The Stellar Content of Local Group Galaxies
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General Discussion

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Introduction

There were two general discussion sessions during the Symposium, lasting about one hour each. The first, on Thursday 10 September, was on the general theme of confrontations between theory and observations, and was chaired by Ken Freeman. The second, on the final day, was on future observational requirements and the use of new facilities, and was chaired by James Lequeux, with additional input from Eva Grebel.

The discussions were far-ranging and raised a number of important issues, so it seemed worthwhile to include some account of them in the Proceedings. However, no formal records were kept, but participants were invited to complete the usual 'question and answer' sheets. The result was a somewhat random and rather incomplete set of questions and comments, sometimes with relevant responses, sometimes not. The editors have taken the liberty of arranging the comments received into a quasi-logical sequence (which bears only a passing resemblance to the actual time sequence). The editors take full responsibility for the results of this exercise and apologise in advance if, in the course of their editing, they have misinterpreted or misrepresented any of the comments they received.

The discussion points have been arranged into a number of general topics; this means that the two separate sessions have been partially mixed together. The first session opened with a set of fundamental questions by Sidney van den Bergh:

Sidney van den Bergh: I should like to ask four questions:

(1) What became of the "Boojums" (Babul & Ferguson 1996, ApJ, 458, 100) that are observed at $z \geq 0.5$? Could any Local Group galaxies have been such objects say 7 Gyr ago?

(2) Are there many more undiscovered dSph galaxies with $M_V \sim 10$? Observations of $\sim 20\,000$ square degrees in the southern sky by Irwin et al. suggest that there are not. However, Karachentsev and Armandroff have recently reported the discovery of a few such objects.

(3) Do dark matter galaxies have a minimum mass? Dwarf spheroidals appear to exhibit a sharp cutoff at M (visual) $= 1 \times 10^7 M_\odot$. Are there no less

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massive galaxies or did such low-mass galaxies all lose their gas before they had a chance to form stars?

(4) The Local Group is a sort of Noah's Ark that contains one or more examples of many kinds of galaxies:

Early-type Spirals	M31
Late-type Spirals	M33
Dwarf ellipticals	M32
Spheroidals	NGC 205, NGC 185
Dwarf Spheroidals	Sculptor, Fornax

However, it does not contain a cD or gE (for anthropic reasons ?!), or a compact blue dwarf (although IC 10 comes close to being such an object). Finally, the Local Group does not seem to contain an over-sized dSph, of the kind found in Virgo, of which the M81 group contains an example. However, such a large low surface-brightness object might be difficult to discover.

How many "Boojums" do we expect in the Local Group?

Dennis Zaritsky: The colour distribution of satellites both in our galaxy and around other spirals implies *if the original distribution was spherical* that between 2 to 10 satellites existed for every one currently seen.

If accreted objects were preferentially located in the galactic plane, then the lack of young, metal rich clusters in the halo is not a strong constraint on the number of accretion events.

About one-third of spiral galaxies are lopsided. Using a lifetime for lopsidedness of ~ 1 Gyr, the inferred accretion rate is one, 10% by mass, satellite every ~ 3 Gyr for a galaxy like the Milky Way.

Eline Tolstoy: The similarity between VII Zw 405 and NGC 6822 suggests it is easy to create BCDs and they fade quickly. Thus dIs could easily be remnants of Faint Blue Galaxies. We need to get deep CMDs, reaching main sequence turnoffs, to definitively make this connection – we need unambiguous evidence for bursts of star formation.

Kenneth Mighell: It is certainly possible to now do deep and complete surveys of the Local Group dwarfs if the 4 m TACs are willing to give time. The Hubble Space Telescope can go quite deep but its small field-of-view is a fundamental limitation. Large format CCDs in mosaics now cover 0.5×0.5 square degrees or more which allows a dwarf spheroidal satellite of the Milky Way to be completely surveyed down to $V = 25$ or more in just a few nights on a 4 m telescope.

