THE EVOLUTION OF OLD STELLAR POPULATIONS IN OUR GALAXY

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1. Introduction

I would like to focus on one aspect regarding the evolution of Galactic stellar populations that is particularly relevant to discussions at this symposium: Where were the sites of early star formation in the Galaxy? The large scatter in abundance ratios for metal poor stars suggests multiple early settings of star formation in the Milky Way. In this and other ways, interpretation of detailed stellar chemical abundance analyses are converging with those of spatial-kinematical analyses of field stars, star clusters and satellite galaxies.

The latter now point to so-called "dual halo" models (Hartwick 1987, Zinn 1993, Majewski 1993, Norris 1994, Carney et al. 1996), which, in the simplest view, may be no more than a combination of the Eggen et al. (1962) collapse model leading to the formation of a flattened old population (most likely the Intermediate Population II – "IPII" – thick disk), with the Searle & Zinn (1978) scenario as the genesis of an "accreted" halo collected from disrupted satellites (see Sandage 1990). However, it would be imprudent not to state at the outset that the issue of the origin of the IPII remains unresolved, even at the most basic level of "top down" versus "bottom up" scenarios (cf. Majewski 1993).

Perhaps more progress is being made in understanding the origin of the more extended, outer halo. Evidence now suggests that this stellar population is dynamically unmixed – an important indication of continuing dynamical processes most likely related to accretion – and, while it dominates he most extreme spatial and kinematical distributions of the Milky Way, the outer halo does *not necessarily* dominate the most extreme [Fe/H] distribution in the Galaxy. Extremely metal poor stars are likely to make up both the accreted and flattened old populations of the Milky Way (Norris 1994). That the ages of some stars in the flattened halo are at

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least as old as some in the outer halo, and perhaps even older (see below), suggests two major, parallel venues of star formation in the early Milky Way. A picture emerges whereby stars were forming in a major structure of substantially flattened, dissipated gas – leading to formation of the IPII and other flattened populations – nearly coincidentally with the onset of star formation in chemodynamically very different sites that gave birth to stars now constituting the outer halo. With an origin (possibly exclusively) through accretion, the outer halo represents stars and clusters likely to have formed in multiple, disconnected star formation sites (dwarf galaxies?) resulting in great chemical diversity. Depending on the precise nature of Galactic accretion processes, the ultimate number of original sites may still have been somewhat limited in the outer halo, perhaps in the form of several previously larger, LMC-like satellite galaxies.

2. Flattened, Old Stellar Populations

The need for a flattened, rotating, metal weak halo population, in addition to a more spherically shaped metal weak halo, is exhibited by RR Lyrae stars (Harwtick 1987), other horizontal branch (HB) stars (Kinman et al. 1994), dwarf stars (Sommer-Larsen & Zhen 1990, Ryan & Norris 1991, Allen et al. 1991, Majewski 1992, 1993, Carney et al. 1996, Wilhelm et al. 1997) and globular clusters (Zinn 1993). The fractional contributions of each of these subpopulations to the total "halo" remains to be clarified. The best that might be said is that in the local "halo" population, the densities of the two subpopulations are probably of the same order of magnitude (Sommer-Larsen & Zhen 1990, Kinman et al 1994). Understanding selection biases is crucial to this enterprise, and most critical is the distinction of "flattened halo" components from the IPII and other disk populations which overlap spatially and chemodynamically. In my opinion, such distinctions are obviated by our present inability to even identify distinguishing characteristics; so any separation represents an unnecessary obfuscation for the time being. With little weight of evidence suggesting otherwise, it is much simpler to consider all of the flattened, metal weak populations (e.g., the "metal weak thick disk", the "lower halo", the "flattened spheroid") as the same, and here I refer to this all-encompassing population as the IPII. Note that this simplification is not related to (the also unresolved) arguments over the separability of the IPII/thick and thin disks of the Milky Way – an issue with great bearing on the IPII origin (Gilmore et al. 1989, Majewski 1993).

