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SPECTROSCOPIC SURVEYS OF THE MILKY WAY AND THE SCIENTIFIC EXPLOITATION OF GAIA

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Abstract. It is now one year until the launch of Gaia and spectroscopic surveys of the Milky Way are already a reality. This contribution tries to present the state of the art of ongoing and planned surveys by describing their targeted populations and spectral data properties. The importance of such Galactic Surveys for the scientific exploitation of the ESA Gaia mission is also highlighted.

Keywords: Stellar populations, Galaxy: stellar content, Gaia, Spectroscopic surveys.

1 Introduction

The advent of multiobject ground-based spectroscopy has opened new horizons in the era of Galactic Archaeology, initially driven by large photometric surveys and the preparation of the European Space Agency Gaia mission. Galaxy assembly, star formation histories, element-nucleosynthesis, cosmological initial conditions and fundamental physics have left their fingerprints in a high-dimensional parameter space constituted by spatial, kinematical and chemical distributions, plus their temporal gradients. Therefore, our understanding of the Milky Way history will always be ill-defined if only a few dimensions of that parameter space are probed.

As explained in Gilmore et al. (2012), there are four basic observational thresholds that we need to pass to have a complete view of the fossil record of our Galaxy formation and evolution. Fig. 1, taken and modified from Gilmore et al. (2012), shows the dimensionality of the data and parameter spaces, illustrating those observational challenges. The first step is source identification (or discovery) trough its position and photometric data. This is provided today by photometric surveys of the Galaxy like VISTA and VST. Secondly, the temporal domain is added, allowing us to explore a 5-dimensional space formed by parallaxes (and therefore distances) and proper motions (or transverse velocities). The Gaia mission will be revolutionary here by providing this 5-D view of the Galaxy for about one billion stars down to a magnitude of G=20. The third step is radial velocity, that allows to determine stellar orbits. Finally, if the spectral domain and resolution and the data quality are high enough, the stellar chemical abundances can be derived. Gaia, thanks to its Radial Velocity Spectrograph (RVS) will provide low resolution spectra for most stars brighter than 17th magnitude. This will allow the determination of the radial velocity, the global metallicity and whenever possible, the alpha-element abundance for several tenths of millions of stars (c.f. Fig. 3). Unfortunately, the Gaia RVS magnitude limit is three magnitudes brigther than that of astrometry and photometry. For this reason, the contribution of ground-based spectroscopic surveys is crucial in the two last observational thresholds mentioned above (radial velocity and detailed stellar chemistry). Galactic spectroscopic surveys will complement Gaia data to permit the high-dimensional view of the Milky Way, necessary to disentangle its evolution.

The general picture of on-going and planned spectroscopic surveys is presented in Fig. 2 by locating each project in a space formed by three axis: targeted galactic populations, spectral resolution and probed magnitude range. As the spectral resolution is usually fixed for a particular survey, each project appears as a plane in the above figure. The following sections will briefly descrive the characteristics of each survey, dividing them in low-resolution and high-resolution surveys. The projects for next generation halo surveys will be also mentioned in a separate section.

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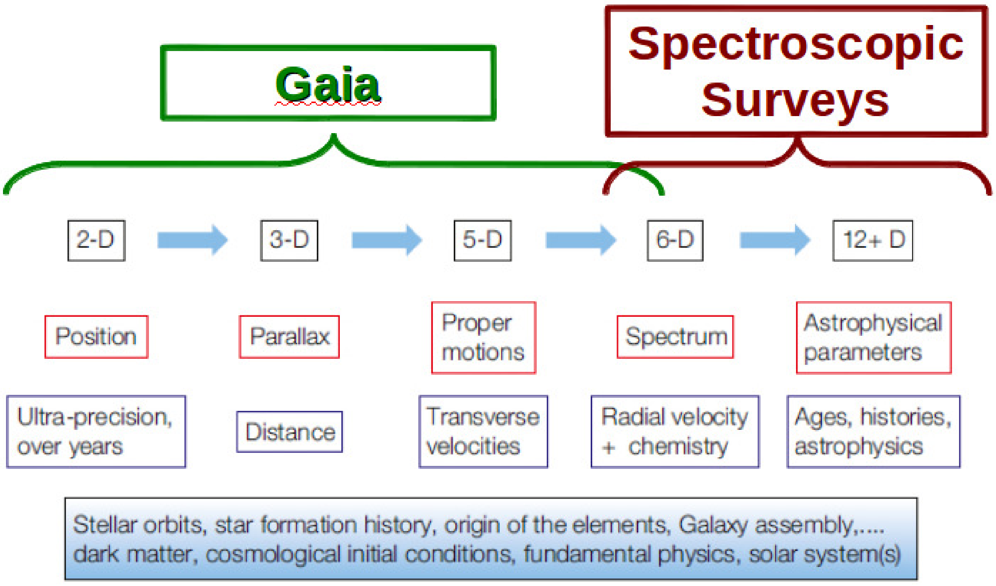

Fig. 1. Dimensionality of data and parameter spaces for Galactic Archaeology studies. The contribution of the Gaia mission and that of ground-based spectroscopic surveys is specified at the top of the picture. This figure has been taken and modified from Gilmore et al. (2012).