Eva Grebel: One of the posters at this conference, by Drozdovsky and collaborators, determined the distance to a galaxy classified as BCD galaxy, NGC 6789. They found a distance of 2.1 Mpc, which places this galaxy outside the generally

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assumed boundaries of the Local Group but makes it the nearest BCD known to date.

How many undiscovered dSphs are there?

Jim Hesser: (Addressed to Irwin/Whiting) Could you please quantify the current status of searches for new, faint dSphs, etc. in your southern sky surveys? How do your limits compare with those Taft Armandroff is reporting from his approach?

Alan Whiting: I have examined the whole southern sky on ESO/SRC survey plates, visually looking for faint objects of dwarf size (one to a few arc minutes). Visual completeness is hard to quantify, but all known dwarfs were found without trouble, which gives a limiting surface brightness of something like 25-26 mag arcsec^{-2}. We have followed up all candidates, coming up with two Local Group dwarfs, two very near the Local Group, and about three partially resolved but further away. It's very unlikely that MANY more remain to be found, with the caveat that up to half the sky is so affected by Galactic nebulosity that low surface brightness dwarfs could be present but would not be seen there.

Mike Irwin: Our survey splits into two parts: resolved objects within ~ 300 kpc of the Milky Way are typically many sigma detections. Two-thirds of the sky at higher Galactic latitudes has been surveyed and only Sextans found. Further out objects are unresolved in Survey material and are found by an excess of "background" light over their surroundings. In the southern sky we (Whiting, Hau & Irwin) have surveyed all of the UKST B_J survey plates in a consistent way and found (rediscovered) Antlia, a few objects in the Sculptor Group direction and one other excellent LG candidate. Regions close to the Galactic Plane are difficult to work in but that caveat aside, the discovered objects are well above the survey limits and again no evidence for significant numbers of low luminosity LG objects is found.

Com A is within 1 degree on the sky of NGC 1560 and is quite likely associated with it at ~ 2 Mpc. I suspect most of the generic Local Group candidates of Karachentsev are at > 2 Mpc. In other words there are not currently a large number of likely extra LG members at the faint end.

Taft Armandroff: As I said in the discussion after my talk, we have not yet carried out completeness simulations for the M31 dSph survey by Davies, Jacoby and myself. However, we plan to carry out such simulations. Because And V, which has M_V near −10, is detected with high statistical significance by our methodology, we probably are sensitive to significantly fainter magnitudes. Once we complete our survey, we will evaluate its impact on the faint end of the luminosity function for the Local Group.

Alan Whiting: Addressing the discrepancy between the Karachentsev/Armandroff survey (many new dwarfs in a small area) and ours (Whiting/Irwin/Hau) (few new dwarfs in a large area), it can be explained at least in part by their surveying toward Andromeda which would be expected to collect small galaxies

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(as in fact happens). We searched not only away from the center of the Local Group but away from the concentration of galaxies in the larger external volume.

Concerning the luminosity function, during my visual examining of survey plates I found roughly half the sky to have enough galactic nebulosity to hide the lowest surface objects. This would bias the derived function in favour of brighter objects.

Do dark matter galaxies have a minimum mass?

Albert Zijlstra: The luminosity function of dSphs is presumably strongly affected by the way they formed, interacting with the formation of the Milky Way. It is not clear what this luminosity function tells you. In contrast to the luminosity function, the mass function is strongly peaked at a few 10^7 $M_\odot$. Is this real or artificial?

Taft Armandroff: I note that the total masses of dwarf spheroidals are not as well known as their total absolute magnitude or central mass density. Pryor, Olszewski and myself, and other groups, have determined velocity dispersion profiles for dwarf spheroidals which imply that the mass is distributed differently, in a more extended distribution, than the light. Hence, much effort is currently underway in order to understand the total masses.

Eline Tolstoy: MacLow & Ferrara have recent results from numerical simulations – how easy is it for supernovae to destroy galaxy luminous mass? The dark matter content is important.

Why are there no gEs or oversize dSph in the Local Group?