What we *can* say with confidence is that the extreme age of stars and clusters in the flattened, metal-poor components are *old* – near the limits of Galactic stellar ages (Carney et al. 1990, Latham et al. 1992, Marquez & Schuster 1994, Gilmore et al. 1995, Agostinho et al. 1996, Schuster et

al. 1996), and comparable to, if not older than, the outer, spherical halo subpopulation. This antiquity is supported by the few well-studied disk globular clusters (Fullton 1996), and of course by the "old halo" (à la Zinn 1993) globulars, but even the age distribution of *open clusters*, which canonically are a population of the *thin disk*, now extends past the ages of the youngest halo globular clusters (Phelps 1997; Majewski et al. 1996c, Figure 4). Relatively old ages (> 12 Gyr) are also found for disk stars (Edvardsson et al. 1993, Nordstrom et al. 1997), and from white dwarf cooling theory (Isern et al. 1996, Oswalt et al. 1996). That some halo globular clusters (e.g., Rup 106, Pal 12, Ter 7, N6366, Arp 2) were forming gigayears after star formation in the disk commenced is strong evidence supporting late contributions to the outer halo after any global Galactic collapse (Searle & Zinn 1978). The combined distribution of open and globular cluster ages demonstrates the additional characteristic of a more or less continuous star formation rate in the integrated disk components, a fact also reflected in detailed chemodynamical analyses of starcount data (Haywood et al. 1997).

We must conclude that a primary site for early star formation was within the rather deep potential well of a fairly dissipated early Milky Way. Whatever the future direction of dynamical evolution of this flattened population (collapse with or without spin-up, heating by secular or stochastic processes), a signature of the *earliest* star formation here may be well-defined elemental abundance patterns specific to first nucleosynthetic sites of this particular environment (Brown et al. 1991, McWilliam et al. 1995) since there would be a lack of pre-enrichment by star formation sites now corresponding to the outer halo. Contributions by a possible pre-Galactic Population III (Ostriker, this symposium) would likely be rather homogeneous on relevant length scales. Observed disk age-[Fe/H] relations (Marsakov et al. 1990, Friel & Janes 1991, Edvardsson et al. 1993), while showing significant scatter at intermediate ages, do have more defined metal-poor tails at the greatest ages; however the latter must be regarded with great caution until survey selection biases are assessed. On the other hand, the remarkably small scatter in [α/Fe] in the low metallicity tail of disk stars (Edvardsson et al. 1993) attests to efficent large-scale mixing expected in the more global setting of this flattened halo, while the absolute value of the [O/Fe] ratio for these stars reflects enrichment dominated by Type II supernovae (Matteuci & Tornambé 1985, Truran & Thielemann 1987, Wheeler et al. 1989, Wyse & Gilmore 1988), consistent with expectations for a first population of Galactic stars. A practical complication to verification of a scenario as described is later contribution (via satellite mergers – a viable origin model for the "thick disk") of old stars formed in external sites to the flattened population of old stars formed *in situ*.

While the true identity of the damped Lyman α systems seen in high

redshift QSOs is controversial, competing interpretations of these systems are particularly relevant to the dual halo picture of galaxy formation outlined here. Based on line profiles, Wolfe & Prochanska (1997) suggest that damped Ly α systems represent formation of galactic thick disks as described above. On the other hand, abundance patterns suggest a closer association of damped Ly α systems to "halo clouds", reminiscent of dwarfish galaxies (Lu, this symposium), perhaps like the Small Magellanic Cloud (York, this symposium). These "halo clouds" in high redshift systems may be related to accreted systems now evident in our own Galaxy.

3. Accretion in the Halo

Cold dark matter cosmological models predict large amounts of accretion by galaxies since $z \approx 3$, usually by the accumulation of discrete, "sub-galactic units". In "standard" CDM, the majority of dark halos have endured $\approx 10\%$ mass mergers since $z = 0.4$ (Frenk et al. 1988, Kauffman & White 1993, Lacey & Cole 1993), and since then their embedded L^* galaxies sustained smaller, yet still significant merger rates (Carlberg 1990, Tóth & Ostriker 1992, Navarro et al. 1994). Assessments of the rate of decay of satellite orbits from dynamical friction in dark matter halos also point to the normalcy of such events in the lives of Milky Way-like galaxies, to the level of an LMC mass per Hubble time (Ostriker & Tremaine 1975, Hernquist 1991, Mihos & Bothun 1997). Thus, it would be peculiar *not* to identify a significant role for accretion in the evolution of our Galaxy.

