THE FUTURE OF GALAXY POPULATIONS

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ABSTRACT
What the future holds for the stellar populations of the Milky Way Galaxy may (optimistically) be predicted by study of their past histories, as written in the chemical abundance distributions, angular momentum distributions, velocity dispersion tensor, ages and spatial structure of their constituent older stars.

INTRODUCTION
The study of the spatial distribution, kinematics and chemical abundances of stars in the Milky Way Galaxy constrains models of disk galaxy formation and evolution. One can address specific questions such as
(i) When was the Galaxy assembled? Is this an ongoing process? What was the merging history of the Milky Way?
(ii) When did star formation occur in what is now ‘The Milky Way Galaxy’? Where did the star formation occur then? What was the stellar Initial Mass Function?
(iii) What are the relationships among the different stellar components of the Galaxy?

The nature of Dark Matter determines the way in which structure forms in the Universe. The popular theory of Cold Dark Matter (CDM; e.g., reviewed by Silk and Wyse 1993) predicts that the first objects to collapse under self-gravity are a small fraction of the mass of a typical galaxy, so that galaxies form by clustering and merging of these smaller objects. All density fluctuations are initially just gas and dark stuff. The star formation histories in these ‘building-blocks’ can be very varied, and at present cannot be predicted with any level of certainty by theory. However, feedback from stars plays a major role in the energy balance. The rate of merging and growth of mass of a protogalaxy can be estimated by studying the dark matter, which is assumed to be dissipationless and hence to have simpler physics than the baryonic component. Analytic calculations of the rate at which structure grows in dark halos agree remarkably well with that seen in N-body simulations (e.g., Carlberg 1990; Lacey and Cole 1993, 1995). Typically at a redshift of unity, a galaxy would be \( \sim \frac{2}{3} \) of its present mass (Carlberg 1995). Consideration of dark matter haloes

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most probably underestimates the longevity of individual baryonic structures which would be observed as distinct galaxies, since they can dissipate and thereby reduce their merging cross-section. Summers (this volume) summarizes the complex physics that one may model with sophisticated hydrodynamic codes.

Lacey and Cole (1993) have a particularly vivid schematic representation of the merging process as a tree (their Figure 6), where time increases from top to bottom, and the width of the branches indicates the mass of a particular halo associated with galactic substructure. The merging history of a galaxy is then described by the shape of the tree. The extremes of morphological type may perhaps be the result of merging histories that are described by the two types of trees that I at least was taught to draw as a child – either one main trunk from top to bottom, with many small branches joining the trunk at all heights, or a main trunk that splits into two repeatedly. The latter, dominated by ‘major mergers’ or equal mass mergers, may lead to an elliptical galaxy. The former, where the merging history is dominated by ‘minor mergers’, or very unequal mass mergers with a well-defined central core at all times, may lead to a disk galaxy. This picture of disk galaxy formation – building up by accretion of substructure onto a central core – provides a synthesis of elements of the much-discussed and previously apparently mutually exclusive ‘monolithic collapse’ paradigm of Eggen, Lynden-Bell and Sandage (1962) and the ‘chaotic’ halo formation envisaged by Searle and Zinn (1978).

I will discuss recent observations of the stellar populations of the Milky Way with an aim to understanding their past evolution, as a means to predicting their future.

