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RESOLVED STELLAR POPULATIONS AND NEARBY GALAXIES

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Resolved stellar populations are a demonstrably powerful tool for unraveling the formation and evolution of galaxies that directly impacts stellar, galactic, and cosmological science. Large fields of view and multiplexing capabilities are essential to obtain data for representative samples of stars. Near-UV and optical wavelengths exhibit the most sensitivity to age and metallicity variations for stars in a given evolutionary phase, and it is here that the majority of previous progress in this field has been made; IR will play an increasingly important role in the future, but needs to be coupled with optical studies for maximum impact. In the next decade, key science drivers for stellar populations and nearby galaxies will include (i) phase-space mapping of the MW, Local Group and Local Volume galaxies to reconstruct the accretion and assembly history of these systems as powerful tests of galaxy formation scenarios, (ii) measuring the chemical abundance distribution of large numbers of stars in the MW sub-group to determine the early chemical evolution of galaxies and the signature of the first generation of star formation in the Universe. We identify necessary facilities and infrastructure to allow Canadian astronomers to continue in a leadership role in this science.

1. STARS, GALAXIES & COSMOLOGY

Modern simulations of galaxy formation are able to use our current, incomplete, understanding of baryonic evolutionary processes to provide testable predictions about the small scale distribution of mass and light in and around galaxies (e.g., Bullock & Johnston 2005, Cooper et al. 2009, Governato et al. 2009). Data are required that will provide critical tests of the models on galactic scales and advance our understanding of the interplay of baryons with dynamical (dark matter) processes[3]. In the prevailing cosmological paradigm, galaxies form hierarchically through the continuous merging of sub-units[7] that, prior to merging, undergo independent dynamical and chemical evolution. Since stellar evolutionary times are long[2], and phase space densities are conserved, the remnants of these proto-galactic fragments can be identified at z=0 through their ages, chemical, and dynamical properties. *Stellar populations provide a uniquely powerful, high resolution, window on the time-resolved, dynamical and chemical evolution of galaxies that cannot be obtained for galaxies in the far-field, and an essential pre-requisite to understanding the formation and evolution of galaxies in a cosmological context.*

1.1. *Science drivers in the next decade*

Canada maintains a leadership role in resolved stellar populations research. Table 1 provides a summary of many of the different research programs pursued by Canadian astronomers, and demonstrates the breadth of expertise available. Here, we identify main science drivers in these fields for the next decade, from the perspective of near-field cosmology/galactic archaeology.

1.1.1. *Stellar populations in phase-space*

In the CDM paradigm, the entire luminous galactic halo is built from stars shed by merging sub-units (e.g., Bullock & Johnston 2005; Abadi et al. 2006), the progenitors of which have mostly since merged with the central galaxy (Fig. 1). The luminous material around galaxies is therefore remnants of, and clues to, the formation of the galaxy (Johnston et al. 1996; Fig. 2). Since phase-space densities are conserved, wide-field imaging, radial velocity and proper motion analysis of large numbers of stars can identify these dynamical "fossils" (e.g., the Sagittarius dwarf galaxy and its tidal stream; Ibata et al. 1994, 2001, Majewski et al. 2003) and aid in the reconstruction of the progenitor's properties, including its luminosity, dynamical mass, accretion time and orbital history.

New generations of wide field photometric and spectroscopic surveys, particularly SDSS (photometry over $\sim 45\,000$ degree^2; redshifts for $> 40\,000$ stars), are revolutionizing our view the MW, with copious discoveries of stellar streams, dwarf galaxies, and other large-scale overdensities (e.g.,Yanny et al. 2000; Newberg et al. 2002; Belokurov et al. 2006; Juric et al. 2008, Grillmair et al. 2009; Fig. 3), as well as revealing complexity within previously-recognized components (e.g., Carollo et al. 2007, 2009). Follow-up, intermediate-res spectroscopy ($R \sim 5000$; CaT, Mgb) with low SNR (SNR<5) are used to measure radial velocities, allowing the reconstruction of stellar orbits and tracing their dynamical evolution in the MW (e.g., for the Sagittarius stream; Majewski et al. 2004) and constraining the mass and shape of the MW halo (Ibata & Lewis 1998, Law et al. 2009). In the next decade, GAIA (and potentially SIM-lite) will provide proper motion measurements for a billion stars, providing full 6-D phase-space information for $\sim 1\%$ of stars in the MW, to enable an unprecedented study of the structure of our region of the Galaxy.

For more distant galaxies in the Local Group (LG), wide field cameras on large aperture facilities are essential. The distribution of ~ 5 million RGB stars to $g = 25.5 (S/N = 10)$ over 300 square degrees surrounding M31 using CFHT/MegaPrime is shown in Fig. 4 (McConnachie et al. 2009). This image reveals the complexity of the outer regions of galaxies, only theorized previously. Many of these structures are at $\mu_V <$ 30mags arcsec^{-2} and so cannot be detected when stars are not resolved. Deep, pencil-beam imaging to $V \sim 30$, e.g., HST-ACS, allows the derivation of star formation histories with unrivaled time-resolution in LG galaxies (e.g., Cole et al. 2007, Brown et al. 2009), but for M31 the HST-ACS FOV ($\sim 2\times2$ arcmins) is not well matched to the area of interest (degrees).

Intermediate-res ($R \sim 5000$) spectroscopy on 8-meter telescopes measure radial velocities of RGB stars in these more distant galaxies in the LG (V<22) to typically 5 km/s (e.g., Chapman et al. 2006, Kalirai et al. 2006, 2010, Battaglia et al. 2006, Walker et al. 2009a). In dwarf galaxies, radial velocity data provide the tightest constraints on the mass profile of dark matter haloes (e.g., Strigari et al. 2008, Walker et al. 2009b); these data is also required to separate the baryonic component from studies of dark matter halos[3]. Currently, the FOV and limited multiplexing capabilities (∼100 objects within 15-30 arcminutes per exposure) make it difficult and expensive to obtain sufficient samples (1000's of stars) for detailed kinematic analyses of many LG galaxies.

