Introductory Papers

What is the Galaxy's Halo Population?

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Our current understanding of the Galaxy's halo population is reviewed, including its partial origins in accretion or merger events. Evidence is also presented for a metal-poor proto-disk population. While neither of these populations can be responsible for young, solar-metallicity early-type stars at large distances from the plane, consideration of both sources of metal-poor stars, the proto-disk and the accreted fraction, will be necessary to interpret the distributions of old, hot stars far from the Galactic plane.

1. Introduction

For a very long time, we have wondered about the structure and the history of our Milky Way Galaxy, and how similar it might be to other disk systems. The historical, or archaelogical, perspective has become wrapped up in the discussion of stellar "populations", the equivalent, perhaps, to the archaeologists' studies of dynasties in ancient kingdoms. Which one preceded and which succeeded? How far did their influences extend? And how did they affect the current state of affairs? Like the archaeologists, we have available for study only the surviving pieces of the ancient material, and we have been able to study only a tiny fraction of what is known. We have therefore been guided in our choices of what to study and how to interpret our findings by our own ideas of what the historical picture is like. And in the past few years, our ideas about what the halo is, where it came from, and how it is related to the solar neighborhood, have been in a state of flux.

It is not the purpose of this paper to present an extended review of the studies of the Galaxy's halo—the reader is advised to begin with Steve Majewski's (1993) excellent review article. Instead, we will begin with a quick review of how far from the plane disk-like populations may dominate the stellar densities, and how far one must look to be certain that the "traditional" halo population dominates. Then we will update the Majewski review to see what new insights on the halo population have been gained.

Before we proceed, however, be warned that the stellar populations approach will still be relied upon here, partly for taxonomic simplicity, like dynasties, but also because, similarly, it is the changes from one population to another that may reveal the historical dramas of the past. To this end, we must keep in mind the definition of a stellar population. For our purposes, a stellar population is an ensemble of stars and gas that share a similar history. The stars in a globular cluster would certainly qualify, then, as a population, but would all globular clusters also qualify as being members of a larger single population? No. The best perspective here is the elegant study by Bob Zinn (1985) of the spatial and chemical distributions of the Galaxy's globular clusters. He made it clear that there are in fact at least two separable populations of clusters: one that is metal-rich and concentrated in a disk and toward the Galactic center; and a second that is metal-poor and distributed spherically about the Galaxy. The two populations might have an historical link in that as the Galaxy was becoming enriched in heavy elements as it shrank, spun up, and flattened out. But we would still classify the "thick disk" globular cluster population as distinct from the "halo" globular clusters since they represent different epochs in the same history. And the two populations may not even have had an historical link at all. They could have evolved completely independently, in different but perhaps contemporary "kingdoms", as it were. The key here is to look at the metallicity distribution function: the numbers of clusters as a function of metallicity. In the simplest, closed box model of chemical evolution, gas with some initial metallicity begins producing stars, the stars enrich the gas in heavy elements, and the numbers of stars of a given metallicity rise as the metallicity increases. This continues until the gas begins to become depleted, whether through being locked away in long-lived stars or stellar remnants, or simply expelled by the energetics of star formation and death. Thus the halo globular clusters are, on average, probably metal-poor because most of the gas in the star-forming regions was expelled before significant enrichment took place. Had the gas not been lost, the mean metallicity of globular clusters would probably have been about the same as in the regions where gas loss is more difficult, like the disk or the bulge, where the mean metallicity is close to solar. That the disk and halo clusters have separate metallicity distribution functions, with peaks in [Fe/H] at values of about −1.6 and −0.5, rather than a continuum suggests (but does not prove) that they are separate populations with separate chemical and dynamical histories.