THE STELLAR HALO

The hierarchical clustering and merging picture of galaxy formation predicts that there should be many shredded satellite galaxies for every parent galaxy. Indeed, the field stellar halo would consist of disrupted smaller-scale structure. Observational evidence has been accumulating that merging of smaller systems has played a role in the evolution of the stellar halo. The discovery of the Sagittarius dwarf spheroidal galaxy (Ibata, Gilmore and Irwin 1994), apparently in the process of being digested by the Milky Way, argues quite irrefutably for on-going accretion. Stars which become unbound from the outer regions of satellite galaxies, beyond their tidal radius set by the Milky Way gravitational potential, will remain on orbits close to that of the satellite galaxy at the time of their evaporation. Thus, provided that the satellite is tidally disrupted prior to significant orbital decay through dynamical friction, shredded stars may be expected to contribute to the stellar halo. A typical dwarf spheroidal galaxy contains a significant fraction of its stars in intermediate-age or young populations, despite a low metallicity. For example, Smecker-Hane et al. (1994) demonstrated definitively that the majority of stars in the Carina dSph were of age \( \sim 8 \) Gyr, and Lee et al. (1993) have shown that the age of the dominant population in Leo I is rather young, at \( \sim 3 \) Gyr. Few, if any, have exclusively old populations. This intermediate-age, metal-poor population provides a distinctive signature of their contribution to the field halo.
The Age(s) of the Stellar Halo

One of the defining characteristics of the field population II is its clear lack of massive main sequence stars (Sandage 1969 and refs therein). The distinct turn-off of the stellar halo, at $B-V \simeq 0.4$, is a striking feature of deep star counts (e.g. Gilmore and Wyse 1987, their Fig. 3). This turn-off color corresponds to an age, derived from comparison with stellar isochrones, of $\gtrsim 15\,\text{Gyr}$, for a population with the mean metallicity of the stellar halo, $<\lfloor \text{Fe}/\text{H} \rfloor > \sim -1.6$ dex. Any halo stars significantly younger than this are restricted to a tracer population. A few high-velocity dwarf stars bluer than the halo turn-off were identified in early surveys (e.g. Bond and MacConnell 1971; the few high-latitude B main-sequence stars identified by Conlon et al. (1992) are metal rich and apparently unrelated to the field halo population). More recently, Preston, Beers and Schectman (1994) concluded that a significant fraction of their sample of stars, selected on the basis of the weakness of their Calcium H and K lines, were dwarf stars bluer than the halo turnoff. The absolute normalisation is difficult to quantify given the selection criteria of the sample, but they suggest that perhaps 4%-10% of the stellar halo is in this component, which they attribute to the accretion of dwarf spheroidal satellites. Evidence in favor of accretion also comes from the kinematic ‘moving groups’ which have been tentatively identified in the Galactic halo (e.g. Arnold and Gilmore 1992; Majewski 1993).

Quantification of the fraction of the stellar halo that is younger than the dominant population requires careful analysis of samples where the selection effects are understood. The recent survey by Carney et al. (1994 and references therein) contains the largest sample of halo stars (1447 stars), selected on the basis of proper motions, for which accurate abundances and photometry are available. Adopting a working definition of the metal-poor halo for the moment as stars in this sample with $\lfloor \text{Fe}/\text{H} \rfloor \lesssim -1$, yields 477 stars. The relationship between $B-V$ color and $\lfloor \text{Fe}/\text{H} \rfloor$ for this sub-sample is indicated in Figure 1, taken from Unavane, Wyse and Gilmore (1995). The color distribution in this figure shows clearly the turnoff of an old, metal-poor population, with the turnoff color being a function of $\lfloor \text{Fe}/\text{H} \rfloor$, just as the isochrones behave. Main sequence stars which are bluer than a given isochrone (at fixed metallicity) are younger than the age of that isochrone. There is clearly room for a couple of Gyr scatter about the age of the isochrone defining the dominant population, especially since the $B-V$ turn-offs colors of the old isochrones crowd together. However, the $\gtrsim 15$ Gyr isochrones adequately represent the cut-off color for the majority of the stars; bluer stars are rare.

One may determine a firm upper limit to the number of field halo stars that are much younger than the dominant old population by counting all stars that lie to the blue of a chosen fiducial, old isochrone, taking account of the observational uncertainties to assign a probability to each star that it is bluer, and then weighting this number by the luminosity function to include the lower mass, redder stars of the younger population. Counting all stars that are bluer includes, e.g., blue stragglers of the type found in globular clusters etc. This exercise (see Unavane et al.) leads to the conclusion that the upper limits on younger star population in the field halo comprises $\sim 3\%$ in the most metal-poor range, $\lfloor \text{Fe}/\text{H} \rfloor < -1.95$; $\sim 6\%$ in the middle range, and $\sim 28\%$ in the most metal-rich range considered, $-1.5 \leq \lfloor \text{Fe}/\text{H} \rfloor < -1$. 