The relatively small number of galaxies available for detailed studies in the Local Group is a critical limiting factor. Morphological types not represented (such as lenticular galaxies and giant ellipticals) need to be examined in similar ways to M31, the MW, and other disk galaxies to explore dependences on mass, environment, and morphology as well as stochastic variations. Hundreds of galaxies are present in nearby groups (< 5Mpc; Maffei, IC342, Sculptor, M81, M83, Cen A and Canes Venatici I) and the vast reservoir of galaxies in the Virgo and Fornax clusters[3] are also potentially in reach of future instrumentation. HST-ACS can be used to resolve stars in some nearby groups (e.g., NGC891; Ibata et al. 2009), but the limited FOV rules out global studies such as presently conducted for the MW and M31; at 5 Mpc, the equivalent of Fig. 4 would subtend an area of nearly 8 degrees^2 and require reaching a depth of $V \sim 28.5$; at the distance of Virgo (18 Mpc), the area would be ~ 0.5 degrees^2 at $V \sim 31.5$.

1.1.2. *Chemical tagging and first stars*

Moving groups of stars in the MW halo that have similar chemical abundances (like globular clusters[1]), or that have coherent abundance ratios suggesting that they formed in an environment outside of the MW that had its own chemical evolution and were accreted later, is *chemical tagging* (Freeman & Bland-Hawthorn 2002). Piecing together the history of these components is one way to examine galaxy formation and early chemical evolution in the near-field (e.g., Helmi 2008, Tolstoy et al. 2009; Fig. 5). High-res spectroscopy ($R > 20,000$) is needed for detailed chemical abundance ratios, and chemical tagging requires a statistically significant number of stars. Currently, high-res spectra of sufficient SNR are available for RGB stars with V<18.5, reaching to d≤150 kpc, allowing for analyses of stars in the closest MW dwarf satellites. The higher luminosities of massive, hot stars[6] mean that they can be observed in M31, however they only trace the current chemistry, similar to HII regions (e.g., Venn et al. 2003).

In the next decade, proper motion and wide-field spectroscopic surveys will identify stellar groups in the MW from dynamics. The ultimate goal is that the chemical abundances of those groups will characterize the mass, age, and star formation history of their host galaxy, before it was accreted. A wide field MOS instrument would have an enormous impact. Parallel to this, detailed chemistries of stars in a wider variety of dwarf galaxies is necessary, since the nearby dwarf galaxies are the survivors of early accretion and may not represent the typical proto-galactic components. The gas-rich dwarf galaxies in the LG are more isolated and may better represent of early proto-galactic fragments. However, these galaxies (other than the Magellanic Clouds) are $\sim$ 1Mpc distance, just barely within reach of the intermediate-res (CaT) studies (Leaman et al. 2009), and will require spectroscopy with from the TMT, with its larger light gathering ability.

Chemical abundances of stars in dwarf galaxies also contribute to the important search for and analysis of the first generation of stars. From numerical simulations, these objects are predicted to be located in the Galactic center and in the dwarf galaxies (e.g., Gao et al. 2010; Fig. 6). First stars had an outsized influence on everything that happened in the universe afterwards: cosmic reionization (e.g., Bromm & Larson 2004), the formation of the first black holes (e.g., Mayer et al. 2009), powerful feedback on early proto-galaxies, and the chemical enrichment of subsequent generations of stars.

While the search for first stars is equivalent to searching for metal-poor stars, the difference is in their chemistries; first stars will be polluted only by first supernovae, predicted to be from very high mass progenitors (>140 $M_\odot$; Nakamura & Umemura 2001, Heger & Woosley 2002), and not due to dilution by HI gas or dust formation (e.g., Venn & Lambert 2008). The Hamberg/ESO survey has been extremely successful in locating metal-poor stars in the MW halo. It uses an objective prism and order blocking filter (Ca H & K) at a 1-meter telescope, and has sufficient statistics to represent the metal-poor end of the metallicity distribution in the MW halo (e.g., Schoerck et al. 2009; Fig. 7). Application of this technique, or other medium-band imaging filters, could be done at the CFHT to search for extremely metal-poor stars, possibly out to 150 kpc, which would reach RGB stars in the nearby dwarf satellite galaxies. Medium band imaging has also been shown to be uniquely useful in discriminating red giants and dwarfs, and to ascertain the membership and distribution of stars in the nearby, ultra faint dwarf galaxies (Aden et al. 2009).

2. FACILITIES AND OTHER CONSIDERATIONS

2.1. *Optical versus infrared wavelength considerations*

Imaging: Resolved stellar photometry is best performed at optical+IR wavelengths for the maximum science return, i.e., V and K band imaging. While RGB stars are less luminous in V then K (Fig. 8), and the effect of interstellar extinction is more severe in V, the sensitivity to age and metallicity of a stellar population is the most extreme in the V-K colors; Fig. 8. This is not true when IR colors alone are used, e.g., there is almost no sensitivity to age or metallicity in J-K, and the bolometric corrections are much larger at K. The contributions to JHK from AGB stars also overwhelm the RGB population, making it nearly impossible to separate out the various components. To date, nobody has published SFHs from JHK colors for galaxies. This problem is worse in the mid-IR (e.g., Bolatto et al. 2007). We note JWST and TMT will be most useful for deep imaging in small fields, but the typical FOV of their instruments (1-6 arcmins) will generally be too small for stellar populations survey work.

Spectroscopy: Several optical and near-IR intermediate-res ($R \sim 5000$) surveys are currently scanning the MW halo (RAVE, LAMOST). Also the APOGEE survey planned for the bright time during SDSS-III will search for metal-poor and first stars in the Galactic bulge using H-band MOS (<300 fibers and H<13). In the future, spectroscopic surveys of more distant and crowded fields will require AO, currently only available in the IR. Intermediate-res spectroscopy at H and K bands can be used for radial velocity measurements and the determination of many chemical elements from oxygen to iron for chemical tagging studies of galaxy evolution. A significant drawback to IR spectroscopy though is the lack of access to neutron capture elements (Hinkle et al. 1995), necessary for studying the yields from TyII supernovae (and the r-process). This is particularly important in the analysis of extremely metal-poor and first stars, where it is predicted that the yields from the first supernova (metal-poor & M >100 $M_\odot$) would have unique heavy element signatures.