Metallicity is also not the only discriminant among populations. For example, had the Large Magellanic Cloud already been accreted by our Galaxy, we would now find a large number of field stars with mean metallicities of [Fe/H] ≈ -0.3, the mean metallicity of most of the LMC stars. The Galaxy itself has produced large numbers of stars with this same metallicity, but there would be in this case at least two post-merger populations, not one, because the histories of the stars would have been so different. The stellar dynamics would be bimodal throughout the metallicity regime [Fe/H] ≈ -0.3. Such a merger is one (Carney *et al.* 1989) explanation of the origin of the thick disk, although it is also very possible that the thick disk is simply the earlier stage of our current "thin disk" (see, for example, Ryan & Norris 1991). Disentangling the histories then involves the studies of metallicities, distributions, dynamics, and when possible, ages and detailed chemistries such as element-to-iron ratios (see, in particular, Edvardsson *et al.* 1993).

2. In Situ Studies

Studies of the halo population, which is a trace constituent in the solar neighborhood, have for decades relied upon either field stars selected with significant biases (i.e., proper motion samples to preferentially study high-velocity stars) or upon the globular clusters. As noted already, the clusters themselves comprise two, possibly distinct, histories, and in any case the number of clusters available for study is small. The selection biases on the vastly more numerous field stars (whose combined mass in the halo probably exceeds the combined mass in clusters by a factor of about 100) must either be well understood and modelled out, or samples must be selected without such biases. Norris (1986) was among the first to undertake such an unbiased study, utilizing samples of stars selected via spectroscopic or other means (e.g., variability to identify RR Lyrae variables) that did not involve a kinematic bias. His work and that of others led to a well-defined value for the asymmetric drift ($v_{drift} = -V$; $v_{rot} = V + \Theta_0$), where v_{rot} is the rotational velocity about the Galactic center, V is the velocity toward $l = 90$, b = 0 with respect to the Local Standard of Rest, and Θ_0 is the circular rotational velocity at the solar Galactocentric distance, which is about 220 km s^{-1}. Norris derived values for V, v_{drift}, v_{rot}, and the velocity ellipsoid (the velocity dispersions in the three orthogonal Galactic directions) as functions of metallicity, and thereby derived the values for the metal-poor solar neighborhood stars. With no data to controvert him, he assumed the most metal-poor stars in his sample defined the result for a single Galactic halo population. He found a slight prograde V velocity for the most metal-poor stars, of -192 ± 21 km s^{-1} for those with [Fe/H] < -2.28. He was unable to determine the distance from the plane at which this metal-poor population begins to dominate because his sample did not extend far enough.

A major step forward in this effort was the Ph.D. work of Steve Majewski. He used Kitt Peak 4-meter prime focus *UBVI* plates taken during two epochs, one from the mid 1970's and the second from the late 1980's. His calibrated photographic photometry enabled him to measure $\delta(U-B)_{0.6}$, the "normalized" ultraviolet excess defined by Sandage (1969) and calibrated in terms of [Fe/H] by Carney (1979). Much more impressively, however, Majewski also utilized quasars and galaxies in the field to determine proper motions for essentially all the stars down to a limiting magnitude of $B = 22.5$. His most distant stars are 25 kpc from the plane. The photometry leads also to distance estimates (under the assumption that all the stars are dwarfs, which at these faint magnitudes is a reasonable assumption), and hence both U and V velocities. The latter is the more important since it essentially is a measure of Galactic orbital angular momentum, and Majewski's (1992) plot of V vs. $\delta(U-B)_{0.6}$ was particularly noteworthy. As expected, at the distances closest to the plane (Z $<$ 1.25 kpc), the stars all had small asymmetric drifts (small V velocities), and most were only slightly metal-poor. At the largest distances, Z $>$ 10 kpc, the stars had large asymmetric drifts and generally low metallicities. There were two surprise treats. First, for Z $>$ 5 kpc, the mean V velocity/asymmetric drift was so large, $<V> = -275 \pm 16$ km s^{-1}, that for the preferred value of Θ_0, the net rotation of the "high halo" was retrograde. The importance of this result is obvious: the sign of the high halo angular momentum vector differs from that of the disk, and hence it is unlikely that the high halo is a predecessor to the Galaxy's disk population(s). Second, Majewski found that the metal-poor population did not begin to dominate the number count statistics until Z values of 4 to 5 kpc are reached. Below that, disk stars dominate, although these are fairly "hot" (dynamically) disk stars whose W velocities carry them to such large distances from the plane.