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This is a sample selected by high proper-motion, and although as mentioned above one may expect stars to be removed from low density satellite galaxies prior to much orbital decay, here is no robust a priori expectation that the kinematics of any young halo population should be closely similar to those of the older halo stars. However, Ryan and Norris (1993) investigated the probability that a star with a given space motion would pass into a proper-motion selected sample of given selection criteria. In situations where the lag in rotational velocity of the parent population behind that of the Sun dominates, the survival probabilities, albeit low, do not vary by more than a factor of a few, over the range $v_{\text{lag}} \sim 100 - 200 \text{ km/s}$.

\section*{How Many dSph Could Have Been Accreted?}

Unavane et al. discuss how this derived fraction of young stars in the halo may then be re-expressed in terms of the number of satellite galaxies that could have been accreted, given the characterization of the stellar populations of the satellites. A direct comparison of the color distribution of the Carney et al. sample with the appropriate metallicity ($-1.95 \leq [\text{Fe/H}] < -1.55$, equal to the range in the Carina dwarf) and of the stars in the Carina dwarf may be made, circumventing model and isochrone dependencies. They concluded that 3\% of these halo stars are consistent with being drawn from a parent population similar to that of the Carina dwarf; renormalising to the entire halo metallicity distribution reduces this to around 1\%.

The Carina dSph has a total luminosity of $M_V \approx -9.2$, while the halo has $M_V \approx -17.5$. Thus this limit of 1\% of the halo amounts to $\sim 20$ Carina dwarfs.

Extending this result to constrain the recent accretion of all dwarf galaxies drawn from the present population of satellite galaxies would require detailed color and metallicity data for each of the satellite galaxies. Detailed deep photometric data are not generally available, but reliable metallicity estimates are. Figure 2 shows the halo metallicity distribution function taken from Laird et al. (1988), together with the mean metallicities of the seven dSph companions to the Milky Way for which reasonably reliable spectroscopic metallicity estimates are available. The composite stellar population of dSph complicates the determination of photometric metallicity estimates from analysis of their color-magnitude diagrams.

The upper panel shows these distributions simply normalised to unity in the highest bin, with the Magellanic Clouds as indicated. The dwarf companion galaxies to the Milky Way have an approximately uniform distribution of metallicity (and indeed of luminosity, unlike the simplest predictions from CDM cosmology which predict a steep mass function in this range). The lower panel compares the luminosity-weighted metallicity distribution for the dSphs with the halo metallicity distribution. It is this weighted distribution function which would correspond to the metallicity distribution of stars accreted into the halo from a random subset of the present day dSph luminosity function. It clearly does not match the metallicity distribution function of the field halo. While this weighting is rather uncertain, as all dSph parameters are still only approximately known, the luminosity–metallicity relation (e.g. Armandroff et al. 1993) ensures that Fornax and Sagittarius dominate, providing a relatively metal-rich mean to the stars that make up the present dSph population. This weighting excludes the Magellanic Clouds, which are completely inconsistent with providing any contribution to the field halo.

The signature of recent accretion from the present parent population of dSph would be intermediate-age stars in the halo, with metallicity strongly peaked at
[Fe/H] \gtrsim -1.5 \text{ dex}. This is indeed the metallicity distribution for the candidate young halo stars, in Figure 1. Detailed age distributions are lacking for the metal-rich dSph, but one can derive a rough limit on the number of such that could have been assimilated into the halo, by assuming 100% intermediate-age. The \sim 28\% contribution of the stars in the Carney et al. sample in the metallicity range -1.55 \leq [Fe/H] < -1 younger than \sim 15 \text{Gyr} corresponds to approximately 10\% of the entire halo (using the Laird et al. halo metallicity distribution) being ‘young’. The field halo is approximately 50 times more luminous than Fornax, adopting a luminosity of -13.2 for Fornax, so that of order 5 systems similar to Fornax are implicated.