First strong clues that the outer halo endured a protracted phase of accumulation and integration of initially chemodynamically independent systems derived from analysis of the globular cluster system (Searle & Zinn 1978). More recent analysis of the globular system incorporating kinematics, spatial distributions, [Fe/H] and HB morphology (Zinn 1993, van den Bergh 1993), nicely demonstrates the utility of a "dual halo" model (Zinn 1993, Da Costa & Armandroff 1995). If the second parameter of HB morphology is age, a slow formation – at least 3 Gyr – is suggested for the spherically distibuted, "young halo" in which reside the youngest (i.e., "second parameter") halo globular clusters. This spread of ages is robust to interpretations of the second parameter for at least some clusters dated by other means, such as main sequence turn offs (see summary in Richer et al. 1996). The "old halo" clusters are in a flattened, rotating distribution and, when considered in combination with the disk globular clusters, exhibit ELS "spin-up". The kinematics of the "young halo" system, the lack of a metallicity gradient therein, and the apparent relatively younger age for this population compared to the "old halo" + disk system all support the original Searle & Zinn scenario of accumulation of "fragments"

in the outer halo even after the flattened, "old halo" system was well established. Evidence for association of specific halo clusters with Galactic satellite galaxies – Ter 7, Arp 2, Ter 8 and M54 with Sagittarius (Ibata et al. 1995) and Pal 12 and Rup 106 with the Magellanic Clouds (Lin & Richer 1992) strengthens the notion, anticipated by Rodgers & Paltoglou (1984), that a number of outer halo globulars may have been accreted from dwarf satellites of the Milky Way. The majority of these suspect clusters appear to belong to Zinn's "young halo" and, statistical correlations of extreme second parameter clusters with dwarf galaxies (Lynden-Bell 1982, Majewski 1994, Lynden-Bell & Lynden-Bell 1995, Fusi Pecci et al. 1995) provide a natural explanation for the ages (Majewski 1994), though exceptions (e.g., Ter 8) do muddy the picture somewhat (Da Costa & Armandroff 1995). Of course, there is still no concensus that age *is* the sole second parameter (Catelan & de Freitas Pacheco 1996, Buonanno et al. 1997, Ferraro et al. 1997) although this controversy in itself does not preclude accretion as an explanation for HB differences, whatever the direct physical cause.

The age scatter in halo field stars is at least as great as that in the young halo cluster system (Schuster et al. 1996), and perhaps greater – as shown by the apparently young, blue metal poor stars of Preston et al. (1994) and the carbon stars of Totten & Irwin (1996), both of which are attributed to satellite accretion. Evidence for significant phase space complexity, manifested as "moving groups", streams, or other kinematic substructure of halo stars (Carney et al. 1996, Majewski et al. 1996a, summary in Majewski et al. 1996b) is consistent with a dynamically unrelaxed, accreted outer halo.

Direct evidence that halo accretion may be a ubiquitous phenomenon and provide an important source for stars in the "outer halo" is of course provided by the Sgr dwarf galaxy (Ibata et al. 1995). Sgr has now been shown to extend to some 40° in length (Majewski et al. 1997a), but, according to models by Johnston (1997), it would take only 3 Gyr for this debris to circle all of the way around the Galaxy, and in 10 Gyr Sgr stellar debris may cover a substantial fraction of the sky (15% if multiple wrappings overlap, and more if not). But this is factors smaller than the model results for sky coverage of debris from the break-up of the Magellanic Clouds after 10 Gyr. The latter prediction is in apparent contradiction with failed searches for excesses of main sequence stars (Mathewson et al. 1979, Recillas-Cruz 1982, Brück & Hawkins 1983, Guhathakurta & Lin 1997) near the H I Magellanic Stream.