What effect does this have on the interpretation of the numbers of hot stars far from the plane? Clearly models that predict the numbers of such stars must take into account the rather great extent of the disk population(s), and the rather low densities of the halo relative to them below, say, 5 kpc from the plane. But the disk stars at these great heights are not likely to be producing stars in the current epoch. This large-Z domain is that of the thick disk, and the thick disk is apparently very old. At one level, we may estimate its age from its constituent clusters: the thick disk globular clusters studied by Zinn (1985). If we use the recent proper motion work of Cudworth (1993) to select globular clusters with disk kinematics, the results of Carney *et al.* (1992) reveal that 47 Tuc and M107 both have ages like those of the metal-poor halo globular clusters, perhaps 12 to 14 Gyrs. Are these clusters representative of the ages of the entire thick disk? Carney *et al.* (1989) derived a histogram of dereddened $B-V$ color indices for their sample of proper motion stars whose metallicities and kinematics matched those of the disk globular clusters. Their sample had no bias against blue stars, but there was an obvious blue limit in the results, consistent with the color of the main sequence turn-off of the disk globular clusters. Apparently the thick disk is old and unlikely to harbor many hot stars other than the types found in the halo: blue stragglers, blue horizontal branch stars (although probably few in number given the relatively high metallicity of the thick disk), and rarer types. Other explanations must be found for metal-rich, massive/short-lived early type stars in the halo.

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3. The Historical Perspective

3.1. *The Halo's Relation to the Disk*

The "normal" hot stars produced by the traditional halo population, such as the RR Lyraes and the blue horizontal branch stars, are thus expected to be relatively rare in the solar environs compared to disk stars, and become, again relatively, more common only at distances of several kpc above or below the plane. But have we made an unsupportable assumption? We have assumed there is only one "halo" (i.e., metal-poor and old) population that might produce such stars. Might there be more than one? After all, Majewski's results implied the high halo, defined here to be those objects with $Z > 4$ kpc, are on average in retrograde rotation and that therefore the majority of them were probably accreted by the Galaxy rather than formed during its earliest stages. Where are the metal-poor, old predecessors to the Galaxy's disk?

There is not yet consensus on the answer to this last question, but before addressing it, let us recall one of the first, most elegant ideas about the relation between the metal-poor halo and the metal-rich disk, that of Eggen *et al.* (1962; hereafter ELS). They found clear relations between the Galactic orbital angular momentum (the V velocity) and metallicity, implying a "spin-up" process, and another clear relation between the planar Galactic orbital eccentricity and the metallicity. Since the eccentricity was essentially an adiabatic invariant, the correlation between it and time/metallicity implied a short timescale for the "collapse" of the Galaxy from its spherical halo incarnation into its current rapidly rotating disk state. In recent years, the ELS data and model have been subjected to serious criticism, beginning with the cluster studies by Searle & Zinn (1978), and more recently with the field star studies of Ryan & Norris (1991), Carney *et al.* (1990b), and, of course, Majewski (1992). Further, the significant age spread among the metal-poor globular clusters (see, for example, Sarajedini & King 1989, VandenBerg *et al.* 1990 and Carney *et al.* 1992) is inconsistent with the rapid ELS timescale. The field star dispute is, perhaps, best summarized in Figures 1 and 2. These are taken from the expanded study of proper motion stars, begun by Carney & Latham (1987), and continued for over a decade in collaboration with John Laird and, recently, with Luis Aguilar. Briefly, the sample now contains 1452 F, G, and early K stars selected from the Lowell Proper Motion Catalog, although the proper motions used were taken from the Luyten NLTT catalogs, which are more precise and less biased. Photometry leads to distance and temperature estimates, while high-dispersion ($R \approx 30{,}000$) but low signal-to-noise (typically 5 to 10) echelle spectra are used to obtain the radial velocities to high precision, as well as the metallicities by χ^2 fitting to grids of synthetic spectra (see Carney *et al.* 1987; Laird *et al.* 1988).