**Other Signatures of dSph Accretion**

The range of ages and chemical abundances within these systems indicate a level of self-enrichment, which implies some retention and/or re-capture of gas (e.g. Silk, Wyse and Shields 1987). As discussed in Unavane et al. (1995), the star formation history of a typical dSph may impart an observable signature in the elemental abundance ratios, specifically evidence of enrichment by Type Ia supernovae. This is to be contrasted with the three-times-solar value of the oxygen-to-iron ratio seen in halo field stars, generally attributed to enrichment by Type II supernovae alone (e.g. Wyse and Gilmore 1988; Nissen et al. 1994). Specific observations of the element ratios in candidate ‘young’ halo stars have not been made with modern detectors, to be analysed with up-to-date stellar atmospheres. This will be an important observation.

It is impossible at present to say anything reliable from carbon star statistics due to lack of data, particularly for the field halo.

**The Future of the Stellar Halo**

The past of the stellar halo apparently involved assimilation of stars that plausibly were formed in satellite galaxies, albeit not amounting to a large fraction of the luminous mass of the halo. Such accretion of dSph is apparently on-going, and may be expected to continue into the future. Thus one may conclude that the future of the field stellar halo is to get (relatively) younger.

**THE CENTRAL BULGE**

The central regions of galaxies are obvious potential repositories of accreted systems, being the bottom of the local potential well, provided the accreted systems are sufficiently dense to survive disruption while sinking to the center (e.g. Tremaine, Ostriker and Spitzer 1975). The mean metallicity of the bulge is now reasonably well-established at \langle[Fe/H]\rangle \sim -0.3 \text{ dex} (McWilliam and Rich 1994; Ibata and Gilmore 1995), with a significant spread to below -1 \text{ dex}, and to above solar. Thus satellite galaxies that could have contributed significantly to the bulge are restricted to those of high metallicity, more like the Magellanic Clouds, or the most luminous dSph.

The Sagittarius dwarf spheroidal galaxy was discovered through spectroscopy of a sample of stars selected purely on the basis of color and magnitude to contain predominantly K giants in the Galactic bulge. After rejection of foreground dwarf stars, the radial velocities isolated the Sagittarius dwarf galaxy member stars from the foreground bulge giants. Not only the radial velocities distinguish the dwarf galaxy, but also its stellar population – as seen in Figure 1 of Ibata et al. (1994), all giant stars redder than B_J - R \gtrsim 2.25 have kinematics that place them in the low
velocity-dispersion component \(i.e.\) in the Sagittarius dwarf. This is a real quantifiable difference between the bulge field population and this dwarf spheroidal galaxy, and demonstrates that the bulge could not have formed by accretion of such systems.

As with the halo above, the carbon star population of the bulge can be compared with those of typical extant satellites. In this case there is a clear discrepancy between the bulge and the Magellanic Clouds and the dSph (Azzopardi and Lequeux 1992).

The observation that the mean iron abundance of the stellar halo is well below the theoretical yield for a solar neighborhood IMF is most easily explained by gaseous outflow, truncating chemical evolution (Hartwick 1976). The stellar bulge could then form from this gas. Wyse and Gilmore (1992) demonstrated that the specific angular momentum distributions of the stellar halo and bulge are extremely similar, strengthening their association. Further, the mass ratio of stellar halo and bulge is as expected if the bulge formed from gas removed from the halo (Carney 1990). Elemental abundance data for stars in the bulge, over the range of iron abundances seen, would provide a good discriminant of the star formation history of both the halo and bulge, in this picture (see Wyse and Gilmore 1992). Such data are becoming available (McWilliam and Rich 1994) although at present the uncertainties are too large to make definitive statements.