However, we (Majewski et al. 1997b) have been conducting a survey for *giant stars* in a 45° swath cutting across the H I stream some 20° downstream from the MC center and have found some provocative results consistent with Johnston's models. Giant stars, while not as abundant as main sequence stars, are much easier to find since they may be identified photo-

metrically (with intermediate band filters) in large area, shallow surveys. While a spectroscopically verified sample of giants to $V \approx 18$ indicates a more or less even sky density across the ten fields of ~ 4 deg^{-2}, the giants show some correlations between apparent distance and longitude. For example, a group of giants, found mainly in the $l = 300°$ to 315° fields, have a distance grouped at ≈ 25 kpc, while most of the giants between $l = 275°$ and 290° are grouped at a distance some 2.5 times greater. To some degree, these data match predictions of tidal stream locations in the Galactic halo derived from new semi-analytical models by K. Johnston of the tidal disruption of the LMC over the last 10 Gyr. In these models, the multiply wrapped Toomre bridge streamer concentrates stars to the range 20-40 kpc, while the Toomre tail stars tend to concentrate at larger distances, 50-80 kpc. Precessional shifts of inner and outer concentrations are roughly consistent with the apparent longitudinal concentrations found in our giant sample. This general correspondence of the model predictions with the early results of our survey suggests the possibility that we may be identifying *widely dispersed* tidal star streams of the Magellanic Clouds.

Disruption of the Magellanic Clouds was not accounted for in the analysis of the amount of accretion in the halo by Unavane et al. (1996), on the grounds that the mean Cloud metallicity today is much too high compared to the bulk of the halo field stars. They also point out the significantly higher mean abundance of the present retinue of Galactic dSph's – when luminosity weighted – over that of the halo field stars, and they conclude that (1) $< 3\%$ of the halo could have derived from Carina-like predecessors (a galaxy which contains significant numbers of intermediate aged stars; Smecker-Hane et al. 1994), and (2) the fraction of halo stars younger than the dominant halo population is $< 8\%$ for [Fe/H]< -1.5 – consistent with estimates from the blue metal-poor stars of Preston et al. (1994). However, substantial *early* shredding of dwarf galaxies which are no longer, or only marginally, represented in a luminosity-weighted distribution (e.g., Ursa Minor, Draco?) of the present Galactic satellite family, is not ruled out (as they point out). Moreover, if the Magellanic Clouds have been disintegrating for nearly a Hubble time, the most widely dispersed stars would presumably be the oldest and most metal-poor; indeed, the oldest, most metal-poor stars in the LMC are found to be as old as those in the Milky Way (Barbuy, this symposium).

The implications of continuous shredding (from early times) of substantially larger satellites, like the Magellanic Clouds, Sgr and Fornax have yet to be fully worked out. But the correlation of the present dSph's and young halo clusters in the sky suggest several possible accretionary paths. Dwarf spheroidals *themselves* may have derived from larger dIrr galaxies, possibly as a first phase of break up of the latter (Lynden-Bell 1982, 1994, Kroupa

1997), followed by a second phase whereby the daughter dSph break up to contribute further to the halo (Kuhn et al. 1997). There is utility to this evolutionary path for explaining multiple generations of stars in the dSph (Smecker-Hane et al. 1994), which presents a somewhat problematical dilemma if these dwarf systems are not sufficiently massive to retain gas after starbursts; initial populations in these systems may have formed before breakoff from a larger system. Galaxy interactions involving larger satellites are seen to *initiate* formation of both globular clusters (Ashman & Zepf 1992, Schweizer et al. 1996, Brodie, this symposium) *and* dwarf galaxies (Mirabel et al. 1992), showing that these objects might constitute from gas (and stars) derived from larger dIrr galaxies, but external to them. The young, blue star associations in the intercloud region of the Magellanic system (Kunkel 1980, Irwin et al 1990) may present us with a more local paradigm for such a phenomenon. The lumpy, and widespread distribution of high velocity HI (Murphy et al. 1995) may be a signature of gas stripping from large satellites, as the HI Magellanic Stream almost certainly is. The high velocity clouds have low metallicity, but this is highly variable from complex to complex. The general conclusion is that this gas cannot be *entirely* primordial (Schwarz et al. 1995, Wakker 1991)