Ann Zabludoff: With respect to the question of why there is no giant elliptical in the Local Group, it is possible that there will be if we wait long enough. Poor groups nearby are of many types differentiated by their X-ray properties and the morphologies of their members. We see groups with a relaxed-looking X-ray halo and a central giant elliptical. Other groups, which may be dynamically younger, have several interesting galaxies in the core and relatively weak, asymmetric X-ray emission. It is possible that the Local Group represents the beginning of an evolutionary sequence on which the other types of groups lie.

Taft Armandroff: My comment is in response to Sidney's remark that our Local Group lacks the very extended dwarf ellipticals seen in the Virgo cluster and the M81 Group. I wonder whether one of these galaxies could be "hidden" in the Local Group. Consider the large low-surface-brightness dwarf F801 in the M81 Group (Caldwell et al. 1998, A.J., 115, 535) with a central surface brightness in V of 25.4 mag arcsec^{-2}. If it had the distance of the LMC, its length scale would only be 15% smaller than the LMC. One wonders if such a galaxy was located > 200 kpc from us, where there would be no resolution into stars on the sky survey plates, whether we would detect if via current searches.

Content and extent of the Local Group

Eva Grebel: We are following up on the Karachentseva & Karachentsev objects in collaboration with them and have at present 28 Local Group candidates. This number explicitly excludes newly discovered nearby dwarfs that belong to nearby groups. Distance determinations to the new nearby dwarfs place some of them at the "outer boundaries" of the Local Group. At the same time, galaxies usually considered to be associated with nearby groups (e.g., NGC 55 in the Sculptor Group, which may be as close as 1.6 Mpc) seem to overlap with the Local Group. Thus what are the boundaries of the Local Group? Where does it "end", and where do nearby groups start? The zero-velocity surface of the Local Group, calculated from recent mass estimates for M31 and the Milky Way, is 1.8 Mpc, a definite overlap with galaxies in the Sculptor Group, the Maffei/JC 342 Group, etc. Similarly, a $\cos\theta$, V_{hel} diagram shows overlap. Local Group Galaxies must definitely feel the influence of nearby groups and *vice versa*. As long as we are lacking orbits, even distance determinations are insufficient in determining Local Group membership.

Mike Irwin: Membership of the Local Group using all dynamical and age information gives a fairly well defined boundary to the Local Group. For example, in the Sculptor direction there is no obvious spatial or velocity discrimination unless we invoke age of Universe/LG arguments.

Donald Lynden-Bell: I wish to ask what is the velocity of the M31 group? The following list gives the data:

Galaxy	V_H	θ^{o}_{M31}
M31	300	0°
M33	180	14.7°
IC 10	343	18.4°
M32	190	0°
N 205	239	1°
N 185	208	7°
N 147	199	7°
Pegasus (DD0 216)	181	31°
IC 1613	236	39°
WLM	116	57°
Pisces (LGS-3)	277	20°

Should we use the great clunker M31 as the velocity of the M31 group or should we think of it as a small fly in a massive halo and take the average of all the velocities as the velocity of the group?

Haloes and Dark Matter

Jaan Einasto: In the Local Group we have a possibility to estimate the total mass and outer radius of the dark halo. The masses of dark halos of the Galaxy and M31 can be calculated from the rotation curves if they continue to be flat for very large distances, then masses can be very large. The total mass of M31 plus the Galaxy can be found by the Kahn-Woltjer method using the inward relative velocity. Both methods give identical results if individual dark halos fill the inner Roche limits of the double system Galaxy - M31. In other words, the outer radii of dark halos of the Galaxy and M31 are of the order of 200–300 kpc. The overall size of the Local Group is larger, but it is already outside the inner Roche limit.

Donald Lynden-Bell: We are all inclined to believe that halo material is smooth. We have evidence that the halo is in blobs when we have a dwarf spheroidal in a blob. If one asks how far in such blobs can survive, one gets about 30 kpc. Outside that we should perhaps believe that all the halo is in blobs but we don't know how blobby it is.

