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Concluding remarks

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Abstract. Summary of Joint Discussion 13 of the 26th IAU General Assembly, Prague.

It is a pleasure to thank the organizers for putting together such an interesting and enjoyable Joint Discussion on exploiting ongoing and future large surveys for galactic astronomy. The program covered a little over one day, and concluded with a wide-ranging discussion session, involving many of the speakers and other participants. It was good, but also slightly nerve-wrecking, to hear many of the points I had planned to mention coming up naturally in the past hour. For this reason I will restrict myself here to a brief overview of the key science goals and some highlights, and then give my personal view on the challenges and opportunities for the future.

1. Galaxy formation & the Milky Way

Much world-wide observational effort concentrates on understanding galaxy formation. It uses the principle that 'far away = long ago', which is sometimes referred to as the fundamental equation of astronomy. Numerical simulations of structure formation by now have the resolution to model individual galaxies. The motions and properties of old stars contain much of the 'fossil record' of the formation history. This fossil record can be read in detail in the Milky Way and its nearest neighbors, because of our ability to resolve the individual stars, and measure their properties. The Milky Way is an average galaxy, in a representative Local Group, so understanding how it formed is central to the entire field of Galaxy formation. This 'near-field' cosmology (Freeman & Bland–Hawthorn 2002) provides a key test of the paradigm of formation through hierarchical merging of many small building blocks, as summarized by Wyse, Bland–Hawthorn, and Helmi. Specifically, we need to determine i) When the stars in the Milky Way formed, ii) When and how the Milky Way was assembled, and iii) How dark matter in the Milky Way is distributed. It is no coincidence that these are exactly the top three science goals for the stereoscopic census of the Milky Way to be provided by Gaia (Perryman et al. 2001), and indeed for many ongoing and planned surveys.

2. Surveys from ground and space

Many exciting photometric surveys are being carried out, including 2MASS and SDSS/SEGUE (Newberg, Ivezić). They reveal many coherent structures in the Galactic halo which include tidal tails of globular clusters and debris from accreted satellites. Akari is carrying out a mid-infrared all-sky survey (Ishihara), and both VST/VISTA and Pan-Starrs 1 (Kaiser) are about to come on

Send offprint requests to: P.T. de Zeeuw line. Ambitious plans for massive follow-up with Pan-Starrs 4 and LSST are in place, but these are not yet funded.

Many thousands to multiple millions of radial velocities are being provided by the Geneva/Copenhagen survey (Holmberg), SDSS/SEGUE (Ivezić), the RAVE project (Steinmetz) and, in the future, by Gaia. The tremendous scientific impact of the HIPPARCOS proper motions and parallaxes for the brightest 120000 stars has stimulated much astrometric work from the ground, using digitized old photographic plates and new surveys with large-area CCD detectors (Turon). A major jump in accuracy will come when ESA launches Gaia in 2011, which will provide proper motions and parallaxes for a billion stars to magnitude 20. Institutions in Japan and the US have plans for other space astrometry missions as well.

Many of the photometric and kinematic surveys also measure (or at least estimate) stellar parameters including $T_{\rm eff}$, $\log g$, the extinction A_V, [Fe/H], and [α/Fe]. High-resolution spectroscopy for subsets of survey stars has already provided more accurate values, as well as specific elemental abundances (Feltzing).

I was impressed by the mounting evidence for different kinematic groups with very homogeneous elemental abundances within the group, but distinct differences between groups. Such evidence is found not only in the stellar halo, but now also in the thick disk (Feltzing, Helmi), and is very suggestive of successive merging of separate building blocks. Helmi demonstrated convincingly that these building blocks are not the same as the precursors of the dwarf spheroidals that we observe around the Milky Way today.

All of this shows that systematic kinematic selection from unbiased large-scale samples, in particular the dataset to be provided by Gaia, and follow-up high-resolution spectroscopy, holds much promise for unraveling at least part of the formation history of the Local Group. This can be done in unprecedented detail in the Milky Way, and is also becoming possible for the nearest galaxies with instruments such as FLAMES on the VLT (Helmi).

