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MULTIOBJECT SPECTROSCOPY AS COMPLEMENT FOR GAIA

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Abstract. The Gaia mission will have an unprecedent impact on our knowledge of the Milky Way by unveiling populations through the study of chemistry and dynamics. It will open new horizons that, nevertheless, will need to be completed with specific surveys of Galactic Archaeology. An analysis of those needs for the different Galactic stellar populations has recently been carried out during a workshop gathering the French community involved in Galactic Archeology and stellar physics. The outcome of this meeting regarding the needs for ground-based spectroscopic surveys as a complement to Gaia, placed in the context of present and future surveys, is presented here.

1 Introduction

Gaia is a pioneering ESA astronomy mission set to revolutionise our view of the Galaxy with a precise and detailed stereoscopic survey of the billion brightest celestial objects. High-accuracy astrometry will allow Gaia to exactly pinpoint the position of a star and to measure its movement across the sky, whilst spectroscopic measurements will allow the radial velocity to be determined. Gaia will also gather photometric data, measuring the brightness of a star in a few dozen colours. This array of data will reveal a moving, three-dimensional Milky Way map of unprecedented scope and precision, as well as providing profiles of the physical properties of each star, including luminosity, surface gravity, temperature and elemental composition. The Gaia satellite will be launched Spring 2012.

Gaia will provide accurate estimates of a range of key parameters, however, the Gaia Radial Velocity Spectrometer (RVS) indeed has a higher limiting magnitude than the astrometric instrument (g$\sim$ 14 to 16.5 vs. 20) and a very limited spectral coverage hampering the chemical analysis of the stars. During the Nice workshop, supported by the AS Gaia, (19-20 February 2009; http://www.oca.eu/rousset/GaiaSpectro/), the needs of complementary spectroscopic observations were examined at the light of the Gaia inpact on our knowledge of the different Galactic populations. The workshop gathered 23 participants, and was specifically timed to trigger thoughts about such complements in the french community, in time to participate the ESO Spectroscopic Survey Workshop (http://www.eso.org/sci/meetings/ssw2009), where we presented the conclusions[1] of our meeting. The context of other present and future surveys has also been taken into account.

2 The context of future surveys

On the observational front, the international scene is evolving fast. Very wide (or all-sky) multi-band photometric (SDSS, 2MASS), have flourished, allowing to probe the Milky-Way populations (especially the halo) to a depth (and homogeneity) that had never been reached before. One striking example concerns the recent tomography of the Milky Way halo from SDSS down to magnitudes of g$\sim$22 by Juric et al. (2008) or Ivezic et al. (2008), providing strong constraints on stellar densities associated with the discs and halo, as well as rough but very large scale metallicity maps that are challenging our views of the thick disc formation. Large spectroscopic surveys (SDSS including SEGUE; RAVE) are also on the way, promising to unravel the chemo-dynamics of Galactic stellar populations. Both these surveys are based on low-resolution spectra (R$\sim$2000 for

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[1]http://www.eso.org/sci/meetings/ssw2009/presentations/RecioBlanco.pdf