An alternative, dissipationless formation picture for the central bulge has gained favor recently, largely due to the images from the COBE satellite in which the bulge has a pronounced ‘peanut’ shape, and the analyses of these and other data, including gas kinematics, that imply that the bulge is triaxial (Blitz and Spergel 1991; Binney et al. 1991). This picture appeals to a buckling instability of an initially-thin stellar disk (Combes et al. 1990; Raha et al. 1991). The disk first forms a bar in its plane, and the bar subsequently thickens through an out-of-plane bending instability. However, the latest analysis of the DIRBE data (Weiland et al. 1994) concluded that the peanut morphology is an artefact of varying extinction. Indeed, all physical parameters of the central regions of the galaxy remain rather uncertain; the bar models in the literature do not successfully explain all of the features in the gas kinematics (cf. Lizst 1995), while the inner disk structure is clearly ill-defined. The scheduled 15\(\mu\) survey of the inner Galaxy with the ISO satellite (PI A. Omont) should mitigate these circumstances. Extant models for the bar provide gravitational torques to the surrounding disk gas that can drive gas inflows of amplitude \(\lesssim 0.1M_\odot/yr\) (Gerhard and Binney 1993). This could fuel continuing star formation, providing a young tail to the age distribution in the bulge, and probably stars with low oxygen-to-iron. The age distribution of stars in the bulge is unfortunately rather uncertain at present, but is probably quite broad, with a mean of \(\sim 10\) Gyr (e.g. Holtzman et al. 1993).

A lack of a chemical abundance gradient argues against dissipational formation, and for such a dissipationless mechanism (the opposite is not necessarily true). Hence, the recent revision downwards of the mean metallicity of the bulge, to a value that is remarkably similar to that of K giants in the solar neighborhood (McWilliam 1990), and indeed across the disk (Lewis and Freeman 1989) supports this latter disk-instability mechanism. Further, Ibata and Gilmore (1995) find that even within the bulge itself the data are consistent with no gradient in mean metallicity out to 3kpc. In this picture for bulge formation, the similarity in specific angular momentum distributions of halo and bulge, and their difference compared to those of the thick and thin disks, would then have to be a coincidence.

It is extremely difficult to cast a horoscope for the bulge, other than to say that as the bottom of the local potential well, it is likely to grow in mass.
THE THICK DISK

The characteristics of the thick disk at the solar neighborhood are reasonably well defined, but the global properties of this stellar population are not. Locally it can be described by a predominantly old population (Gilmore and Wyse 1987; Carney et al. 1990; Schuster and Nissen 1989; Gilmore, Wyse and Jones 1995), with mean metallicity about one-third that of the Sun, and a significant dispersion in metallicity, of \( \sim 0.3 \) dex (Gilmore and Wyse 1985; Laird et al. 1988; Friel 1987; Morrison, Flynn and Freeman 1990; Gilmore, Wyse and Jones 1995). It is a kinematically ‘warm’ component, with vertical velocity dispersion of around 45 kms\(^{-1}\), and with a constant lag behind circular velocity of amplitude \( \sim 50\) kms\(^{-1}\), out to \( z = 2.5\)kpc (Soubiran 1993). The scaleheight of the thick disk is a factor of 3 – 4 larger than that of the old thin disk, reflecting its higher velocity dispersion. Note although there is indeed an age–velocity dispersion relationship for stars in the thin disk, the value of the vertical velocity dispersion saturates at \( \sim 20 \) km s\(^{-1}\) for stars older than a few Gyr (eg., Freeman 1991). This may be understood if the heating mechanism responsible is confined to the thin disk itself, such as scattering by giant molecular clouds (eg., Lacey 1991).

