2.2 GALACTIC POPULATIONS, KINEMATICS AND DYNAMICS

A GALACTIC POPULATION CENSUS IN SUPPORT OF ASTROMETRIC MEASUREMENTS

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Abstract. A galactic counterpart of the Sloan Digital Sky Survey, consisting of two dedicated 2–3-m class telescopes (one in each hemisphere), could provide precisely those stellar data necessary to complement the information furnished by a future astrometric space mission: in particular, an automated acquisition and analysis system could provide spectral types, metallicities, and radial velocities of several tens of millions of stars down to about 15–16 mag. Such a dedicated spectroscopic stellar survey would provide considerably more information about the details of the stellar distribution within our Galaxy than is known at present. It is suggested that a galactic version of the Sloan Digital Sky Survey, utilising the GSC-II as an observing list, and capitalising on recent developments in multi-fibre spectroscopic survey capabilities, would be a timely initiative.

1. Requirements derived from a future astrometric mission

"*Optical astronomy has long lagged behind other astronomical disciplines of more recent origin in the production of survey data of well-known and characterised completeness and in digital form, both for imaging and spectroscopy. This has had an adverse impact in many areas, since it is still true that for the most part an object is not 'understood' until it has been identified in the optical and its nature as revealed by optical observations is understood*". I quote the introduction to a description of the Sloan Digital Sky Survey (Gunn & Knapp 1993), which employs a dedicated 2.5-m telescope, for an observing programme of five years duration commencing in late 1995. The goals include, for half the northern sky, four-band imaging with a limiting magnitude of ~ 23 mag, combined with a spectroscopic survey capable of yielding 10^6 galaxy redshifts complete to ~ 19 mag, and 10^5 quasar redshifts complete to ~ 20 mag.

E. Høg and P. K. Seidelmann (eds.),
Astronomical and Astrophysical Objectives of Sub-Milliarcsecond Optical Astrometry, 211–215.

Following the success of the Hipparcos space astrometry mission, concepts for a follow-up astrometry mission—GAIA (Lindegren & Perryman, this volume) and ROEMER (Høg, this volume)—have been proposed for ESA's long-term scientific programme. Preliminary studies indicate that a future mission could provide positions, parallaxes and proper motions at the 20 μas level, for $\sim$ 50 million stars brighter than $V = 15-16$ mag, along with multi-epoch multi-colour photometry. The scientific potential in areas such as stellar evolution and galactic dynamics is immense (Lindegren & Perryman, this volume). Such results would underline the absence of complementary stellar information, which could be acquired from ground, and which would be required for full exploitation of the astrometric data.

The global observing programme for Hipparcos was based on an 'Input Catalogue' of 120000 stars, which was laboriously assembled from a variety of existing ground-based observational catalogues, complemented by auxiliary data acquired specifically for the programme (Turon *et al.* 1992). The Input Catalogue provides an important database for an astrophysical interpretation of the Hipparcos astrometric data, although it will be inhomogeneous and incomplete in particular in terms of spectral types and, especially, radial velocities. The importance and feasibility of acquiring bulk radial velocity data through a concerted observational initiative was recognised by several individuals, and a specific proposal to fund and carry out such a programme was proposed, before the launch of Hipparcos, by Dr R. Griffin in Cambridge. Despite its uncontested scientific appeal, and its small relative cost (say, 0.5 per cent) compared with that of Hipparcos, necessary support was not forthcoming, and it was left to individuals to acquire these data for subsets of the Hipparcos programme through separate initiatives. The proposals were well-received, by ESO amongst others, and this programme now looks set to provide very valuable information for exploitation of the Hipparcos astrometric data (Mayor *et al.* 1991).

Radial velocities are important not only for completing the kinematic information—they represent the third component of the space velocity in addition to the two proper motion components (with 20 μas/yr corresponding to 1 km/s at 10 kpc). Repeated measurements provide a powerful way of identifying and characterising binary systems; this information again complements the Hipparcos astrometric data, where multiple systems prove a considerable complication to the main reduction process, but are scientifically important because of the possibility of mass determinations on the basis of well-determined distances and orbits. And separating the effects of time-dependent photocentric motions—and perspective acceleration—will demand such supporting observations.

A dedicated radial velocity programme for Hipparcos would not have ceased with multiple measurements of the 120000 programme stars; the

Tycho Catalogue, derived from the star mapper observations, will provide proper motions at the 10–20 mas/yr level (and perhaps at the 2 mas/yr level in combination with Astrographic Catalogue positions) for slightly more than one million stars! For the majority of these stars, radial velocities and spectral types will, unfortunately, be unknown.

Determination of elemental abundances and ratios are used to provide information on the star formation history of the Galaxy, information on the overall chemical enrichment (which is sensitive to its dynamical evolution), and the timescales of formation of different components of the Galaxy. Metallicity determinations would obviously provide much additional information and could, in principle, be acquired at the same time.

2. A Dedicated Spectroscopic Survey

If a deep, microarcsec class, astrometric mission is adopted by ESA, it will provide a formidable quantity of highly-accurate stellar distances and space velocities. One of the lessons that must be learned from the Hipparcos programme is the importance, and difficulty, of acquiring the data necessary for (i) efficient operation of the satellite; (ii) an optimum conduct of the scientific observing programme; (iii) a rigorous reduction of the satellite data; and (iv) a proper exploitation of the scientific results. These are not satisfied simply with the positions used to identify and observe the target objects. Photoelectric standards, accurate colour indices, variability data, and information on double and multiple systems, were needed. For the number of stars involved this was just achievable by *ad hoc* methods. Even so, interpretation of the astrometric results will highlight the incompleteness and inhomogeneity of certain associated data.