In Figure 1 we see the mean V velocities plotted against metallicity. The interpretation of this Figure is straightforward: it is consistent with the ELS model. If metallicity is a chronometer, so that more metal-rich stars are younger, then it appears that the Galaxy has indeed "spun-up". A problem is that the Galaxy did not, apparently, spin up or begin to do so until the metallicity level had reached $[m/H] \approx -1.4$. Perhaps the metallicity enrichment timescale was so rapid that spin-up did not have time to occur. Another problem is the very low $<V>$ values at the lowest metallicities: they are consistent with zero net angular momentum (for $\Theta_0 = 220$ km s^{-1}, at least). Of course, they do not appear to be consistent with Majewski's (1992) retrograde rotation, either. But study of Figure 1 is misleading: what is necessary, when more than one population is involved, are the data themselves, not the means.

The data are shown in Figure 2, and now it appears that the halo population, if we can identify it most reliably using only stars on retrograde orbits, extends to quite

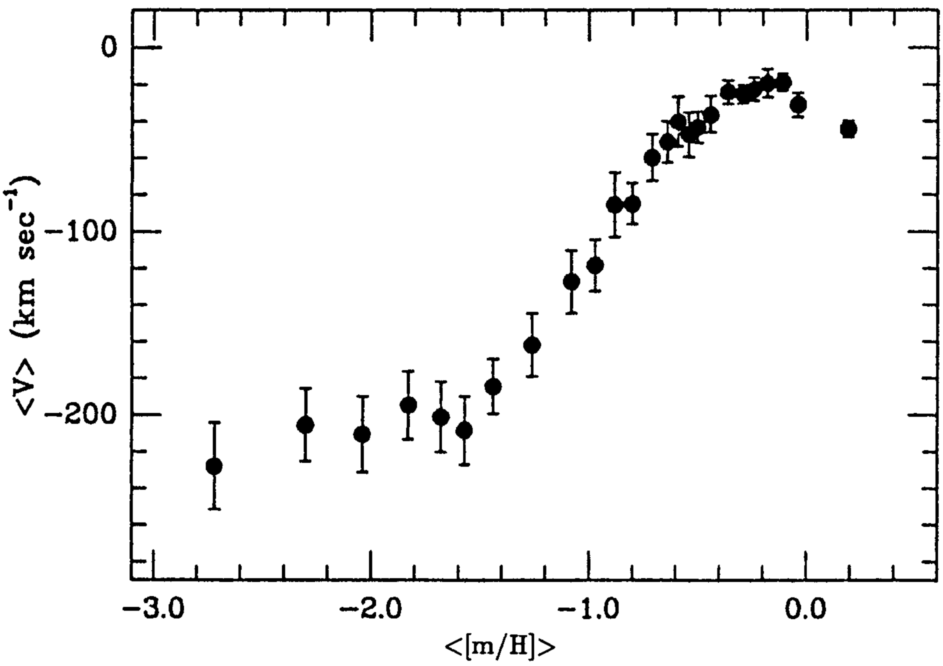

FIGURE 1. The relation between mean V velocity, <V>, vs. metallicity from a sample of proper motion stars. The 25 bins were chosen to each have equal numbers of stars.