Stellar evolution and CMDs

James Lequeux: We have seen beautiful CM diagrams of LG galaxies in this Symposium, and also conclusions derived from them about the history of star formation etc. We have, however, to realise that interpretation of some parts of these CM diagrams is on shaky ground; this is clear for the AGB but from André Maeder's talk we realised also how little we understand on the evolution of massive stars - how can we progress in this understanding? This is mostly a question for André.

André Maeder: There are several links between the understanding of LG galaxies and stellar evolution. One is that we may use LG data to make new tests of stellar evolution to better understand stellar physics. Reciprocally, I think we could get more on the physical evolution of the LG by putting more emphasis on chemical abundances and chemical evolution, combined with the discussion of CMD diagrams.

Kenneth Mighell: The $V - I$ colors of the tip of the red giant branch predicted by most stellar evolution codes do not match the observed fiducials of Da Costa & Armandroff (1990; AJ, 100, 162). Observers do realize the great difficulty theoreticians face transforming effective temperatures to standard colors. However, proper CMD analysis using synthetic CMDs will remain, at best, problematical as long as the models do not match the observational data. Looking out to one megaparsec, the AGB and RGB may be the only phases of evolution that are easily observable for intermediate-age or ancient metal-poor stellar populations.

Michele Bellazzini: (In response to a remark from Don Terndrup.) I think the only serious statement that can be made about the second parameter (SP) problem is that there are *many* SPs! The HST photometry of the globular clusters of Fornax (Buonanno et al. 1998, ApJ, 501, L33) have provided the final demonstration that age IS NOT the only SP at work. This is a somewhat "negative" statement but it's a *very robust* one. This can also have important spin-off on the analysis of CMDs via synthesis, since HB morphology can be considered as an additional free parameter of the simulations (at least when old-intermediate components are involved).

Ken Mighell: I would like to point out that from WPFC2 observations, the Draco dwarf spheroidal (Grillmair et al. 1998, AJ, 115, 144) is a second parameter *galaxy*. If Draco really is as old as the ancient Milky Way globular clusters, then it poses a real challenge to our understanding of stellar evolution.

Star formation rates

John Hutchings: Since we now have star-formation histories of local galaxies, we should try to understand what triggers and what limits star-forming episodes. For instance, what has caused the current episode in NGC 6822 after a long period of quiescence? It does appear to be tidally triggered. Are there clues in H I dynamics, data on molecular clouds or internal dynamics? Is there a similarity to the Magellanic Clouds?

This relates to how and for how long galaxies appear when forming stars, as well as understanding whether there are global variations in stellar rotation, binary fraction and IMF depending on gas motions or even metal abundance (via opacities). There are many statistical observational programs that can address these questions among local galaxies. The implications are potentially of wide importance.

Russell Cannon: It is striking that Carina gives such clear evidence for a relatively recent spike of star formation. Is it the Carina dSph that is unique, or is it its CMD? In other words, could we see more such features in other galaxies if we had better data? Although we have seen many beautiful and impressive CMDs this week, in most cases, even where the old main sequence turn-off has been reached, it is still only possible to say that we are seeing populations of stars with ages between 5 Gyr and 20 Gyr. The age resolution between isochrones collapses dramatically as you go older (and fainter). What scope is there for further improving the data with existing facilities, simply by spending more time on faint photometry? [See Mighell's response to van den Bergh's first question, above.]

Regina Schulte-Ladbeck: Regarding the triggers of star formation - star formation is observed to be an ongoing process in completely isolated systems. Take, for instance, the case of the two Blue Compact Dwarf galaxies discussed at this meeting:

VII Zw 403, at its new distance, is isolated from massive neighbours (Schulte-Ladbeck & Hopp, 1998, AJ, in press)

NGC 6789, presented by Drozdovsky et al. at this meeting, is actually located in the Local Void.

As a matter of fact, there are quite a few star-forming dwarf galaxies known that are located in voids (e.g. Hopp et al. 1994, IAU Symp. 161, p.705). Hence,

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star formation can certainly proceed without interaction with a massive galaxy.

Donald Lynden-Bell: For the theory of chemical evolution the most important function is the number of stars as a function of their metallicity - the star formation rate as a function of time is to some extent irrelevant to the theory.