2.2. *Facilities: short-term (< 5 years)*

CFHT: Much of Canada's success in stellar populations stems from wide field capabilities at CFHT, and presently MegaPrime is unrivaled for its FOV. HyperSuprimeCam on Subaru in 2012 will end this dominance since it has a larger aperture and FOV. Prior to new instruments or changes with CFHT itself, CFHT can occupy an important niche for stellar populations with the addition of medium-band filter capabilities, or an objective prism survey (Section 1.1.2); Strömgren or DDO filters are ideal for dwarf/giant discrimination (a major source of contamination for all LG science); Ca H & K filters for finding metal-poor stars ([Fe/H]< -2). These are comparatively "cheap and easy" options that will guarantee CFHT remain internationally competitive prior to major instrumentation/facility upgrades.

Gemini: Gemini is the least competitive of the 8-m class telescopes for stellar populations science. For example, Gemini-N/GMOS lacks the FOV (<5 arcmins) and throughput of Keck/DEIMOS (>15 arcminutes). It also lacks a high-res mode for chemical abundances, such as is available with VLT/FLAMES (R≤20,000, FOV<30 arcmins). Further, Gemini is optimized for the red (Section 2.1). Blue optimization and a larger FOV, or a high-res MOS mode would be significant improvements to the instrumentation suite at Gemini for stellar populations research; we note that Keck, Subaru and VLT presently already have some or all of these capabilities.

2.3. *Facilities: Medium-term ($\sim 5-7$ years)*

LSST: LSST offers transformative science should it proceed as scheduled. It is currently expected to provide homogeneous broad-band photometry for billions of stars in the MW and LG to r $\sim$ 27 at S/N > 5 over 20 000 degrees^2 using an 8-m facility. If there is the opportunity for Canadians to participate in *and shape* the science projects, then this should be seriously explored.

Wide-field MOS: Dynamical studies of stellar structures subtending degrees on the sky are limited by the FOV of spectrographs on 8-m facilities (Section 1.1.1). While there are several intermediate-res spectroscopic surveys operating in the MW for phase-space studies, obtaining detailed chemistries to compare with galaxy evolution models and to search for first stars requires high-res spectra of thousands of targets (Section 1.1.2). A wide-field (∼degree FOV) multi-object ($\sim$ 1000 stars per field) spectrograph with intermediate ($R \sim 5000$) and high-res ($R > 20,000$) modes on an 8-m class facility will deliver transformative science for both MW and LG studies, as originally envisaged for WFMOS.

The GYES multi-object spectrograph currently being considered for CFHT addresses some of these science goals, but the 3.6m aperture of CFHT will confine the science to the region of the MW. The high-res MOS mode would currently be unique in the north, and HERMES at the AAT would do complimentary science in the south. Note that the science for an intermediate-res mode would closely resemble those of the LAMOST survey, also a 4-meter class telescope in the northern hemisphere, and with a proposal for a high-res mode. An aperture upgrade of CFHT to $6-8$ meters with WFMOS would be internationally competitive in the era of HyperSuprimeCam, TMT and LSST. Canada should pursue all available routes for building or collaborating in such a facility.

2.4. *Facilities: Longer-term*

Thirty Meter Telescope: The aperture of TMT allows spectroscopy on fainter stars, and the AO capabilities (in which Canada leads several aspects) means IR spectroscopy can be carried out in crowded fields. The two most important instruments for stellar populations are IRMOS and HROS. IRMOS is an IR AO-corrected multi-object spectrograph, delivering IR spectra of over 20 objects simultaneously over small FOV (≤5 arcminutes). HROS is a high resolution optical spectrograph, possibly with some multiplexing capabilities (greatly desired for this science). These instruments are expected to gather spectra 2-3 magnitudes fainter than currently available at the 8-meter class telescopes. Individual RGB stars in M31, its satellites, and the isolated LG dwarf galaxies will become available for detailed abundance analyses (H<16 for IRMOS, or V<21 for HROS).

Diffraction limited wide-field optical imaging: Stellar populations beyond the LG require imaging facilities with HST-like resolution operating over a large ($\sim$ degree) FOV (Section 1.1.1). In contrast, the FOV for the TMT imaging camera is $\sim$ 5 arcmins and operates in the IR with AO (Section 2.1). Extending LG stellar populations science into the Local Volume requires optical wavelengths. Optical AO lags significantly the progress in the IR, and it is unclear if ground-based AO technology will improve to the extent that it rivals space-based facilities. IMAKA, proposed for CFHT, will improve the median seeing by a factor of 2 (to $\sim$ 0.3 arcsecs), highly desirable, but with a limited magnitude for long term goals. On the other hand, a space-based, wide field, optical imager could provide 0.1 arcsec resolution and superb quality dependent mainly on aperture size. Such a facility has already been proposed to the CSA as part of a DWG report by Côté et al. (2009). This type of observatory would have a transformative impact on stellar populations and many other fields of astronomy.

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Footnotes: Other LRP 2010 white papers are referenced by the following footnote numbers:
1. Harris (globular clusters)
2. Herwig (stellar evolution)
3. Cote, P. (galaxies)
4. Johnstone (star formation)
5. Barmby (extragalactic star forming regions)
6. St. Louis (massive stars)
7. Willis (galaxy formation)

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TABLE 1
Science Topics in Stellar Populations and Nearby Galaxies