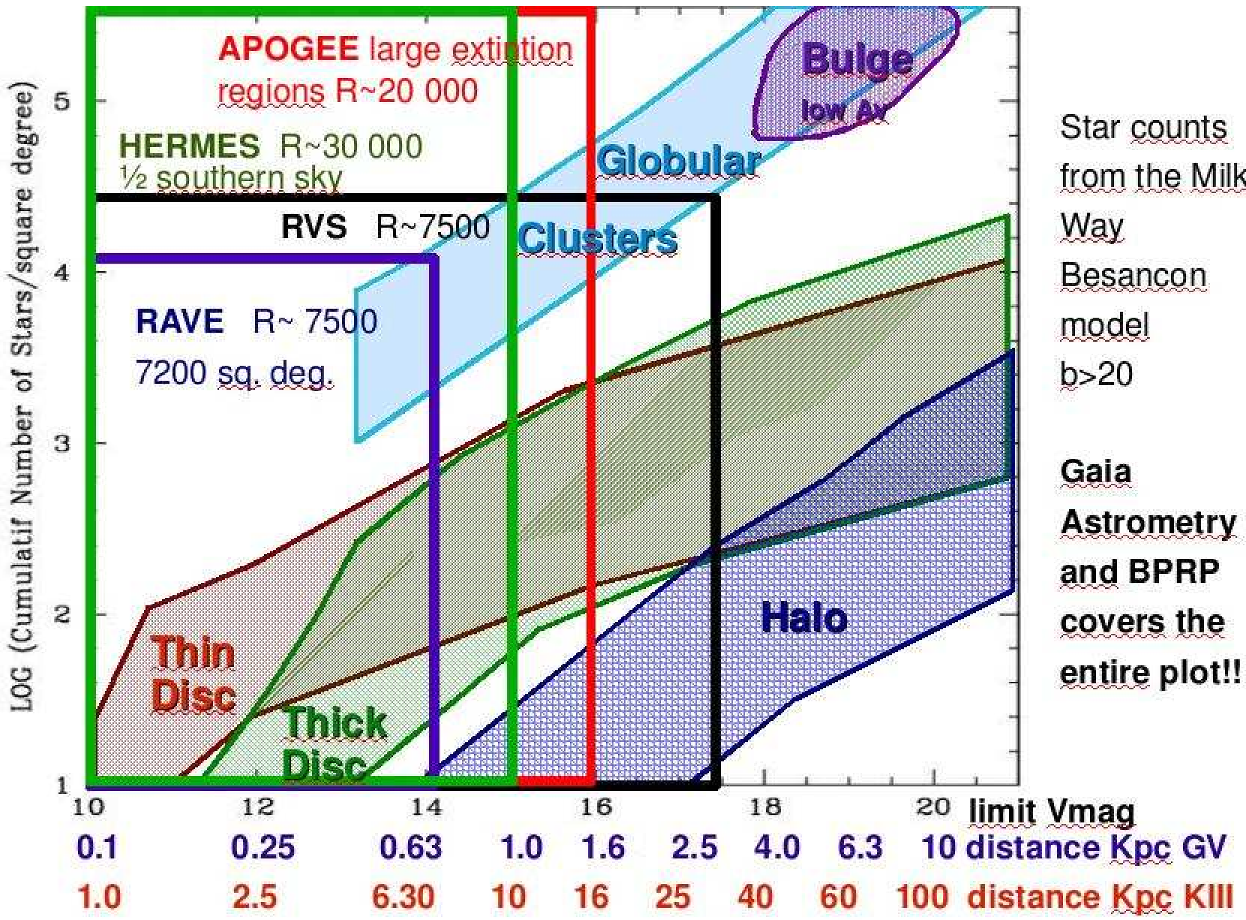

Fig. 1. Plot of the number density and locus of different components of the Milky Way v. V magnitude and equivalent distance for two spectral types as relevant to the follow-up of stars from Gaia. Stellar densities were computed using the Besancon model (Robin et al. 2003) for lattitudes of b>20. The magnitude limits of some other spectroscopic surveys are indicated for comparison, and their resolution and total area coverage are are noted. [note: the various y-axis location of these surveys are meerly for lisibility and do not correspond to any real stellar density.]

SDSS and 7500 for RAVE), and will provide radial velocities (to ∼5-10 km/s and 2km/s accuracy resp.) as well as stellar parameters and a global metallicity indicator for gigantic numbers of stars (around 240000 and ∼80000 respectively). These two major surveys are complementary in that the SDSS is much deeper (g∼20) and probes mostly the galactic halo and thick disc, while RAVE is restricted to a much smaller volume (limited to I=13) and therefore probes best the thin and thick discs. Future stellar surveys at the 2014 horizon include low-resolution surveys such as SEGUE II (part of SDSSIII), LAMOST, but also a new generation of surveys based on higher resolution spectra (R∼20000 or more) such as APOGEE (part of SDSSIII, dedicated to the Galactic plane in IR), WFMOS (GEMINI-Subaru project), or HERMES (R∼30000, V<14, covering one half of the southern sky).

Figure 1 is a plot of the stellar number density and locus of different components of the Milky Way vs. V magnitude and equivalent distance. Two spectral types as relevant to the follow-up of stars from Gaia are considered. The star counts have been taken from the Besancon model for a Galactic latitude b>20. The locus of most of the previously mentioned spectroscopic surveys is shown. The Gaia astrometry and spectrophotometric data will cover the entire plot. It can be seen that there is lack of a high resolution survey *in the north* for stars with V<16, that is, stars that will have good geometric distances and kinematics from the Gaia observations. On the other hand, no high or low resolution surveys are planed for the fainter stars, for which Gaia will furnish neither the radial velocity nor the precise chemical information. This opens two different pathways for the Gaia complementary observations.

3 Science cases

During the workshop, the science cases concerning the different Milky Way and dwarf galaxies populations were examined. The impact of the Gaia mission, but also the information that will not be provided by Gaia were taken into account.

Concerning the Milky Way Thin disc, Gaia will provide, for the first time, disc evolution constraints as a funtion of stellar absolute ages. In particular, the star formation rate over several kiloparsecs will test the inside-out formation scenario. In addition, the infall evolution will be constrained by the chemical abundances evolution with age. For all those purposes, an improvement of the Gaia atmospheric parameters for stars fainter than V=16 (with no RVS measurements) will be necessary to get good age estimations. Moreover, a spectroscopic survey allowing to refine the chemical abundance information for those faint stars (the Gaia spectrophotometry will only give an estimation of the star's global metallicity) would allow the identification of kinematic groups, the study of the Thin Disc structure and constrain the existence of a radial mixing.

Regarding the Thick Disc, Gaia will allow its characterization far from the solar neighbourhood and the detection of accretion events and inhomogeneities. Nevertheless, a complement of the Gaia radial velocity and chemical abundance measurements for faint stars will be necessary. This will permit, in particular, to constrain the radial and vertical chemical and velocity gradients, the scale-heigh variation with Galacticentric distance and che chemical evolution.