The thick disk of the Milky Way Galaxy at least morphologically could be a minor-merger remnant; provided all the orbital energy of an accreted satellite, mass \( M_{\text{sat}} \), is available to increase the random energies of the stars in a thin disk of mass \( M_{\text{disk}} \), then after a merger the thin disk will be heated by an amount (Ostriker 1990)

\[
\Delta v_{\text{random}}^2 = \frac{v_{\text{orbit}}^2 M_{\text{sat}}}{M_{\text{disk}}},
\]

Of course the internal degrees of freedom of the satellite could also be excited and any gas present could, after being heated, cool by radiation, so this is a definite upper limit to the heating of the disk. This estimate is suggestive, however, that the thick disk, which has a vertical velocity dispersion of \( \sim 45 \) km s\(^{-1}\), could be formed from a thin disk with vertical dispersion of \( \sim 20 \) km s\(^{-1}\) by accretion of a satellite of about 10% of the mass of the disk. Tóth and Ostriker (1992) extended these ideas and argued that the observed thinness of the stellar disk of our Galaxy could be used to limit the allowable accretion of stellar satellites since the birth of the Sun to only a few percent of the mass of the disk. They then argued that this low accretion rate favored a low density CDM Universe, since the growth of perturbations would then be truncated at a redshift of \( \sim \Omega^{-1} \).

Indeed, Quinn, Hernquist and Fullagher (1993) showed through N-body simulations that the accretion of a 10% by mass satellite, sufficiently robust to survive many passages through the disk, could produce a thick disk that had several similarities to that of the Milky Way. This thick disk consists of both heated formerly thin-disk stars and shredded-satellite stars; the mix of these obviously depends on the (many) model parameters, both orbital and internal to the galaxies. The sensitivity of the end-point of a merger to the input was emphasised by Carlberg (1995), who demonstrated that a less dense, arguably more realistic, satellite than the rather extreme case (density within the half mass radius of the satellite fully 75% of that of the inner disk) considered by Quinn et al. could impart essentially no heating. This sensitivity makes constraining \( \Omega \) from disk thickness rather dangerous. However, the large dispersion in the properties of thick disks identified in external galaxies (e.g. van der Kruit and Searle 1982; Shaw and Gilmore 1988; Morrison, Boroson and Harding 1994) is perhaps most readily understandable in the context of a merging scenario,
since so many outcomes are possible in this case, as opposed to other scenarios, such as a cooling instability (e.g. Wyse and Gilmore 1988).

The Large Magellanic Cloud is perhaps the type of satellite modelled by Quinn et al. The Magellanic Clouds are indeed most probably interacting tidally with the Milky Way; the Small Magellanic Cloud appears to be significantly distended along the line of sight, and the Magellanic Stream is plausibly also a tidal effect. Proper motion estimates for the LMC (Kroupa et al. 1994; Jones et al. 1994) suggest even more significant interaction in the future. Indeed, Lin et al. (1995) predict a peri-Galacticon of less than 10kpc for the LMC, about 8Gyr in the future. This will have a profound effect on the present thin disk.

Thus one can say with reasonable confidence that the future of the thick disk is to get more massive, as the now-thin disk is heated.

THE THIN DISK

Many of the major observational advances in recent years in the investigation of the evolution of the thin disk of the Milky Way have come from the analysis by Edvardsson et al. (1993) of the ages, kinematics and elemental abundances of their sample of F/G dwarf stars, observed in the solar neighborhood. The observational errors are small enough that one can state with confidence that there is intrinsic scatter in the iron-abundance–age relation; indeed, over much of the lifetime of the disk, the scatter overwhelms any mean trend. The scatter remains even if one isolates a subsample likely to have been formed in a narrow range of Galactocentric distance. Star formation and chemical enrichment evidently proceeded in a rather inhomogeneous manner.

In keeping with the cosmological leaning of this conference, Figure 3 shows the age–iron abundance data for the Edvardsson et al. subsample which they identify as likely to have formed close to the solar circle, but with stellar age transformed to redshift of formation. Their age estimates are sufficiently old that I have taken a Hubble constant of $H_0 = 42$ km/s/Mpc, with $\Omega = 1$. The errors in (log) age, of 0.1 dex, translate into large uncertainties at redshifts greater than about unity; I have suppressed the oldest stars in the plot. The main point is clear, however, which is that Galactic astronomers are not surprised that there are metals in absorber systems along the line of sight to distant quasars.