Science subtopics:	Canadian content:
1. Spatial, chemical, and dynamical mapping of the MWG and satellites:	*no special order*
(not including globular clusters[1], or star forming regions[4,5,6]):	
• the metal poor halo, thick and thin disk stars,	Venn
stellar lumps, halo distributions, Galactic bulge	Stetson
• proper motions and phase space structures in the halo	Navarro
• theoretical modelling of the formation	Wadsley, Hartwick
and evolution of MWG	van den Bergh
• search for first stars, first supernovae	Herwig
• astrophysical sites of neutron-capture processes	Dotter
and galactic chemical evolution	vandenBerg
• dwarf spheroidal galaxies	McConnachie
• dark matter and tidal stripping of dwarfs	Penarrubia
• metallicity distribution functions	Cote P.
• ultra faint dwarf galaxies	
2. Globular clusters in the Local Group:	
(only as tracers, else see globular clusters[1])	
• outer MWG halo globular cluster, mass and metallicities	Harris
• mulitple stellar components	Stetson, van den Bergh
• inner vs outer halo clusters and MWG formation	Cote, P., Hartwick
• variations in properties of the MWG, M31, and dwarf	McConnachie
galaxy globular clusters	Hesser, Pritchet
• chemical composition variations within clusters,	Dotter, Venn
and between clusters and field stars	VandenBerg
• isochrone fitting, treatment of convection,	Bergbusch
importance of atomic diffusion, rotational mixing,	Dennisenkov
uncertainties in opacities, nuclear reaction rates, the equation of state	Herwig
• dynamical cleaning of the lower mass stars	Richer
• effects of binaries on dynamics	Sills
• integrated light spectroscopic properties	Puzia, Mendel
3. Mapping of M31, M33, and satellites	
• CFHT deep imaging survey	PANDAS survey
• mapping of stellar structures	McConnachie
• dynamical modelling	Dubinski, Widrow
• stellar contents, globular clusters,	Cote, P., Ferrarese
• star forming regions	Pritchet, Harris, Hesser
• discovery of new Andromeda dwarfs	van den Bergh
• differences between of M31 and MWG satellites	Navarro, Babul
star formation histories	Barmby, Venn
4. Gas-rich dwarf galaxies in the Local Group:	
• stellar contents of isolated dwarfs	Venn, Leaman
masses, structures,	Stetson, Hesser
gas contents, and dynamics	Cote S.
• chemodynamical, and spatial studies	McConnachie
• semi-analytic modelling of formation	Wadsley, Navarro
• Magellanic Clouds,	Cote P., Welch
Bridge, Stream	McClure-Griffiths
•star formation history, chemical evolution modelling	Roberts, Drissen
proper motion from HST and first passage around the MWG	Babul
Spitzer IR imaging and stellar contents	
5. Mapping of the Local Volume	
• mapping the local volume	Cote P.
• distribution and morphology of galaxies in nearby groups	Ferrerase
• intracluster stars and globular clusters	Harris
6. Other Topics:	
• hypervelocity stars and ejection from SMBH	Navarro
• Cepheid and variable stars, distance indicators,	Harris
Oosterhoff dicotemy	Stetson
• IMF, stellar feedback	Roberts, Drissen
• white dwarfs and cooling sequences	Richer
• mass loss rates and white dwarf to progenitor mass	Bergeron
• open clusters (CFHT Open Star Cluster Survey)	Kalirai
• brown dwarfs properties, searches	
• eclipsing variables (mass, radii, surface temperature,	
luminosity), age and distance	

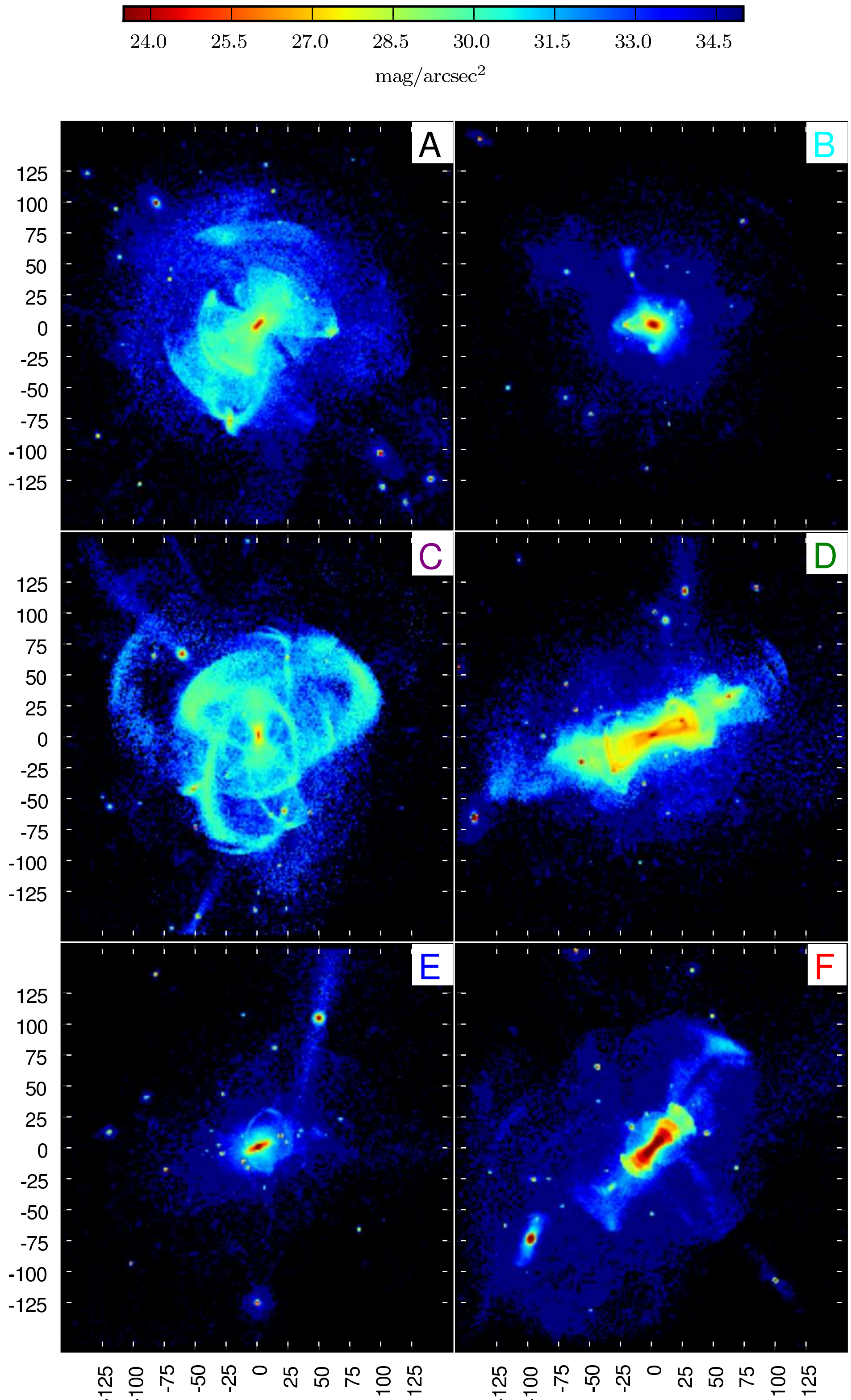

FIG. 1.— Six different realizations of the spatial distribution of stars in galactic halos on a scale similar to the PAndAS map in Fig. 4, color-coded by surface brightness, where the majority of features are fainter than 30 mag arcsec^{-2}. These are derived from semi-analytic models by Cooper et al. (2009) based on n-body dark matter simulations of the formation of $L*$ galaxy haloes by the Aquarius team (Springel et al. 2008). Despite stochastic effects inherent in any process as complex as galaxy formation, theoretical models now make testable, robust, predictions on the statistical distributions of mass and light on galactic scales. Phase-space studies of the global structural properties of galaxies are required in order to provide observational comparisons to these models, and provide unique tests of and constraints on both structure formation on small scales and the baryonic physics of galaxy formation.