3. Challenges

It became clear during the presentations that the ongoing and future large survey projects pose some significant challenges. It is critical to calibrate the various groundbased photometric surveys (Glass), and to be very careful about the derivation of stellar parameters from photometry or spectroscopy (Gray). Methods that have been developed for some class of stars should not be applied blindly to all types.

The importance of correcting for extinction was stressed by some speakers, and ignored by others. It may not be an issue for halo stars at substantial galactic latitudes, but correcting for extinction will be crucial for planned studies of the disk and the Bulge. Galaxy models can help (Robin), as do surveys of the atomic and molecular gas, and studies in the infrared (2MASS, VISTA), but there is little substitute for measuring the distances independently, via the parallax. Gaia will provide the major step forward here, but it is critical that ESA now holds firm on the astrometric specifications.

Variable stars, including eclipsing binaries, can provide much additional physical information on stellar properties and distances, but this requires special attention, including a well-planned cadence of multi-epoch observations (Cook). There is little freedom to do this with Gaia, as it will spin at a fixed rate, but ample opportunity for the groundbased surveys.

Much general preparation is needed to extract the key scientific results from the large databases generated by surveys. For example, it will be very interesting to go beyond star counts in cells, and to connect them with the observed kinematics by use of Newton's laws of motion and gravitation. When applied to the full Gaia data, this will provide massive discriminating power between models and formation scenarios. A number of approaches are known for carrying out the required dynamical modeling, but the existing machinery needs to be developed significantly before it can deal with the large data sets of the future. Work on this should start now. Much experience is available in various institutes in Europe, and support by the national funding agencies, or by an EU RTN, would be very helpful.

4. Opportunities

There is much complementarity between the various ground-based surveys and the data to be expected from the Gaia all-sky survey (Bailer-Jones). The RAVE effort is an excellent example. It gives exciting scientific results for the brighter stars, and also provides pilot experience with precisely the kind of spectroscopic data to be expected from Gaia for perhaps a 100 million objects fainter than magnitude 12.

The Gaia photometry will result in accurate and homogeneous color information for a billion objects to magnitude 20 over the entire sky. SDSS already extends this a few magnitudes fainter, over a large sky area, and the plan is that VST/VISTA, Pan-Starrs 4 and LSST would go fainter still (Kaiser), and even provide some modest accuracy proper motions beyond the Gaia limit. The Gaia space photometry will be very helpful to calibrate all the groundbased measurements, so that they can be used with confidence at these faint magnitudes.

The Japanese space astrometry plans are exciting as they focus on an infrared study of the Bulge, which cannot be reached by Gaia other than in low-extinction windows. NASA's SIM will focus on exoplanets, as it should, but may provide extremely accurate parallaxes and proper motions for a modest set of pre-selected stars. I am puzzled by the OBSS mission proposed by the US Naval Observatory. The science aims appear copied from Gaia, but would be achieved through a different technical solution. It might be good to have a backup in case of a mishap with Gaia, but the scope of the space science ambitions of NASA and ESA relative to their budgets does not seem to favor trans-atlantic duplication. Surely a better way forward could be explored.

Finally, the proposed `WFMOS` for Subaru with funding from the International Gemini Observatory would provide a marvellous opportunity for the needed high-resolution spectroscopic follow-up. It was not clear from the talks whether even more ambitious instruments or dedicated telescopes would be required. If so, then development better start soon.

5. Conclusions

The next decade will see tremendous progress in our understanding of the formation of the Milky Way and the Local Group. Homogeneous large scale photometric, radial velocity and astrometric surveys, dedicated high-resolution spectroscopic follow-up, and theoretical preparation are critical. The talks and the discussion showed that the complementarity of surveys from ground and from space can probably be exploited further with the Gaia mission as the centerpiece, and that plans for this are underway. There is much to look forward to.

References

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