The mean global star-formation rates in disk galaxies have decreased only slowly over the last Hubble time, and it is likely that they can sustain their present star formation for the foreseeable future, over many Gyr (e.g. Kennicutt, Tamblyn and Congdon 1994). The star formation history in the thin disk in the solar neighborhood is also consistent with a fairly constant rate, only a few times higher in the past than at present. Ongoing star-formation rates in disks are, in general, higher in the inner parts than in the outer disk (e.g. Kennicutt 1989). The outer regions of disks are clearly less-evolved than the inner regions, having a higher gas mass fraction and a lower mean metallicity. Detailed analyses of ages and elemental abundances for stars in the disk of the Milky Way are consistent with a higher star formation rate in the early stages in the inner regions of the disk (Edvardsson et al. 1993; Wyse 1995).

Further evidence for age gradients in stellar disks comes from an analysis of recently-established broad-band color gradients, taking into account the effects of dust and metallicity variations (de Jong 1995). Additionally, disk scale lengths in H-α, tracing on-going massive star formation, are significantly larger than the scalelengths in the V
or I bands (Ryder and Dopita 1994). Indeed, many disk galaxies, including the Milky Way (de Geus et al. 1993) are presently forming massive stars beyond the canonical optical edge of the disk (A. Ferguson, Ph. D., in prep.). Many theories of disk galaxy formation and evolution predict that disks form from the ‘inside-out’ (e.g. Larson 1974), and that star formation rates should be a smooth function of galactocentric radius (e.g. Wyse and Silk 1989).

It would appear that the future of the thin disk is to get larger, growing outwards in radius. Note that this is also expected if and when the Large Magellanic Cloud merges with the thin disk, due to angular momentum re-arrangement, together with some heating in the plane.

CONCLUSIONS

The age distribution, and chemical elemental abundances, of stars in Milky Way provide constraints on theories of galaxy formation. The luminosity-weighted metallicity distribution of the present retinue of dSph galaxies is dominated by the most metal-rich systems, with [Fe/H] \( \gtrsim -1 \) dex. This contrasts strongly with the field halo. The more metal-rich central bulge of the Galaxy also could not have formed by accretion of systems with similar stellar populations to these metal-rich dwarfs, nor similar to the Magellanic Clouds. However, accretion is on-going, as evidenced by the Sagittarius dwarf, and the younger stellar population of each of the halo and bulge is likely to increase. The future of the thick disk is to get more massive, as continuing interactions of the Milky Way with more massive satellites (Magellanic Clouds) lead to merging. The thin disk of the Milky Way, and indeed of disk galaxies in general, appears to be increasing in scalelength, and its future is to get larger.

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Figure 1: The distribution of B−V color and [Fe/H] for metal-poor stars from the sample of Carney et al. (1994). Uncertainties have been ignored in the interests of clarity, and are of order 0.1 dex in [Fe/H] and 0.05 in B−V. Superposed are turn-off isochrones (Revised Yale Isochrones; Green et al. 1987) with ages given in Gyr (8, 10, 15, 16, 17). The three metallicity ranges delineated by the dashed lines are discussed separately.

Figure 2: Metallicity distribution of seven of the dSph companions to the Milky Way (solid histogram) compared with the field stellar halo (dashed histogram). Only those dSph with mean metallicity derived from spectroscopic estimates from a reasonably large sample of stars have been included. The dSph are represented by their mean metallicity, but one should bear in mind that an internal dispersion of 0.2 – 0.3 dex is typical. The upper panel shows the unweighted distribution, the lower panel shows the dSph weighted by their individual luminosities. The mean metallicities of the Magellanic Clouds are indicated by arrows.

Figure 3: Iron abundance versus redshift of formation for stars from the Evardsson et al. sample with kinematics consistent with their having been formed in the Galactocentric range of 7–9 kpc. Uncertainties in [Fe/H] and in log age are ∼ 0.1 dex. Stars with ages corresponding to formation redshifts > 1.5 exist, but have been suppressed here.