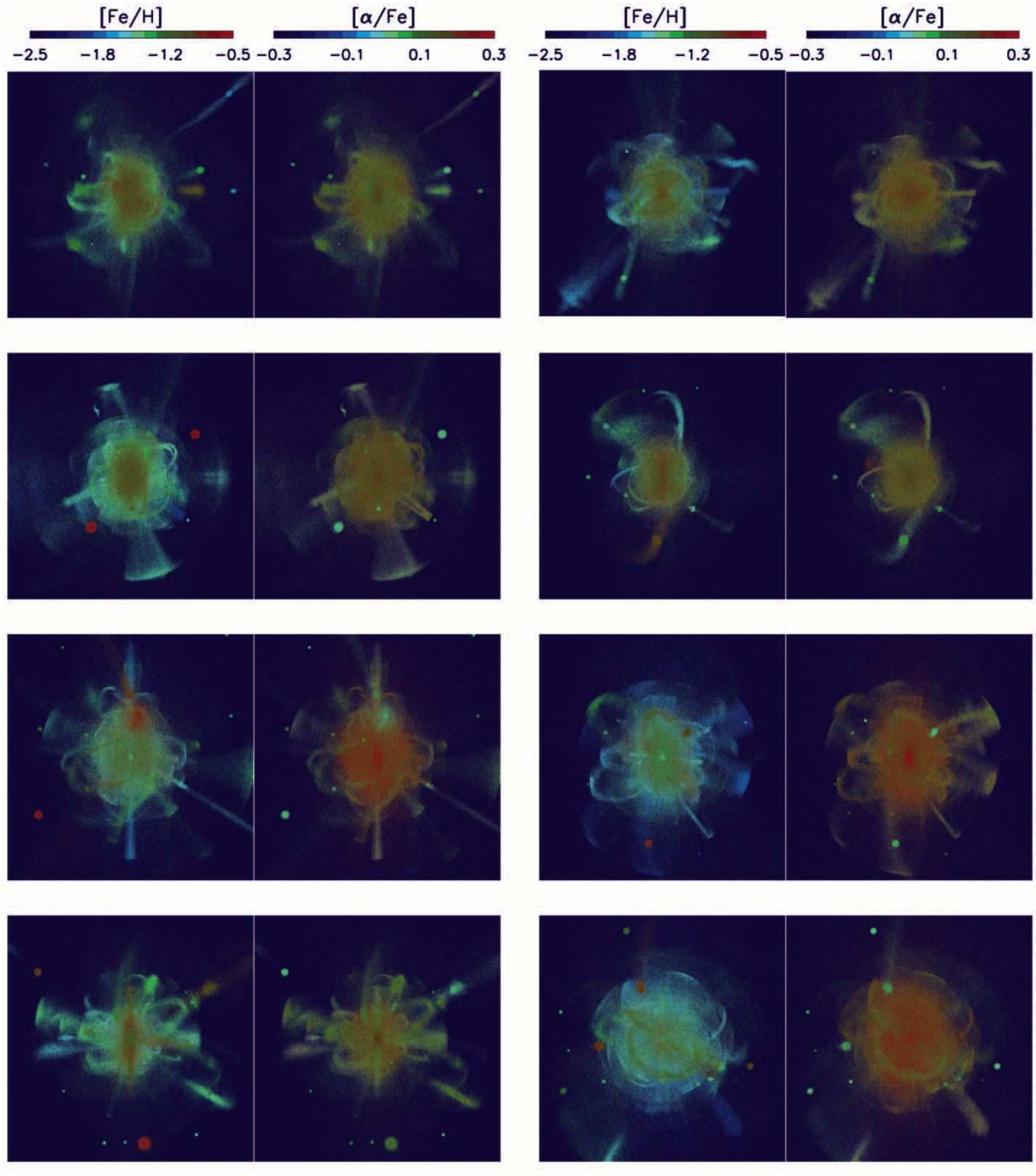

Fig. 2.— Six different realizations of the outskirts of galaxy haloes on a scale similar to the PAndAS map in Fig. 4, showing the distribution of [Fe/H] and [α/Fe], from Font et al. (2006). Here, the distribution of these properties in the outer regions of the galaxy are result of initial assumptions about the efficiency and feedback processes governing star formation in low-mass stellar systems. Chemical evolution studies of stars in the components of the Milky Way and M31, and their satellite galaxies, provide unique constraints on the early chemical evolution of the galaxy and the first generations of star formation in the Universe.

