BEYOND THE GALAXY WITH GAIA: EVOLUTIONARY HISTORIES OF GALAXIES IN THE LOCAL GROUP

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ABSTRACT

Gaia will play an important role in providing information about star formation histories, merging events, intergalactic streams etc, for nearby galaxies of the Local Group. One of the most crucial contributions will be proper motions, especially for stars in the outermost parts of the galaxies, obtainable for stellar populations to ~ 150 kpc with RGB stars. Together with radial velocities for the brightest giants (< 80 kpc), this will provide membership information for individual stars and global kinematical picture of the most nearby galaxies, including the Magellanic Clouds (MCs). Gaia will also provide photometric metallicities ($\sigma([M/H]) < 0.3$) for individual giants and/or supergiants in dwarf galaxies to ~ 200 kpc. MSTO ages will be possible for the youngest stellar populations in the most nearby galaxies (e.g., MCs), whereas stars on RGB/AGB may provide age estimates for populations to ~ 150 kpc. Gaia will allow the study of the outermost parts of the galaxies, which (because of their large spatial extent) are difficult to assess from the ground. Apart from allowing to clarify the structure and evolution of the dwarf galaxies, this will also make it possible to investigate galactic tidal debris, thus providing additional details for the global picture of formation and evolution of the Milky Way Galaxy.

Key words: Gaia; Galaxies; evolution; Galaxies: Local Group.

1. INTRODUCTION

The past few decades have been extremely fruitful in terms of advancing our understanding about the Local Group (LG), both on the level of individual galaxies, and the LG at large (van den Bergh 2000). This was facilitated by the deployment of HST, large ground-based telescopes (VLT, Keck, Subaru, Gemini) and new instrumentation (especially wide field cameras and multi-object spectrographs), crucial for studies of faint stellar populations in the LG galaxies.

Gaia will be a powerful tool to study formation and evolution of the Milky Way, but apart from this it will also provide a wealth of information on individual stars (giants and supergiants) in distant stellar populations, such as galaxies of the LG. However, given the fast development of new observational facilities, especially those foreseen to come into operation already within ∼10 years, it is crucial to understand whether and what Gaia may contribute in this rapidly evolving field of research in 10–15 years from now. We attempt to address this question briefly in the forthcoming pages.

2. THE LOCAL GROUP: CURRENT STATUS AND FUTURE GROUND-BASED PROSPECTS

2.1. Current Status

A list of nearby LG galaxies which may be accessible with Gaia is given in Table 1[1]. It is obvious that a comprehensive study of the nearby LG galaxies requires instrumentation with high sensitivity and large field of view (FOV), as most of them occupy large areas on the sky (note that stellar populations of dwarf galaxies may extend to several apparent radii, see e.g., Vansevičius et al. 2004, thus covering an area of several square degrees on the sky!). The demand for high sensitivity will imply the use of the largest telescopes available; however, their FOVs are prohibitively small compared to the spatial extent of LG galaxies, especially the nearby ones. Thus current studies of LG dwarfs are mostly limited to small areas in individual galaxies (typically their central parts).

The outer edges of dwarf galaxies, however, are extremely interesting, as they may contain important imprints about the formation and evolution of individual

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[1] Note that dwarf galaxies in the LG are clustered around the two major spirals, i.e., the Milky Way and M31 (Figure 1). Beyond 300 kpc and closer than 600 kpc, there are only two dwarf irregular galaxies (Phoenix, 400 kpc, and NGC 6822, 500 kpc). NGC 6822 is a star-forming galaxy and thus may be an interesting (and challenging!) target for Gaia with supergiant stars (see Section 3).

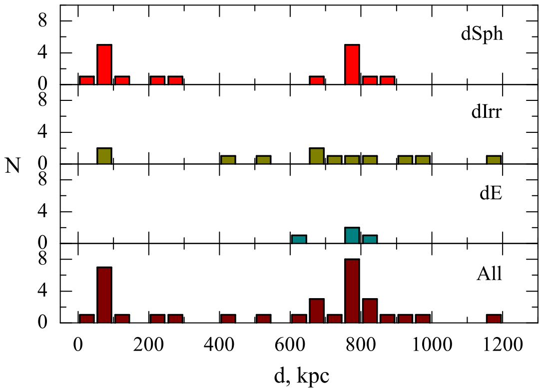

Figure 1. Distances to Local Group galaxies (data from Grebel et al. 2000).

galaxies, as well as their interaction with other galaxies in the LG (spatial gradients in star formation and chemical enrichment histories, kinematical properties, etc). However, field contamination becomes increasingly important at larger radii, thus membership information (typically based on kinematical properties) is crucial to distinguish galactic populations from the field stars.