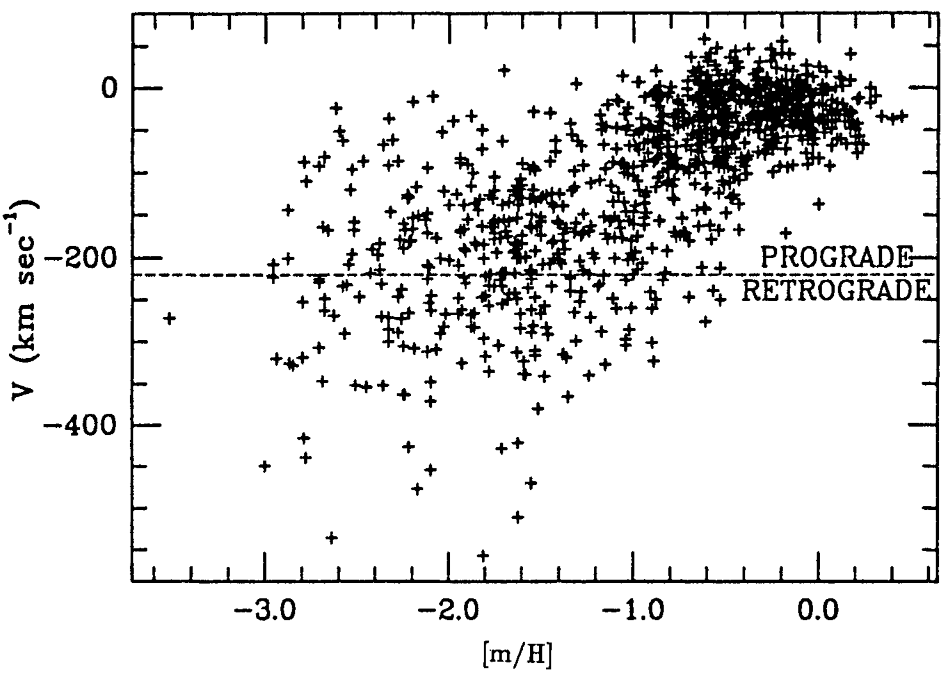

FIGURE 2. The individual data points from the sample of proper motion stars.

high metallicities. The trend seen in Figure 1 is not real: it is the blending in differing proportions of the metal-rich disk stars (V > -100 km s^{-1}) with the halo stars, which diminish in this sample relative to the disk stars as the metallicity increases. The halo population itself does not appear to have any obvious relation between V velocity (i.e., angular momentum) and metallicity, which is consistent with an accretion origin for the halo. In fact, this same trend may exist in the original ELS sample. Ryan & Norris (1993) have modelled the original selection effects in the two catalogs from which the ELS data were taken: one of high-velocity stars; the other of local disk stars. Assuming a dynamically hot halo with no relation between metallicity and kinematics, and a disk population with a monotonic relation between kinematics and chemistry (i.e., that the thick disk is the precursor of the thin disk), Ryan & Norris (1993) found that they could very satisfactorily reproduce the original ELS data, but obviously not their conclusions.

3.2. *More Than One Metal-poor Population?*

But is the halo population nothing more than (mostly) metal-poor stars accreted by our Galaxy? Are they the remains of loosely bound globular clusters or dwarf galaxies that formed stars and enriched their internal gas independently of what was happening within the Milky Way?

A completely independent halo population seems unlikely if for no other reason than it aggravates the "G dwarf problem", which is the failure of simple chemical evolution models to predict as few metal-poor stars in the solar neighborhood as are apparently observed. Removing even the few halo stars to independent origins outside the Milky Way certainly makes this problem only worse.

There have been some signs earlier, however, that have suggested that even the metal-poor stars may belong to two different populations with, presumably, two different histories. For example, Hartwick (1977) found that he could not readily model the distributions and kinematics of the local metal-poor ([Fe/H] ≤ -1) RR Lyraes with only one component. He needed two, one spheroidal as expected, and one flattened. Rodgers & Paltoglou (1984) found a suggestion that there is a "group" of comparable metallicity ([Fe/H] ≈ -1.5) globular clusters in retrograde rotation, presaging Majewski's (1992) result. (The fact that they had similar metallicities is interesting, but since the majority of the metal-poor clusters have a similar metallicity, this is not compelling.) The existence of such a sub-group means, of course, that even the metal-poor globular clusters might be divisible into separate sub-populations or even populations. Finally, Sommer-Larsen & Zhen (1990) studied a kinematically unbiased local sample of metal-poor stars ([Fe/H] ≤ -1.5), and, like Hartwick (1977), found they needed two populations, one spheroidal and one flattened, to provide a good fit to the data. The two populations are of comparable density in the solar neighborhood, but the spheroidal one has a greater total mass due to its greater spatial extent.