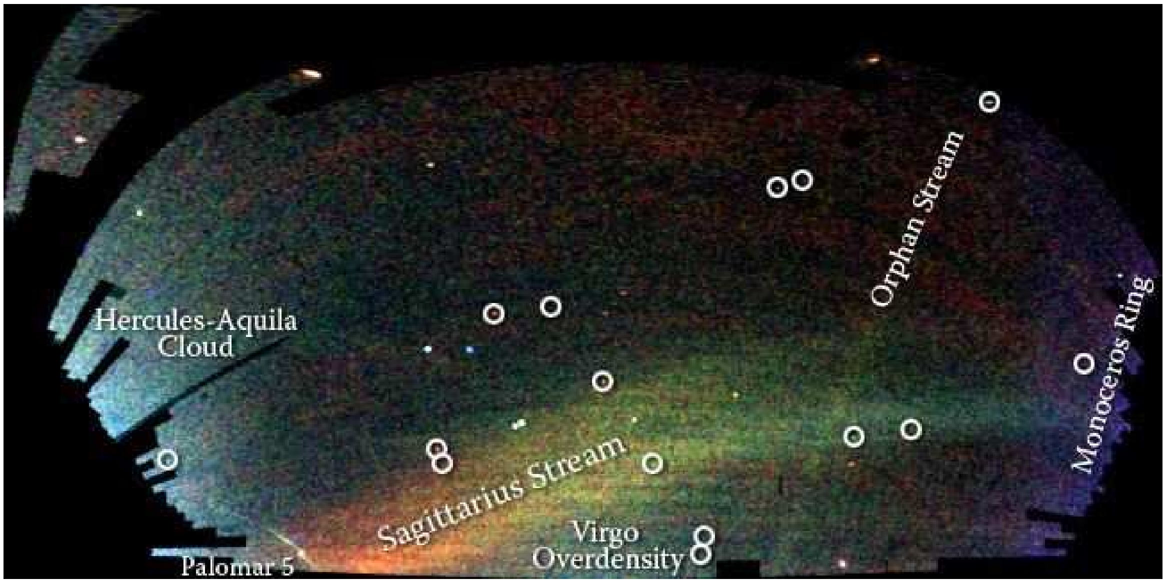

FIG. 3.— The SDSS "Field of Streams" (Belokurov et al 2006). The spatial distribution of upper main sequence, and main-sequence turn-off stars, in the footprint of the SDSS (identified by a simple color cut in g and r, color-coded according to heliocentric distance; blue is closer, red is more distant). Approximately 10^7 stars are shown here. As well as revealing the previously recognized Monoceros Ring feature, the Virgo Overdensity, and the tidal disruption of the Palomar 5 globular cluster, this image also reveals a previously unknown bifurcation of the Sagittarius tidal stream, a new, dynamically cold "Orphan Stream" and a large scale overdensity in Hercules-Aquila. Fourteen new dwarf galaxies have also been discovered from these data, of which some are highlighted in the image. All of these features are expected to be the remnants of objects accreted in the ongoing build-up of the Milky Way halo.

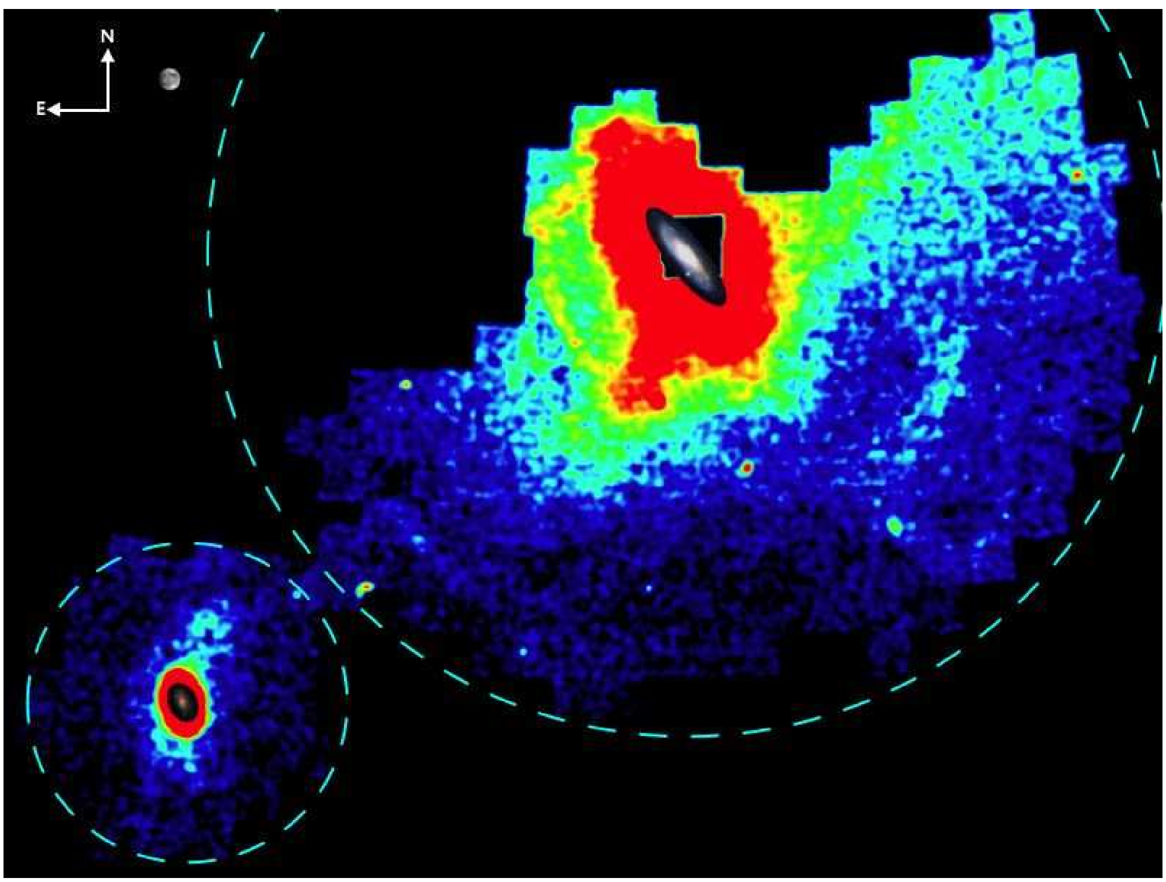

FIG. 4.— The spatial distribution of red giant branch stars in the surroundings of M31 and M33, from the on-going CFHT MegaCam/MegaPrime "Pan-Andromeda Archaeological Survey" (PAndAS; McConnachie et al 2009). Optical images of the main disks of M31, M33 and the Moon are overlaid for scale. Dashed circles correspond to maximum projected radii of 150kpc and 50kpc from M31 and M33, respectively. The complete survey area will by > 300square degrees. Stars are discovered everywhere in the survey area, emphasizing the vast extent of galaxies and the degree of structure in their outer regions. Currently, such a panoramic view of galaxies to such low surface brightness levels are only possible for Local Group galaxies. Further, the scale of the structures present (>degrees) are not well matched to current generations of wide field spectrographs (arcmins; e.g., Keck/DEIMOS, Gemini/GMOS).