Current kinematical studies of LG galaxies are mostly based on radial velocities, which are possible only for brightest giants and supergiants with 8-m class telescopes. Several studies have aimed recently at obtaining proper motions of individual stars in nearby LG galaxies, but: (1) the accuracy is low, mainly due to the relatively short time span between the measurement epochs, (2) studies of this kind require 8-m class telescopes (or HST) to ensure the required spatial resolution which, given today's situation, means small FOVs again. Thus, astrometry of LG galaxies presently remains limited to small selected areas in the most nearby galaxies.

Table 1. Local group galaxies within 300 kpc from the Sun

Name	Type	$D_\odot$ kpc	$r_{\rm core}$ arcmin	$r_{\rm tidal}$ arcmin
Sgr	dSph,N?	28 ± 3	–	> 600
LMC	IrIII-IV	50 ± 5	646	
SMC	IrIV/IV-V	63 ± 10	372	
UMi	dSph	69 ± 4	16	51
Dra	dSph	79 ± 4	9	28
Sex	dSph	86 ± 6	17	160
Scl	dSph	88 ± 4	6	77
Car	dSph	94 ± 5	9	29
For	dSph	138 ± 8	14	71
Leo II	dSph	205 ± 15	3	9
Leo I	dSph	270 ± 10	3	13

Notes: morphological types and distances are from Grebel et al. (2000), core and tidal radii are from Mateo (1998). Apparent diameters at 25 magnitude isophote are given for LMC and SMC (from the LEDA data base: http://leda.univ-lyon1.fr/search.html).

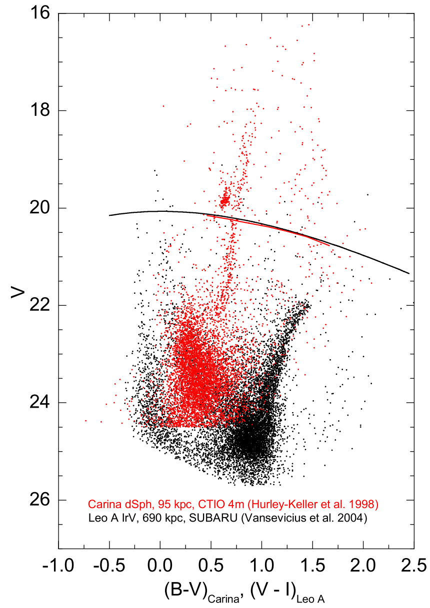

Figure 2. Observed CMDs of Carina and Leo A dwarf spheroidals. Solid lines indicate Gaia detection limit at $G = 20$, in $V - (V - I)$ plane (black) and $V - (B - V)$ plane (grey/red). Note that photometric colour indices $(B - V)$ and $(V - I)_{\rm Cousins}$ are very similar in a given $T_{\rm eff}$ range, thus detection limits nearly coincide in both colour planes.

Star formation histories of the nearby LG galaxies are relatively well understood (e.g., Aparicio 2004; Grebel 2000), as their main sequence turn-off point (MSTO) stars are well within reach with currently available telescopes (see Figure 2, which illustrates the possibilities with currently available instrumentation). Knowledge is accumulating gradually about their chemical enrichment histories too, primarily with the aid of new multi-object spectrographs on 8-m class telescopes (e.g., Venn et al. 2004; Shetrone et al. 2003; Tolstoy et al. 2003). Indeed, the majority of these investigations are confined to the central parts of individual galaxies (or several selected areas at different radial distances), which is imposed again by the limited FOVs of currently available instrumentation.

2.2. Relevant Future Ground-Based Projects

Considerable advances can be expected in all of these fields with the large area surveys which will be carried out in the near future using new wide-field telescopes (Table 2). Although far from being complete, the list in Table 2 gives a clear indication that the FOVs of available instrumentation will increase dramatically in ~5–10 years from now, thus a few pointings will be sufficient to cover areas extending to several square degrees on the sky. Combined with the high sensitivity (8-m class telescope in case of LSST!), this will provide excellent possibilities for studying even the outermost parts of the LG galaxies in a routine way.

