr
72905	3391	π^1 UMa	G1V	0.62	5800	4.98	
75605	3512	—	G5III	0.87	5060	0.64	
85364	3899	6 Sex	A8III	0.17	8320	2.07	
89025	4031	ζ Leo	F0III	0.31	7260	−0.42	
91480	4141	37 UMa	F1V	0.34	8030	3.47	
95418	4295	β UMa	A1V	−0.02	9940	0.68	
103287	4554	γ UMa	A0V	0.03	9080	0.75	
106591	4660	δ UMa	A3V	0.15	8240	1.62	
109011	—	—	K2V	0.93	4780	6.40	
109647	—	—	K0	0.95	4740	6.80	
109799	4803	—	F1IV	0.32	6900	3.31	
110463	—	—	K3V	0.95	4740	6.58	
111456	4867	—	F6V	0.46	6480	4.16	
112185	4905	ϵ UMa	A0p	−0.02	9940	0.08	
113139	4931	78 UMa	F2V	0.36	6860	3.24	
115043	—	—	G2V	0.60	5880	5.14	
116656	5054	ζ UMa A	A2V	0.02	9300	0.57	
116657	5055	ζ UMa B	Am	0.13	8560	2.25	
116842	5062	80 UMa	A5V	0.16	8220	2.33	
139006A	5793A	α CrB A	A0V	−0.03	9980	0.16	SB, $P=17.36$d
141003A	5867A	β Ser A	A2IV	0.06	8980	1.74	
141003B	5867B	β Ser B	dK3	0.99	4620	8.02	
147513A	6094A	—	G5V	0.62	5800	4.08	
165185	6748	—	G3V	0.62	5800	4.80	
180777	7312	59 Dra	A9V	0.31	7260	3.60	
			Possible Members				
85444	3903	υ^1 Hya	G7III	0.92	5010	0.75	
102070	4514	ζ Crt	G8IIIa	0.97	4840	2.12	Too old
125451	5365	18 Boo	F5IV	0.38	6650	3.23	
147584	6098	ζ TrA	G0V	0.55	6080	4.78	
155674A	—	—	K8V	1.16	4260	7.40	VB
155674B	—	—	K8V	1.26	4080	7.87	VB

at or near the geometric center of the UMaG "extended family." The small total number of UMaG members in the solar neighborhood then has to mean that either UMaG formed as an extremely sparse cluster or it has been viciously torn to shreds. The age of UMaG is only slightly greater than the typical cluster lifetime of 0.2 Gyr (Wielen 1971), so the Group's fate is perhaps a normal one for many of the looser open clusters we now see.

There are are least two remnants of high-mass stars left in UMaG: the two white dwarfs that accompany main-sequence members. One of these is the venerable Sirius B, which has a mass of about $1.0\mathcal{M}_\odot$, about the same as LB 1497 (Bergeron *et al.* 1992), the Pleiades white dwarf. That suggests a progenitor mass for Sirius B that is comparable to the turnoff mass in the Pleiades. The other UMaG white dwarf is the companion to HD 147513, for which Wegner (1973) determined $\mathcal{M}=0.65\mathcal{M}_\odot$. The true mass of this star will be higher by about $0.04\mathcal{M}_\odot$ because it is young and has not fully cooled (Bergeron *et al.*). That puts it above the masses of the Hyades white dwarfs (Bergeron *et al.*), which is again consistent with UMaG's age.

The stars of Table 11 form the color–magnitude diagram shown in Fig. 8. The absolute magnitudes correspond to the parallaxes used to compute space motions, with the value for α CrB taken from Tomkin & Popper (1986). As before, the diamonds represent nucleus stars, and the lines are isochrones from VandenBerg (1985). Vandenberg's $T_{\rm eff}$–color relation was used to derive the temperatures of the non-solar-type stars. The top isochrone, for 300 Myr, fits the CMD well and so substantiates the age for UMaG found by other investigators, even when they included some nonmembers. The 400 Myr isochrone fits about as