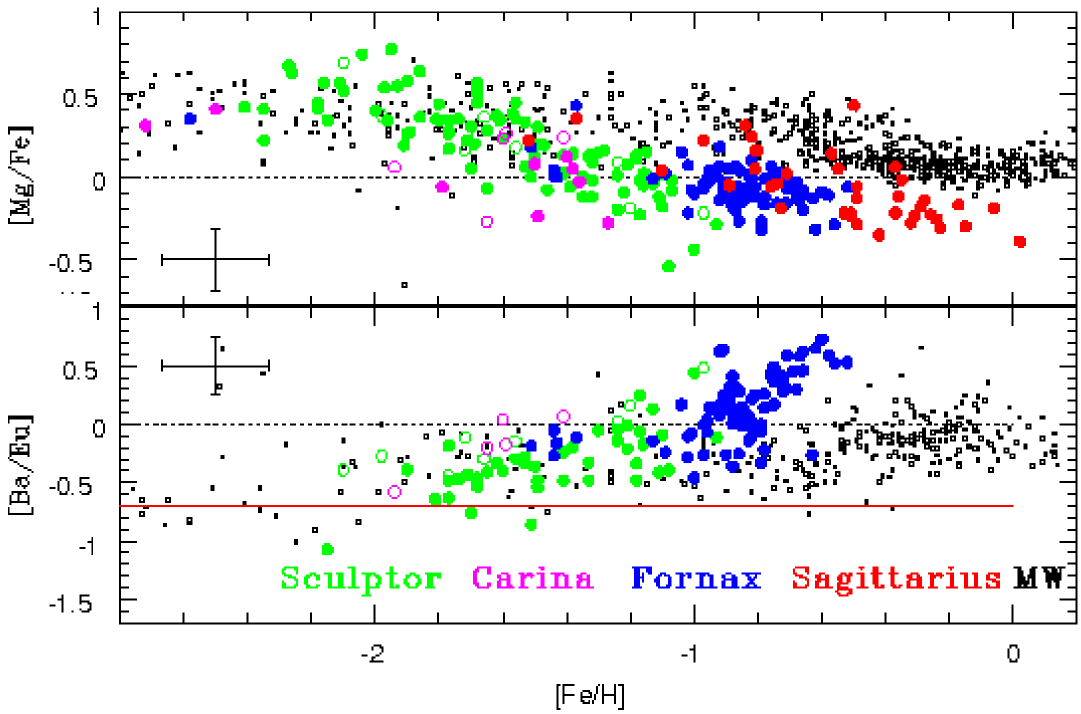

FIG. 5.— Detailed abundances for 4 nearby dwarf spheroidal galaxies (from Tolstoy et al. 2009). [Mg/Fe] ratios are shown in the top panel which represent the yields from [Ty II/ Ty Ia] supernovae (in the simplest case, a detailed analysis is more complicated due to gas infall and supernovae outflows). Clearly the [alpha/Fe] ratios shown here are unique for each dwarf galaxy and separate from those of similar stars in the MW above [Fe/H] = −2. [Ba/Eu] is shown in the bottom panel which represents the yields from the massive supernovae and the AGB stars. Remarkable in this plot is the clear over production of barium in dwarf galaxies that is not seen in the MWG populations at intermediate metallicities. The solid red line represents the ratio of [Ba/Eu] from the r-process in Ty II supernovae. Abundances of Ba and Eu are predicted to be zero in some models of the first supernovae, and/or in the most metal-poor first stars. Data is collected from the literature for the Sculptor dwarf galaxy (green), the Fornax dwarf galaxy (blue), the Sagittarius dwarf stream (red), and the Carina dwarf galaxy (magenta). Black dots represent MW field stars and globular clusters (from Venn et al. 2004).