Table 2. Selected future spectroscopic and photometric wide field surveys, relevant for the studies of Local Group galaxies.

Survey	Type	Limiting mag	Telescope	FOV	Photometry	Year	Webpage
			Spectroscopy				
RAVE	All-sky	$V = 16$	1.2m + ?[1]	6×6 deg	–	2006-2010[2]	1
			Photometry				
CFHTLS	Selected[3]	$i' = 24.4$[4]	3.6m (CFHT)	1×1 deg	Optical[5]	2003-	2
VST	Selected[a]	$i' = 24.2$	2.6m	1×1 deg	Optical[6]	2005-	3
UKIDSS	Selected	$K = 18.4$[7]	3.8m (UKIRT)	0.9×0.9 deg	NIR[8]	2005-2012	4
VISTA	Selected[a]	$K = 20.1$[9]	4.0m	1×1 deg	NIR[10]	2006-	5
Pan-STARRS	All-sky	$i = 25.4$[11]	4 × 1.8m	2.7×2.7 deg	Optical[12]	2006-[13]	6
LSST	All-sky	$V = 24.0$[14]	8.4m	3.5×3.5 deg	Optical[15]	2012-	7

Notes:

[a] *All-sky survey possible.*
[1] *AAO Schmidt; northern hemisphere counterpart sought.*
[2] *Phase I: 2004-2005 (10^5 stars, $V < 13$); Phase II: 2006-2010 (5×10^7 stars, complete to $V = 16$).*
[3] *MegaPrime/MegaCam on CFHT is available for PI programmes.*
[4] *Very Wide survey; deeper for Deep Synoptic and Wide Synoptic surveys.*
[5] *SDSS $u^\star$ g' $r'i'$ z'.*
[6] *SDSS u' g' $r'i'$ z', Johnson BV, Strømgren v, Hα.*
[7] *Large Area Survey (NIR counterpart to SDSS); deeper for smaller area surveys.*
[8] *Broad-band: Johnson JHK + Y; narrow-band: $H_2$1-0 S1, Br-g (Tokunaga et al. 2002).*
[9] *5σ, 15-min exposure limit.*
[10] *$zJHK$; optical camera foreseen in the original proposal too, subject to funding.*
[11] *60 min, 5σ.*
[12] *$griz$ + y, w.*
[13] *First light from the first prototype telescope scheduled for 2006.*
[14] *Single exposure (10 sec), 10σ.*
[15] *$griz$ + Y.*

Webpages:

(1) http://www.aip.de/RAVE/ and http://www.aao.gov.au/ukst/6dF_RAVE.html
(2) http://www.cfht.hawaii.edu/Science/CFHTLS/
(3) http://twg.na.astro.it/vst/vst_homepage_twg.html
(4) http://www.ukidss.org/
(5) http://www.vista.ac.uk/
(6) http://pan-starss.ifa.hawaii.edu/project/
(7) http://www.lsst.org/lsst_home.shtml

3. THE LOCAL GROUP WITH GAIA: MORPHOLOGICAL AND EVOLUTIONARY HISTORIES OF THE NEARBY GALAXIES?

Obviously, an important contribution of Gaia will be proper motions (precise parallaxes of late type giants, $\sigma(\pi)/\pi \leq 0.1$, will not be available beyond $\sim$ 10 kpc). Proper motions of individual giants and supergiants in LG galaxies will allow to discriminate between the member and field stars (Table 3). However, the accuracy may not be sufficient for detailed kinematical studies of individual galaxies (which will require the precision in proper motions of 1–2 km s^{-1} see, e.g., Wilkinson et al. 2002). Note however, that proper motions of individual stars in LG galaxies will be also feasible with future wide-field instrumentation (e.g., with PanSTARSS), with the time spans between the measurement epochs of ~5–10 years possible already in 2010–2015 (though the accuracies will be lower than those obtained with Gaia).