If accretion of chemically individuated stellar sytems plays a key role in the formation of the outer halo, one might expect rather chaotic chemical abundance patterns for stars found there. Depending on star formation histories and dynamical disruption timescales for individual progenitors, abundance patterns from accreted stars will reflect differing ratios of Type II or Type Ia supernovae products. However, if the filling factor of stellar streams is as low as suggested by Majewski et al. (1996), then local volumes of the accreted halo may be dominated by stars from a small number of progenitor star formation sites. Therefore, study of abundance patterns in outer halo stars will provide important complementary fossil data to halo phase space distributions as a means to unravel the Galaxy's merging history. Nice demonstrations of the bright future in the industry of combining detailed chemical and kinematical abundances are (1) the finding (Brown et al. 1997) of low [O/Fe] ratios (compared to most halo stars), characteristic of enrichment by Type Ia supernovae in an environment with multiple star formation events and similar to those in the Magellanic Clouds (Gilmore & Wyse 1991), in the the rogue, young clusters Rup 106 and Pal 12, suspected from their kinematics of being from the Magellanic Clouds (Lin & Richer 1992); (2) King's (1997) finding of comparably low [α/Fe] in high proper motion stars with kinematics suggesting accretion; and (3) Nissen & Schuster's (1997) demonstration that the lowest [α/Fe] and [Na/Fe] are found in stars having kinematics yielding the largest R_{max} and Z_{max} distances.

References

Agostinho, R., Anton, S., Maia, D., Rose, J. & Stock, J. 1996, in *Formation of the Galactic Halo...Inside and Out*, eds. H. Morrison & A. Sarajedini, ASP Conf. Ser. 92, 65

Allen, C., Schuster, W. J. & Poveda, A. 1991, *A&A*, **244**, 280

Ashman, K. M. & Zepf, S. E. 1992, *ApJ*, **384**, 50

Brown, J. A., Wallerstein, G. & Zucker, D. 1997, *AJ*, **114**, 180

Brown, J. H., Burkert, A. & Truran, J. W. 1991, *ApJ*, **376**, 115

Buonnano, R., Corsi, C., Bellazini, M., Ferraro, F. & Fusi Pecci, F. 1997, *AJ*, **113**, 706

Brück, M. T. & Hawkins, M. R. S. 1983, *A&A*, **124**, 216

Carlberg, R. G. 1990, *ApJ*, **359**, L1

Carney, B. W., Latham, D. W. & Laird, J. B. 1990, *AJ*, **99**, 572

Carney, B.W., Laird, J. B., Latham, D. W. & Aguilar, L. A. 1996, *AJ*, **112**, 668

Catelan, M. & de Freitas Pacheco, J. A., 1995, *A&A*, **297**, 345

Da Costa, G. S. & Armandroff, T. E. 1995, *AJ*, **109**, 2533

Edvardsson, B., Andersen, J., Gustafsson, B., Lambert, D. L., Nissen, P. E. & Tomkin, J. 1993, *A&A*, **275**, 101

Eggen, O. J., Lynden-Bell, D. & Sandage, A. R. 1962, *ApJ*, **136**, 748

Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Cacciari, C.., Dorman, B. & Rood, R. T. 1997, *ApJ*, **484L**, 145

Frenk, C., White, S. D. M., Davis, M. & Efstathiou, GH. 1988, *ApJ*, **327**, 507

Friel, E. D. & Janes, K. A. 1991, in *The Formation and Evolution of Star Clusters*, ed. K. Janes, ASP Conf. Ser. 13, 569

Fullton, L. K. 1996, *PASP*, **108**, 545

Fusi Pecci, F., Bellazzini, M., Cacciari, C. & Ferraro, F. R. 1995, *AJ*, **110**, 1664