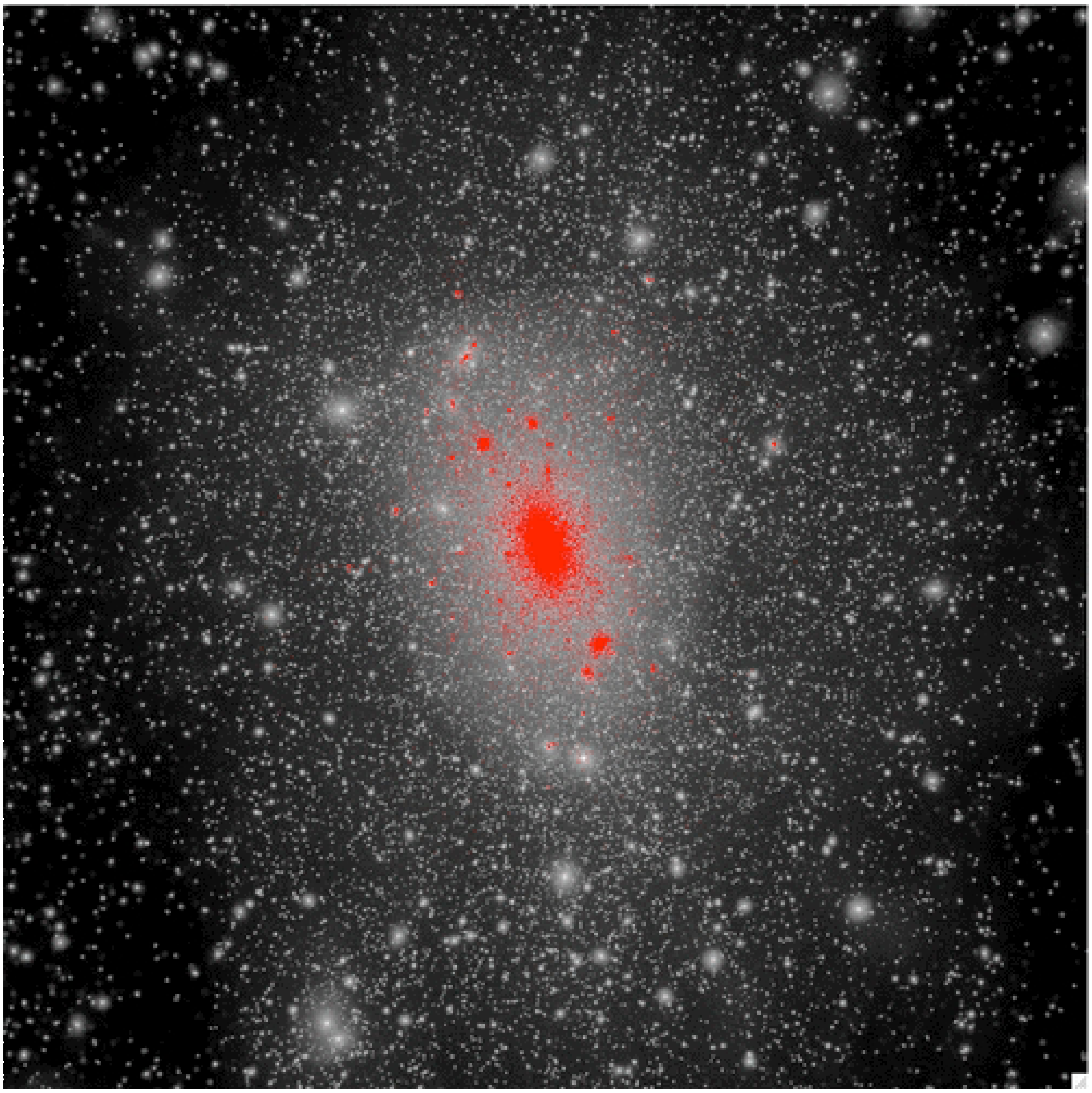

Fig. 6.— Spatial position of first stars at z=0 from a simulated galaxy from the Aquarius project (Gao et al. 2010). The scale is 1080 kpc, 2x the dark matter halo size in the simulation. Red points show the distribution of first stars, which are predicted to be located in the Galactic center and dwarf galaxies.

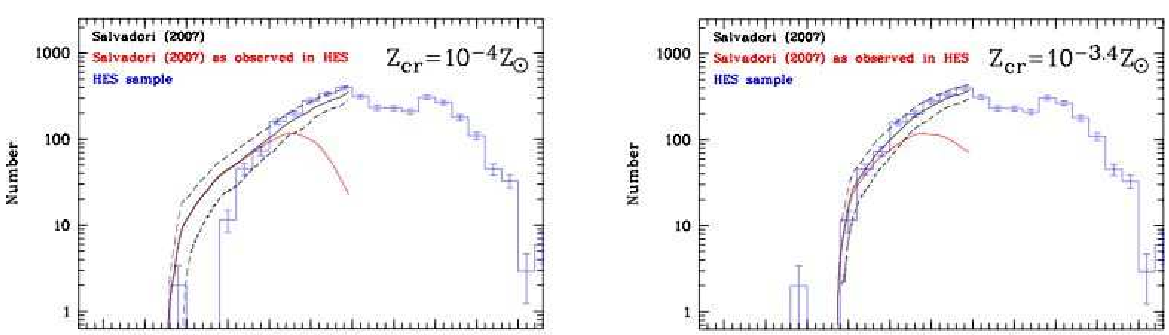

Fig. 7.— Comparison of the metallicity distribution function (MDF) constructed from the Hamberg ESO survey (histogram) with models of the chemical evolution of the MW halo by Salvadori et al. 2007. Different critical metallicities for star formation are adopted, with the region between the dashed lines indicating the uncertainties in the models due to different hierarchical merger histories for the Galaxy. Clearly our understanding of the metal-poor tail is critical to the first generation of star formation and either the MDF is well explained by a critical metallicity of 10−3.4 solar, or there are a significant number of metal-poor stars still missing below [Fe/H]=−3.7. From Schoerck et al. (2009).

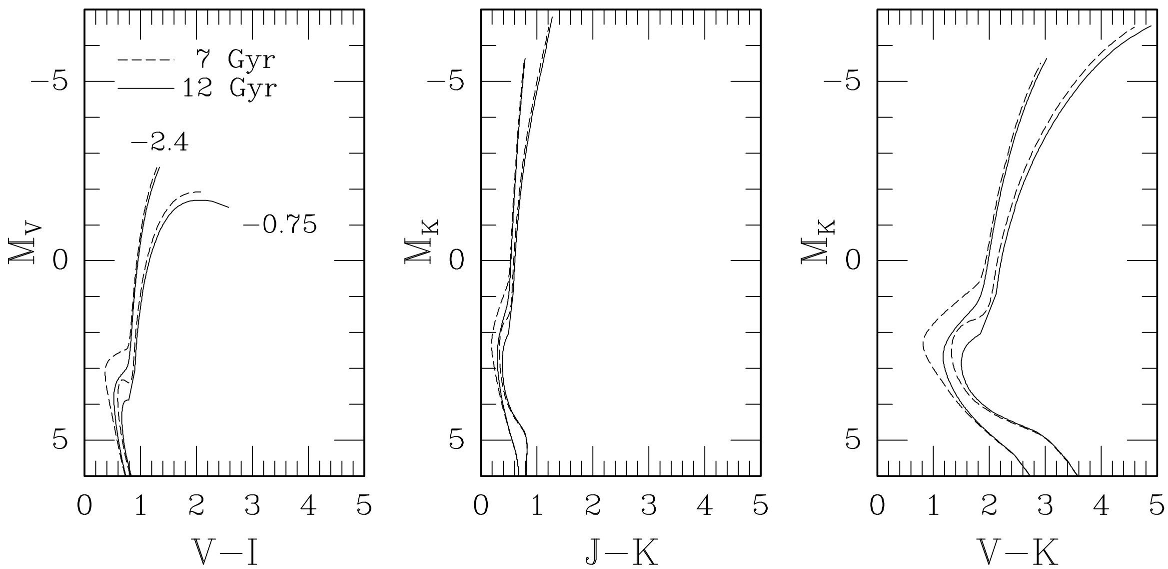

FIG. 8.— Colors and magnitudes from stellar isochrones (VandenBerg 2010) for [Fe/H] = -2.4 and -0.75, and ages of 7 and 12 Gyr. The same scale is used in each plot to emphasize the change in sensitivity between V and K magnitudes (y-axis) and the extreme sensitivity to age and metallicity for V-K colors, but not for J-K colors. This means it will not be possible to use JHK (nor IRAC) colors alone to reconstruct star formation histories.