The view that Gaia will provide of the Galactic Bulge has been recently been analysed by Reylé et al. (2009), and turns out to be quite partial, owing to the combination of extinction on the line of sight and crowding. Complementary measurements of radial velocity and chemical abundances for faint stars and a larger (l,b) coverage are mandatory for a better constraint of the the Bulge formation scenario, the star formation history and the impact on disc chemical evolution and dynamics as well as for the search for matter accretion traces. Because the Bulge is heavily redened in most regions, spectroscopic measurements will be best suited in the infrared.

The external regions of Galactic globular clusters will be observed by Gaia, that will provide the parallaxes of several thousands to several tens of stars (depending on the distance and the cluster concentration). On the contrary, the RVS, due to its lowest density limit will only observe for a subsample of the clusters, several hundreds to some tens of stars. A complement of the Gaia radial velocity measurements is necessary to improve the impact of Gaia on the study of the Globular cluster's internal dynamics. On the other hand, possible new clusters will be identified by the Gaia survey, and follow up observations constraining radial velocitys and chemical abundances will be needed. Similar complementary data will be necessary to improve the scientific exploitation of Gaia measurements in the Halo, including the nearby satellites of the Milky-Way. In particular, the refinement of the Halo substructure, with an estimate of the fraction of accreted stars, and a comparison of the field Halo population and the Milky Way dwarf galaxies will require additional radial velocity and chemical abundance measurements for faint stars. In this case, a wide field of view (>1-2 square degrees) is necessary for dedicated Halo observations, due to the low stellar density.

4 Conclusions - Recommandations

Based on these science cases, two basic recommandations can be made for large public surveys to complement the Gaia database for studies of the Galactic structure, kinematics and stellar populations.

• **A high-resolution follow-up of the relatively bright objects in Gaia (V<16-17)** This survey would aim at characterizing in detail the chemical composition of the stars for which Gaia will provide exquisite 3D kinematics. This will in turn provide direct information to complement kinematics in identify stellar populations, to identify their origins and formation mode(s). The resolution needed to obtain detailed chemical information is of a minimum of R=20000-40000. The scientific cases that will mostly benefit from such a survey are the understanding of the thin and thick disk outside of the solar neighborhood (including their radial, azimuthal and vertical structures, aswell as origin), aswell as the identification of stellar streams in these components. This survey would overlap partly with the current HERMES project, although aiming at deeper observations (typically 1-2 magnitudes deeper). It would therefore be best suited for the northern hemisphere where it would then be complementary to HERMES.

The Galactic halo at these magnitudes is still rather scare (probed mostly by giants), and would benefit most from a deeper survey (down to V of 19), in selected sky regions (requiring a 10m-class telescope).

The Galactic Bulge is heavily reddened and therefore calls for a specific survey in the infrared. The currently planned APOGEE survey (part of the SDSS-III surveys) will partly cover this area (having ideal resolutions and wavelength coverage), but being located in the Northern hemisphere, its visibility of the Bulge will be rather poor, leaving space for a similar survey from a southern 4m-class telescope.

• **A medium-resolution survey of faint stars in Gaia (17<V<20):** This survey would aim at aquiring the third velocity vector (radial velocities), in the magnitude range where it is unreachable with the onboard Radial Velocity Spectrograph (RVS), thereby complementing the transverse motions of Gaia to obtain 3D kinematics for a large fraction of the Gaia catalogue in this magnitude range. Aiming at a minimum resolution of R=5000 insure simultaneously that the radial velocity accuracy is of the order of 2-3km/s, sufficient to resolve cool kinematical streams (including dissolving globular clusters), and a robust estimate of the stellar metallicity. This survey, one magnitude deeper than the SDSS & SEGUE and twice its resolution, is mainly aimed at unravelling the structure and assembly history of the galactic halo, in particular detecting streams and substructures in the halo (out to 100kpc).

• **Need for single-object high-resolution spectrographs:** In addition to these large surveys, Gaia will also call for high-spectral resolution (or even extremely high resolution R>80000-100000) follow up of a limited number of object (hence with extremely low densities on the sky). For example, among others, exquisite chemical abundances and rotationnal velocities, are needed for a whealth of fundamental stellar physics issues that Gaia will adress, ranging from non-standard mixing and diffusion in stars, angular momentum evolution, nucleosynthesis, etc... For these follow-up, the Gaia stellar community will need access to high-resolution echelle spectrographs on 2-30m telescopes.

Resolution	FOV deg^2	Multiplex fibers/deg^2	λ Coverage Å	$\Delta\lambda$ Å(in one shot)	V mag	Total area
20000−40000	0.25 (1 for Halo)	250-1000	3700-12000	> 500	<16-17	Wide
20000−40000	0.25 (1 for Halo)	250-1000	3700-12000	> 500	17-20	Selected regions
> 20000	0.25	1000	J-H bands	one full band		Bulge
5000−10000	>1	250-1000	3700-12000	> 500	17-20	Very wide

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