Gilmore, G. & Wyse, R. F. G. 1991, *ApJ*, **367**, L55

Gilmore, G., Wyse, R.F. G. & Kuijken, K. 1989. *ARAA*, **27**, 555

Gilmore, G., Wyse, R. F. G. & Jones, B. J. 1995, *AJ*, **109**, 1095

Guhathakurta, P. & Lin, D. N. C. 1997, *in preparation.*

Hartwick, F. 1987, in *The Galaxy*, eds. G. Gilmore & B. Carswell, (Reidel: Dordrecht), p.281

Haywood, M., Robin, A. C. & Creze, M. 1997, *A&A*, **320**, 440

Hernquist, L. 1991, in *Warped Disks and Inclined Rings Around Galaxies*, eds. S. Casertano, P. Sackett & F. Briggs, (Cambridge: Cambridge Univ. Press, p. 96

Ibata, R. A., Gilmore, G. & Irwin, M. J. 1995, *MNRAS*, **277**, 781

Irwin, M. J., Demers, S. & Kunkel, W. E. 1990, *AJ*, **99**, 191

Isern, J., Hernanz, M., Garciá-Berro, Mochkovitch, R. & Burkert, A. 1996, *The History of the Milky Way and Its Satellite System*, ASP Conf. Ser. 112, eds. A. Burkert, D. H. Hartmann & S. R. Majewski, (ASP: San Francisco), p. 181

Johnston, K. V. 1997, *ApJ*, *in press.*

Kauffman, G. & White, S. D. M. 1993, *MNRAS*, **261**, 921

King, J. 1997, *AJ*, **113**, 2302

Kinman, T. D., Suntzeff, N. B. & Kraft, R. P. 1994, *AJ*, **108**, 1722

Kroupa, P. 1997, *NA*, **2**, 139

Kuhn, J. R., Smith, H. A. & Hawley, S. L. 1996, *ApJLett*, 469, L93

Kunkel, W. E. 1979, *ApJ*, **228**, 718

Kunkel, W. E. 1980, in *Star Clusters*, ed. J. Hesser, (Dordrecht: Reidel), p.353

Lacey, C. & Cole, S. 1993, *MNRAS*, **262**, 627

Latham, D. W., et al. 1992, *AJ*, **104**, 774

Lin, D. N. & Richer, H. B. 1992, *ApJ*, **388**, L57

Lynden-Bell, D. 1982, *Observatory*, **102**, 202

Lynden-Bell, D. 1994, in *Dwarf Galaxies*, eds. G. Meylan & P. Prugniel, (ESO), p.589