Spectroscopic abundances

Russell Cannon: Spectroscopy has been mentioned very much less than photometry and CMDs at this meeting. It is worth noting that even if (or when) we are able to take spectra of faint stars in Local Group galaxies, it is going to be very hard to measure the abundances that matter most for determining ages and understanding chemical enrichment. Helium is impossible in red giants, Nitrogen is extremely difficult and even Oxygen is very hard, and gives different results depending on which feature is used.

Carmé Gallart: I think this is a question of observational capabilities and amount of time necessary (and possibly not granted) to do the required observations. With a 4m class telescope, you can only address the question of the abundances in the stars in the nearest dSphs, and still you need large amounts of observing time. We need 8m class telescopes to address the problem in more distant galaxies and in particular in the dIr. Now is a good moment to address this question in a systematic way, using the new 10m telescopes, and the larger quantities of time that they may leave available on the smaller telescopes.

Eva Grebel: I find the discrepancy between models and globular cluster fiducials quite worrisome. I would therefore like to suggest an experiment: To create an artificial stellar population based on observed globular clusters and other populations with spectroscopically determined abundances and main-sequence turnoffs. This artificial, composite population could then be truncated above the main-sequence turnoff. Afterwards I would like to ask those who model stellar populations to derive the star formation history of this artificially created galaxy without knowing the details of the input parameters. It would be valuable to see how closely the input data can be reproduced and their parameters determined. It would also be very interesting to see how the results of different groups compare.

Tom Lloyd Evans: In our Galaxy, one globular cluster (Omega Centauri) has a spread of chemical composition. The relative abundances are very different from that in stars in general with the same [Fe/H], in particular s-process elements are overabundant by $\sim \times 100$. Thus we cannot assume the elements will build up at the same rate in all other systems.

Albert Zijlstra: The two PNe in Sgr have identical oxygen abundances. It is surprising that the stellar abundances appear to vary by an order of magnitude.

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Future observing strategies

Don Terndrup: We must pay a lot of attention to increasing angular resolution. Many of our future targets will be superimposed on the faint stars in the host galaxy and against the pile of galaxies at faint magnitudes, etc.

Kenneth Mighell: The radio astronomy community has been dealing with source confusion for decades. The optical community is now confronting this issue. Source confusion must be considered when designing deep observations of stellar populations in Local Group galaxies.

Hans Ulrich Kaufl: Archiving of ground-based data is highly desirable, but it is only possible if processed and calibrated data are archived. Otherwise the data cube becomes prohibitive. The ESO-VLT is working hard to achieve this goal, i.e. to archive data with all instrumental and atmospheric signatures removed.

Don Terndrup: We have not discussed scheduling modes for large optical telescopes. We need to push for scheduling which allows either very large data samples or long time-series observations for variable stars.

Russell Cannon: Although we will need new facilities to do more detailed work on faint stars in Local Group galaxies, there is one job we can do perfectly well with existing telescopes and instruments – if we could get enough observing time. That is good spectroscopy of individual relatively bright stars for abundance determinations. Here the techniques of multi-object spectroscopy can help a lot. We can observe a large sample of stars for many hours, to get good high S/N spectra. Going beyond that, it is possible to add together the spectra from many stars to get effectively extremely long exposures. So what we need are to get fibre feed systems for high dispersion spectrographs on the new 8–10m telescopes. We must lobby to get these relatively simple enhancements built.

Werner Schmutz: If you do intend to get metallicity constraints from spectroscopy, then the objects to go for are hot stars. They are much brighter than red giants, you get the He abundance, and you get the current CNO metal abundance.

Michael Feast: Russell Cannon has emphasised the future importance of spectroscopy for the Local Group. Spectroscopy will also be important in a wider context. Much of the uncertainty in the calibration and use of various distance indicators is due to a lack of detailed chemical abundance data on such indicators. The spectroscopy of indicators is of vital importance both for the Local Group itself and for distance estimates in the wider Universe.