An astrometric catalogue with tens of millions of objects will require dedicated resources to provide the data necessary for the observations and data reductions, and the complementary astrophysical data necessary for a scientific proper exploitation. Spectroscopic follow-up on a vast scale will be required, and the only realistic way of achieving this would seem to be through a substantial multi-fibre spectroscopic survey—I will follow Longair (1993) and classify a set of reduced observations as a survey if it satisfies the following criteria: (a) completeness, (b) systematic observation and reduction of the data, (c) reliability, and (d) accessibility.

An indication of the capabilities of the present generation of fibre-fed spectrographs is the AAT's two-degree field, multi-fibre system (2dF). This employs a 4-component atmospheric dispersion compensated corrector, coupled with a double-buffered robotically driven 400-fibre spectroscopic facility, in turn feeding two separate spectrographs employing 1024 × 1024 CCDs; the resulting minimum object separation is 25 arcsec (Taylor

1994). (The Sloan survey uses a focal plane 2048 × 2048 CCD array with a pair of fibre-fed spectrographs, allowing the measurement of 660 spectra per field, using pre-drilled, interchangeable plug-plates, at a resolving power $\lambda/\Delta\lambda = 2000$, and with a minimum object separation of about 53 arcsec, and spectroscopic exposure times of one hour.)

Da Costa (1994) has already noted that *"there can be little question that stellar science with [the AAO 2dF] has virtually unlimited potential... However, it should be kept in mind that the key to successful observing with 2dF is positions, positions, positions"*. This problem is also, of course, faced by the Sloan Survey, which will generate positions for the spectroscopic observations during a first-pass photometric survey. Fortunately, for both an astrometric space mission and this proposed ground-based complementary observing programme, positions of the target objects down to 15–16 mag, with an accuracy well matched to the requirements, should be available from the ambitious GSC-II digitising programme. GSC-II (Jenkner, private communication) is an all-sky survey planned by the STScI, following on from their highly successful Guide Star Catalog, intended to provide the positions of 2×10^9 objects down to $V = 18$ mag, with an absolute positional accuracy of 0.59 arcsec (worst case) by 2025, proper motions to better than 0.008 arcsec/yr, and two-colour photometry to better than 0.2 mag. If funded, this should provide the main elements of the *a priori* catalogue required for both the space and ground-based observations.

Concerning telescope automation, the 106th Annual Meeting of the Astronomical Society of the Pacific was held in June of this year in Flagstaff, the subject of the meeting being 'Robotic Telescopes', dealing with the construction, scheduling and planning of automatic telescopes. AutoScope Corporation, for example, is reported to be developing a fully automated, fibre-fed spectrograph and matching two-metre class automatic telescope, with other groups considering how such a system could be managed.

Achievable signal-to-noise figures can be roughly estimated from the values quoted for the AAT 2dF performances. Scaling the figures given by Taylor (1994) to a 3-m telescope, would yield a S/N of roughly 20–25 at $\Delta\lambda = 2$ Å, for $V = 16$ mag, seeing in the range 1.5 to 0.8 arcsec, and an integration time of 10 minutes. This should yield a radial velocities to 5–10 km s^{-1}, depending on spectral type and, for late-type stars, an abundance estimate accurate to 0.2–0.3 dex, with dwarfs and giants being readily distinguishable. Kurtz (1991; see also the related articles from IAU Commission 45 on progress in stellar classification) refers to plans for the upgraded MMT with a 300-fibre spectrograph to provide 1000 classification-quality spectra per hour for $V < 14$ mag.

Is an extended, space-related project feasible? Assuming 600 active fibres, and scaling from the AAT/MMT experiences, a project lasting for

10 years and using two telescopes, one in each hemisphere, could indeed generate spectral information on 50 million objects. Evidently, the precise performances of such a system, required S/N ratio and spectral resolution over given wavelength ranges necessary to permit automated MK-type spectral classification, and to establish useful estimates of metallicities and radial velocities, would require much more detailed studies and optimisation, with considerable innovative software development and ingenuity necessary for the automatic collection, reduction, classification and interpretation of the many terabytes of data generated.

3. Conclusions

Optically, our Galaxy looks not so very different, qualitatively and quantitatively, to what it did fifty or more years ago, the biggest advances having been made at other wavelengths (e.g., at 21 cm), and through studies of the interstellar medium. At the 1981 Vatican meeting on *Astrophysical Cosmology* M.S. Longair made a plea for the central importance of large systematic surveys in providing the fundamental data needed for cosmology. Subsequently (Longair 1993), he added: "*I would extend my statement about the significance of surveys for astrophysical cosmology to the whole of astronomy and astrophysics. The unwritten hope is that by making the right types of systematic observation, the answer to astrophysical and cosmological problems can simply be read directly from the data—there would be a minimum need for interpretation or theory to understand the important answers*".

It seems an appropriate time to consider the non-trivial question of precisely what complementary data are needed, if any, and how they might be obtained.

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