Three recent types studies have begun to reveal clearer signs of two metal-poor populations, one perhaps related to a disk population and the other to an accreted, spheroidal population.

First, there have been two detailed studies of the metal-poor globular clusters. Sidney van den Bergh (1993a, b, c) has compared the mean fundamental mode of the pulsation period (the "Oosterhoff class", where type I usually have $<P_{ab}> = 0.55$ day, and type II have $<P_{ab}> = 0.65$ day) against other properties of the clusters, particularly whether their radial velocities indicate prograde (i.e., disk or proto-disk) or retrograde (i.e., accreted) motion. There seems to be a fairly clean division, with the Oo I clusters preferring retrograde orbits, an extension of the Rodger & Paltoglou (1984) results. van den Bergh also found that the more distant clusters were more likely to be on plunging rather than circular orbits, and that this tendency is related to horizontal branch morphology. He interpreted these results as suggesting that both the Searle & Zinn (1978) accretion/merger model and a variant of the ELS continuum model for the formation of the halo may be operating. Perhaps the more quantitative results come from the study by Zinn (1993). He and his colleagues have made a thorough study of the morphology of globular cluster horizontal branch morphologies, using the quantity C = [(B-R)/(B+V+R)], where B, V, and R are the numbers of horizontal branch stars blueward of, within, and redward of the instability strip. Everything else (such as [X/Fe], helium, rotation, etc.) being equal, C should depend on metallicity alone, with more metal-poor clusters having bluer horizontal branches (and more positive values of C). Clusters do not obey a simple such relation, so a "second parameter" must be operating. If this second parameter is age, Zinn could identify, at fixed [Fe/H], younger clusters by the C value, with redder horizontal branches (more negative C values) being indicative of younger ages. The relative ages he derived are supported by those derived by Sarajedini & King (1989), VandenBerg *et al.* (1990), and Carney *et al.* (1992). Zinn then divided up his sample into "old" and "young" clusters, with a shift in C of at least 0.4 required to move a cluster into the latter category. The probable age differences between the two groups were then somewhere between 1 and 3 Gyrs. He then looked for two key signatures of a disk population. Disks and proto-disks ought to have prograde rotation. The 46 metal-poor globular clusters in the "old" category showed a mean rotational velocity ($v_{rot} = V + \Theta_0$) of 70 ± 22 km s^{-1}. The 19 "young" metal-poor globular clusters showed $\langle v_{rot} \rangle = -64 \pm 74$ km s^{-1}. Since the results came from a relatively small sample, and using only the measured radial velocities, large uncertainties in these results were expected, but they do at least suggest that there could be a retrograde component to the metal-poor stars, as Majewski (1992) had argued, and that, further, this accreted component might be younger than the possibly proto-disk sample. The second disk-like signature Zinn studied was the metallicity gradient. Disks are dissipative structures, and metallicity gradients are expected as a consequence of their formation. The "young" clusters showed no sign of a metallicity gradient, determined using the clusters' measured metallicities and their current Galactocentric distances, as might be expected from an accreted population (although other explanations for the lack of a gradient also exist—see Majewski 1993). The prograde rotation, "old" population, however, did show signs of a metallicity gradient. The clusters lying within 6 kpc of the Galactic center have a mean metallicity of −1.44 ± 0.06, while those lying between 6 and 15 kpc have $\langle[Fe/H]\rangle = -1.80 \pm 0.07$, and those lying further than 15 kpc have $\langle[Fe/H]\rangle = -1.93 \pm 0.10$. At least in the inner parts of the Galaxy, a metallicity gradient seems to be present for these older, prograde rotation clusters.