Lynden-Bell, D. & Lynden-Bell, R. M. 1995, *MNRAS*, **275**, 429

Majewski, S. R. 1992, *ApJSupp*, **78**, 87

Majewski, S. R. 1993, *ARAA*, 31, 575

Majewski, S. R. 1994, *ApJLett*, **431**, L17
Majewski, S. R., Hawley, S. L. & Munn, J. A. 1996b, in *Formation of the Galactic Halo...Inside and Out*, eds. H. Morrison & A. Sarajedini, ASP Conf. Ser. 92, 119
Majewski, S. R., Munn, J. A. & Hawley, S. L. 1996a, *ApJLett*, **459**, L73
Majewski, S. R., Phelps, R. & Rich, R. M. 1996c, in *The History of the Milky Way and Its Satellite System*, eds. A. Burkert, et al., ASP Conf. Ser. 112, 1.
Majewski, S. R., Ostheimer, J. C., Kunkel, W. E. & Johnston, K. V. 1997b, *in preparation*
Majewski, S. R., Siegel, M. H., Reid, I. N., Thompson, I. B., Landolt, A. & Kunkel, W. E. 1997a, *ApJLett, submitted.*
Marquez, A. & Schuster, W. J. 1994, *A&AS*, **108**, 341
Marsakov, V. A., Shevelev, Y. G. & Suchkov, A. A. 1990, *Astrophys. Space Sci.*, **172**, 51
Mathewson, D. S., Ford, V. L., Schwarz, M. P. & Murray, J. D. 1979, in *The Large-Scale Characteristics of the Galaxy*, ed. W. B. Burton, (Dordrecht: Reidel), p. 547
Matteuci, F. & Tornambé, A. 1985, *A&A*, **142**, 13
McWilliam, A., Preston, G. W., Sneden, C. & Searle, L. 1995, *AJ*, **109**, 2757
Mihos, J. C. & Bothun, G. D. 1997, *ApJ*, **481**, 741.
Mirabel, I. F., Dottori, H. & Lutz, D. 1992, *A&A*, **256**, L19
Murphy, E. M., Lockman, F. J. & Savage, B. D. 1995, *ApJ*, **447**, 642
Navarro, J. F., Frenk, C. S. & White, S. D. M. 1994, *MNRAS*, **267L**, 1
Nissen, P. E. & Schuster, W. J. 1997, *A&A*, **326**, 751
Nordström, B., Olsen, E. H., Andersen, J., Mayor, M. & Pont, F. 1997, in *The History of the Milky Way and Its Satellite System*, ASP Conf. Ser. 112, eds. A. Burkert, D. H. Hartmann & S. R. Majewski, (ASP: San Francisco), p. 145
Norris, J. 1994, *ApJ*, **431**, 645
Ostriker, J. P. & Tremaine, S. 1975, *ApJ*, **202**, L113
Oswalt, T. D., Smith, J. A., Wood, M. A. & Hintzen, P. 1996, *Nature*, **382**, 6920
Phelps, R. L. 1997, *ApJ*, **483**, 826
Preston, G. W., Beers, T. C. & Shectman, S. A. 1994, *AJ*, **108**, 538
Recillas-Cruz, E. 1982, *A&A*, **124**, 216
Richer, H. B., et al. 1996, *ApJ*, **463**, 602
Rodgers, A. W. & Paltoglou, G. 1984, *ApJ*, **283**, L5
Ryan, S. G. & Norris, J. E. 1991, *AJ*, **101**, 1835
Sandage, A. 1990, *JRASC*, **84**, 70
Schuster, W., Nissen, P., Parrao, L., Beers, T. & Overgaard, L. 1996, *A&AS*, **117**, 317
Schwarz, U. J., Wakker, B. P. & van Woerden, H. 1995, *A&A*, **302**, 364
Schweizer, F., Miller, B. W., Whitmore, B. C. & Fall, S.M. 1996, *AJ*, **112**, 1839
Searle, L. & Zinn, R. 1978, *ApJ*, **225**, 357
Smecker-Hane, T. A., Stetson, P. B., Hesser, J. E. & Lehnert, M. D. 1994, *AJ*, **108**, 507
Sommer-Larsen, J. & Zhen, C. 1990, *MNRAS*, **242**, 10
Tóth, G. & Ostriker, J. P. 1992, *ApJ*, **389**, 5
Totten, E. J. & Irwin, M. J. 1996, in *Formation of the Galactic Halo...Inside and Out*, eds. H. Morrison & A. Sarajedini, ASP Conf. Ser. 92, 200
Truran, J. W. & Thielemann, F. K. 1987, in *Stellar Populations*, ed. C. A. Norman, A. Renzini & M. Tosi, (Cambridge: Cambridge Univ. Press), p. 149
Unavane, M., Wyse, R. F. G. & Gilmore, G. 1996, *MNRAS*, **278**, 727
van den Bergh, S. 1993, *AJ*, **105**, 971
Wakker, B. P. 1991, in *IAU Symposium 144: The Interstellar Disk-Halo Connection in Galaxies*, ed. H. Bloemen, (Kluwer: Dordrecht), p. 27
Wheeler, J. C., Sneden, C. & Truran, J. W. 1989, *ARAA*, **27**, 279
Wilhelm, R., Beers, T. C., Kriessler, J. R., Pier, J. R., Sommer-Larsen, J. & Layden, A. C. 1997, *preprint*
Wolfe, A. & Prochanska, J. X. 1997, *preprint*
Wyse, R. F. G. & Gilmore, G. 1988, *AJ*, **95**, 1404
Zinn, R. 1993, in *The Globular Cluster - Galaxy Connection*, ASP Conf. Ser. 48, eds. Smith, G. & Brodie, J., (ASP: San Francisco), p. 38