Radial velocities will be considerably more difficult with Gaia, as sufficient precision may be achieved only for stars brighter than $V \sim 17$, or up to the distances of $\sim$ 40 kpc (Table 3; $\sim$ 80 kpc with AGB stars, $M_V = -2.5$). Indeed, bright supergiants may be accessible at considerably larger distances (Table 3), however, they will be available only in a few galaxies, as stellar populations in the majority of nearby LG galaxies are old, showing no signs for recent star formation (Aparicio 2002). Moreover, their numbers will be too scarce to perform a detailed kinematical analysis.

Gaia will also provide precise astrophysical parameters for a number of individual stars in nearby LG galaxies, from the medium-band photometry (see Jordi & Høg 2005). This will be indeed an important contribution since so far neither spectroscopy nor medium-band photometry is planned with the deep ground-based wide-field surveys (note though, that the former may be possible with the prime-focus multi-object spectrographs on 8-m class telescopes in the near future, e.g., FMOS on SUB-

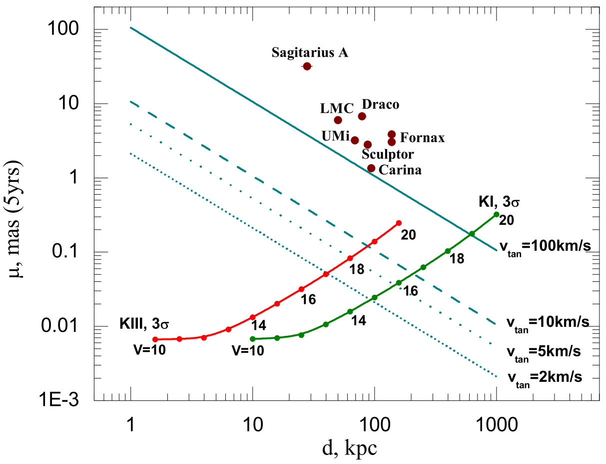

Figure 3. Expected error in proper motion with Gaia (solid lines) for KIII star ($M_V = -1.0$, RGB/early-AGB tracer) and KI star ($M_V = -5.0$, red supergiant). Errors are given at 3σ level; numbers are apparent V magnitudes. Diagonal lines indicate proper motions corresponding to different tangential velocities. Dots indicate LG galaxies with measured proper motions. All proper motions are given for a 5-yr lifetime of the Gaia mission.

Table 3. Predicted accuracies (versus V magnitude) for parallax (π), proper motion (μ), and radial velocity (v_r) with KIII and KI tracers (all for 5 year mission lifetime). Relative parallax error is not shown when $\sigma(\pi)/\pi$ >1.

V	d kpc	$\sigma(\pi)/\pi$	$\sigma(\mu)$ km s^{-1}	$\sigma(v_\mathrm{r})$ km s^{-1}
		KIII, $M_V = -1.0$		
15	16	0.20	0.1	1.7
16	25	0.50	0.3	4.1
17	40	–	0.6	10.3
17.5	50	–	1.1	23.4
18	63	–	1.7	>35
19	100	–	4.4	–
20	160	–	12.3	–
		KI, $M_V = -5.0$		
15	100	–	0.8	1.7
16	160	–	1.9	4.1
17	250	–	5.0	10.3
17.5	320	–	7.8	23.4
18	400	–	13	>35
19	630	–	35	–
20	1000	–	100	–

Note: based on the astrometric accuracies from de Bruijne (2003), and accuracies in radial velocities from Katz et al. (2004).

ARU; and the implementation of the latter is a straightforward task). The availability of precise astrophysical parameters may also allow to study star formation histories of individual galaxies using RGB/AGB stars (Kučinskas et al. 2003).

To a certain extent, however, at least some of these tasks may be accomplished with future wide-field telescopes (e.g., PanSTARSS). With their high sensitivity and large FOVs, these instruments will be serious competitors for Gaia, especially if backed-up with the capability for multi-colour medium-band photometry and multi-object spectroscopy. However, the superiority of Gaia will be in the high accuracy and homogeneity of its data. Gaia will provide precise information both on kinematical and astrophysical properties of individual stars, obtained with a single, stable and well-calibrated instrument. Moreover, the data will be acquired in the same instrumental system as for the millions of stars in the Milky Way. This will deliver an unique and homogeneous data set, which will allow to perform a comprehensive and in-depth analysis of the formation and evolution of the LG galaxies.

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