The second recent study is that of Norris (1993), who has been doing Monte Carlo simulations of large data samples, particularly of the Carney-Latham-Laird (CLL) sample. His procedure is to adopt relative number densities of the populations he will include in his model, and how their dynamics depend upon metallicity, in particular the asymmetric drift and the three components of the velocity ellipsoid. Having defined the relative mid-plane number densities of the constitutent populations and the relations each has between chemistry and kinematics, he can then use the Monte Carlo approach to generate synthetic surveys whose selection criteria match those of real observational programs, including limits on position, magnitude, color, and proper motion. While this procedure may seem somewhat arbitrary, there are already serious constraints upon what values he may adopt for the halo population, for example, and upon the relative densities of the thin disk, thick disk, and halo populations, largely through his previous work (Norris 1986) and that of Majewski (1992). His prior work, in collaboration with Sean Ryan

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(Ryan & Norris 1991) was intended to determine if a separate, accreted thick disk (no relation between kinematics and metallicity) or an "extended disk" (i.e., the thick disk being a precursor to the thin disk, with a monotonic relation between kinematics and metallicity) better matched the CLL results (Carney *et al.* 1990a). The results were ambiguous, with neither model presenting a subjectively suitable match to the behavior of all 4 parameters, V, σ^2(U), σ^2(V), and σ^2(W). In his new work (Norris 1993), he has adopted an infall of unenriched gas, the so-called "Best Accretion Model" of Lynden-Bell (1975), with the amount of such material measured by the ratio of the infalling mass to the original mass, as defined by Pagel (1989). This extra component means, mathematically, that there is one more free parameter that Norris can vary to obtain good fits to the observations. But it is physically plausible, and adds a larger amount of low-metallicity material to the disk component, where it is needed. Thus the metallicity distribution of the disk in this model is no longer symmetric about the mean, but has a strong tail to the lowest metallicities. The best fits result, in fact, when the tail is strong enough that in local samples, the density of the disk population may actually exceed or at least be comparable to that of the accreted halo population even at metallicities as low as [Fe/H] < -2.0. The very good match between Norris' models and the CLL data does not, of course, prove that such an "extended" disk (or, as Norris, dubs it, a "dual halo", but which I prefer to call a proto-disk) exists, but the results are very suggestive. In the words of the detective Nero Wolfe, "In a world of cause and effect, circumstance is suspect". Infall is, of course, not an outlandish idea. It must have occured at some level early on, and it is plausible that it did so at the level suggested by Norris' results. And of course recent infall may even be responsible for some of the massive, young stars seen far from the plane.

The final new contribution is as yet not even in preprint form, but rather still in preparation. This is the extension of the original CLL survey, from its original 900 stars to the current 1452 stars, from the original 6,000 echelle spectra to the current 23,000. Space does not permit a full discussion of the results from this new survey, but there are three points that must be raised and compared to the prior work by Majewski (1992), Zinn (1993), and Norris (1993).

First, following Majewski (1992), the new sample (hereafter CALL, for Carney, Aguilar, Latham, and Laird) is divided into "high" and "low" subsamples. With the proper motions, radial velocities, and distances, we have obtained U, V, and W velocity vectors, and these have been integrated within a model Galactic gravitational potential, following the same procedures outlined by Carney *et al.* (1990a). From these integrations, we have derived the mean apogalacticon, $<R_{apo}>$, and perigalacticon, $<R_{peri}>$ distances, as well as the mean maximum distance from the plane, $< |Z_{max}| >$. All of these represent, typically, the averages over 15 orbits. The "high" subsample includes those stars with $< |Z_{max}| > \geq 4.0$ kpc, while the "low" subsample has $< |Z_{max}| > \leq 2.0$ kpc. We must also add another criterion, one involving velocity, for our sample was selected from a proper motion catalog and hence is kinematically biased. As Ryan & Norris (1993) have shown quite convincingly, this type of bias works against disk-like kinematics, and even for the most metal-poor stars, which presumably have high velocities, it leads to a bias toward, for example, larger asymmetric drifts than an unbiased parent population might possess. Indeed, a sample with $<V> = -190$ km s^{-1} selected according to Lowell Catalog proper motion limits would result in a measured $<V>$ of about -220 km s^{-1}. One important consequence of this is that the remark made earlier about the nearly-zero net angular momentum of the most metal-poor stars (see Figure 1; $<V> \approx -220$ km s^{-1}) was inappropriate since it referred to such a biased sample. The mean V velocity of the most metal-poor stars, when this bias is removed, is thus probably mildly prograde.