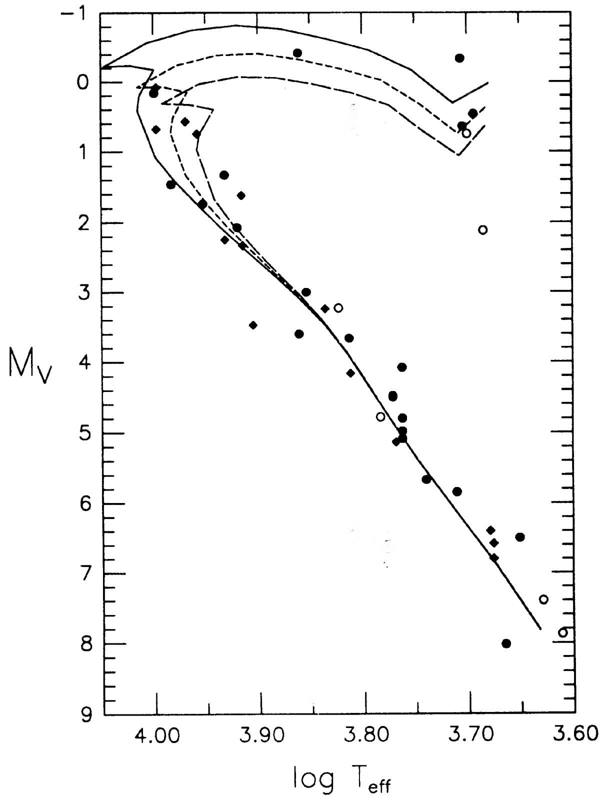

FIG. 8. Color–magnitude diagram for probable and possible UMaG members, and for stars of the nucleus. The nucleus stars are shown as filled diamonds, calculated using $\pi = 46$ mas, and the Probable Members of Table 11 are shown as filled circles. The open circles represent Possible Members. The lines are isochrones from VandenBerg (1985), for 300, 400, and 500 Myr from top to bottom.

well as the 300 Myr one, depending on how one chooses to fit the stars at the turnoff, but the 500 Myr isochrone is clearly an inferior fit. Note that we have fit to the probable members (the filled points), which meet the stricter kinematic criteria defined above. The open points have not been used in the fit. One of the stars judged to be a possible member on kinematic grounds, HD 102070, appears to be much too old to belong to the Group.

Refining UMaG's kinematics allows the Group metallicity to be redetermined. Boesgaard *et al.* (1988) determined [Fe/H] values for 23 UMaG candidates and derived $\langle[\mathrm{Fe/H}]\rangle = -0.079 \pm 0.053$. Six of their stars (or only one quarter) are likely kinematic members, and for those six $\langle[\mathrm{Fe/H}]\rangle = -0.080 \pm 0.094$, essentially the same as Boesgaard *et al.* found, but with twice the uncertainty. The majority of the stars that Boesgaard *et al.* examined are, in fact, not UMaG members at all because their kinematics deviate significantly from those of the nucleus. The fact that a major alteration of the membership of their sample changes [Fe/H] little suggests that metallicity is not a useful discriminant of membership.

7. CONCLUSIONS

We have applied spectroscopic indicators of age in solar-type stars to the problem of membership in a young group of kinematically associated stars, the UMaG. Stars that are judged to be young on the basis of the spectroscopy also have "tighter" kinematics than the original sample, indicating that the procedure helps to isolate genuine group members. The astrometric and radial velocity observations of most of these spectroscopic members are also consistent with them having exactly the same V motion as the nucleus, a requirement for the Group to be considered authentic.

At this time our knowledge of the constitution of UMaG is clearly incomplete because only the nearby and apparently bright stars have been considered. There are especially few low-mass members of the Group known. Whether that reflects initial conditions or the subsequent evolution of the Group cannot be determined until a comprehensive survey has been made. There is no evidence in the present data for systematically higher peculiar velocities among the G dwarfs compared to the A or F stars, as might be expected if equipartition of energy had occurred. But the dependence of velocity on mass after equipartition is weak, even if UMaG is probably old enough to have achieved that state (Binney & Tremaine 1987). Deeper surveys, at least in limited areas, are underway (Méndez & Ruiz 1992; Méndez *et al.* 1992). At the other extreme, one wonders if there are field white dwarfs or neutron stars that remain from once-massive stars that belonged to UMaG.

Among intermediate-mass stars, the improved parallaxes and proper motions that *Hipparcos* will deliver, together with the anciliary ground-based data being collected, will further refine the kinematics of these stars, probably to the point where it will be possible to study the deviant motions of individual stars. We may then hope to see directly the expansion of the Group and learn something of the forces that have rent it. *Hipparcos* should also substantially enlarge the number of known UMaG members. Those stars, together with the probable Group members of Table 11, will provide a sample useful for addressing some astrophysical questions.

This work would not have been possible without a band of able associates: Kip Kuntz reduced and analyzed the *IUE* data; Stephen Fedele reduced the Hamilton echelle data that Tony Misch obtained; Dean Johnson developed the software for computing space motions; Ari Zimmerman and Andrew Dring compiled astrometric data, computed space motions, and helped to illustrate them; Rob Hewett at CfA calculated radial velocities and $v \sin i$ values. W. van Altena was kind enough to supply a copy of his parallax catalog in advance of publication. A. Klemola identified a bug in the program used to calculate space motions, leading to correct error computation. S. Baliunas supplied Mount Wilson observations in advance of publication. J. Russell and M. Lattanzi provided advice on astrometry. Portions of this project were assisted by a grant from NASA to support *IUE* observations. We also benefited from access to *IUE* archival data through the National Space Science Data Center. The assistance of the Director and staff of the Lick Observatory are acknowledged with gratitude. Doctors G. Herbig, B. Jones, D. Popper, R. Saffer, and J. Stauffer were kind enough to provide helpful comments and insight. To all these people we are grateful. Additional support has been provided by the Director's Research Fund of the Space Telescope Science Institute and by the Ultraviolet, Visible, and Gravitational Astrophysics Branch of NASA's Astrophysics Division.

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