Ryan & Norris (1993) estimate the correction to be Δ<V> = 30 km s^{-1}, so that <V> ≈ -190 km s^{-1}. Without invoking Monte Carlo modelling at this early stage in our analyses, however, we can avoid it somewhat by selecting only those stars with large U and W velocities, large enough to avoid large biases against their selection in the Lowell catalog. Thus for the "low" subsample, we require the stars to have $(U^2 + W^2)^{1/2} \geq$ 200 km s^{-1}. Such stars will easily be included in a proper motion catalog by virtue of their large U and W velocities. This not only means the V velocity component should not be affected by the proper motion bias, but that its overall value can have, physically, almost any value since the total kinetic energy content in the U and W motions is enough to keep the star at this Galactocentric distance (i.e., the net velocity is comparable to or greater than Θ_0). The results are very interesting: the "high" sample, like Majewski's, reveals retrograde rotation, $<v_{rot}> = -35 \pm 17$ km s^{-1}, whereas the "low" sample shows prograde rotation, $<v_{rot}> = +48 \pm 12$ km s^{-1}. If the "high" limit to $< |Z_{max}| >$ is increased to 5.0 kpc, $<v_{rot}>$ increases to -50 ± 21 km s^{-1}, in excellent agreement with Majewski's (1992) result of -55 ± 16 km s^{-1}. His result had been criticized on the grounds that his distance estimates may have been systematically in error, leading to the net retrograde rotation, but the CALL distances for both the "high" and "low" samples are determined using one algorithm, so the difference between the "high" and "low" subsamples is real. The "high" halo does indeed seem to be in net retrograde rotation and, therefore, at least the majority of it probably is an accreted component. The "low" halo, on the other hand, could be composed of a proto-disk component.

The second study is to search, like Zinn (1993), for a radial metallicity gradient, indicative of a dissipational process that may signal the formation of the disk. Using $<R_{apo}>$ as the radial variable, the "high halo" shows, as expected, no metallicity gradient, $d[m/H]/d<R_{apo}> = +0.003 \pm 0.014$ dex kpc^{-1}. The "low" halo, however, does manifest a metallicity gradient, $d[m/H]/d<R_{apo}> = -0.030 \pm 0.012$ dex kpc^{-1}, or about 0.5 dex from the inner part of the "halo" to the outer part, consistent with Zinn's (1993) findings for the "old" clusters.

Finally, Zinn (1993) began by dividing his sample into "young" and "old" metal-poor globular clusters. Can we find the same thing in our field stars? Ages of individual field stars are hard, but not impossible, to estimate. Schuster & Nissen (1989) have used model isochrones and *uvbyβ* photometry to estimate ages for metal-poor stars, many of which have been studied by CALL. As they had already determined, there is no clear relation between the ages and the metallicities of the metal-poor field stars. Stars with [Fe/H] ≈ -1 were the same age as those with [Fe/H] < -2.

However, Figure 3 shows that the "high" halo stars appear to be younger than the "low" halo stars, just as Zinn (1993) found. While the statistics are not great due to the limited sample size, the "low" halo formally has $<[m/H]> = -1.71$ and $<t_9> = 15.7 \pm 0.3$ (N = 29, t_9 is the age in Gyrs), while the "high" halo has $<[m/H]> = -1.64$ and $<t_9> = 13.2 \pm 0.8$ (N = 5). (It even appears that there might be two age groups, with the younger one having a greater scale height that the older one.) The CALL survey, in other words, confirms that the "high" halo is in retrograde rotation and lacks a metallicity gradient, while the "low" halo is in prograde rotation and does show a metallicity gradient, and like Zinn's two samples that display these properties, the retrograding population is apparently younger than the prograding one. Clearly, a larger sample of metal-poor stars with measured stellar ages is needed, and the observations are already underway, in collaboration with Bill Schuster.