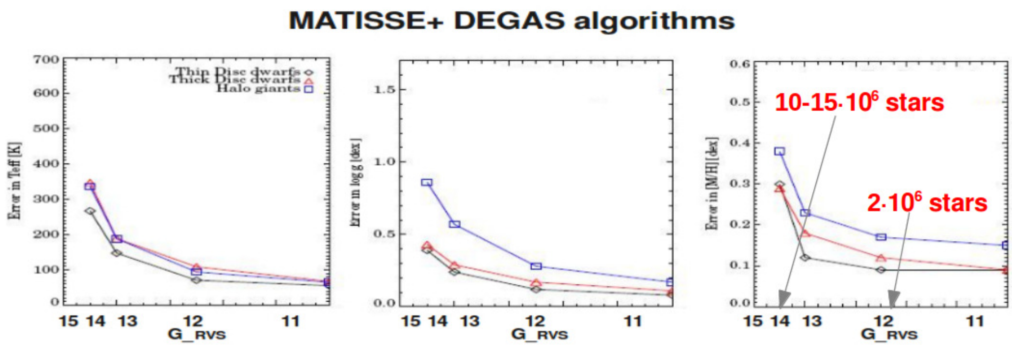

Fig. 2. Error estimations for the atmospheric parameter determinations from the Gaia/RVS spectra. The errors are taken from the results of the analysis algorithms MATISSE ((Recio-Blanco et al. 2006)) and DEGAS ((Kordopatis et al. 2011)) integrated in the analysis pipeline of the Gaia Data Processing and Analysis Consortium

2 Low-resolution surveys

The Sloan Digital Sky Survey (SDSS, (Eisenstein et al. 2011)) project, in its series of operations (SDSS I, II and III) has publised about 250K spectra from the Sloan Extension for Galactic Understanding and Exploration (SEGUE). SDSS spectra have provided only limited information on the structures revealed in the SDSS photometry, but they produced radial velocities measurements to ∼10-20 km/s and [Fe/H] abundances to 0.25 dex for stars with $14 < r < 19$ mag. SDSS3 stellar spectroscopy continues, at ∼ 5 stars/sq deg, as this project does not observe the Galactic thin disc and the Bulge. The spectral resolution of SEGUE data is R=1800. SEGUE has already provided several scientific results. One of the most recent ones regards the metallicity distribution of the disc ((Schlesinger et al. 2011)).

The RAdial Velocity Experiment (RAVE, (Steinmetz et al. 2009), (Steinmetz et al. 2006)) is obtaining accurate radial velocities (< 5 km/s) and global metallicities for $\sim 5{\cdot}10^5$ stars with I<13. RAVE spectra have a resolution of R=7500 and are centered in infrared CaII triplet, sharing the same spectral window of the future Gaia/RVS data. This project, due to its rather bright magnitude limit is probing essentially the galactic discs populations. More than thirty papers have already been published up to date based to the RAVE survey and

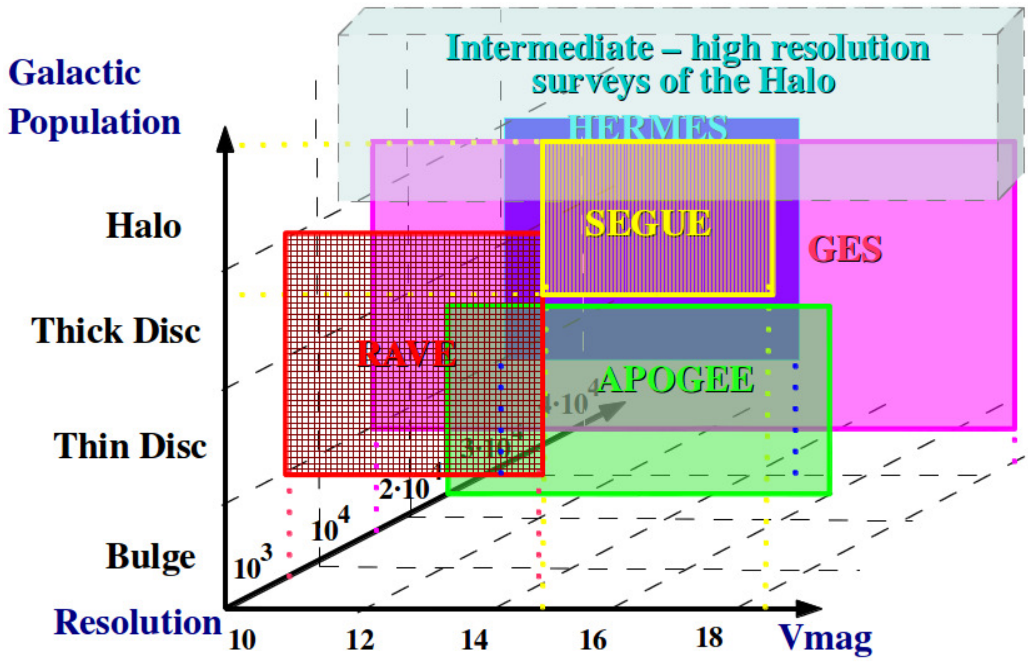

Fig. 3. General picture of on-going and planned spectroscopic surveys in a space formed by three axis: targeted galactic populations, spectral resolution and probed magnitude range.

the fourth data release is expected by the end of 2012.

Finally, the AAOmega Exploration of Galactic Structure (AEGIS) survey started end of 2011 will observe, during 45 nights accross 3 semesters, Thick Disc, Thin Disc and Halo substructures, plus extreme metal poor candidates. The spectral coverage includes a blue arm (370-570nm) at R$\sim$3 000 and a red arm (830-885nm) at R$\sim$11 000.

3 Intermediate and high-resolution surveys

Contrary to the low-resolution surveys started in the last decade, the recent intermediate and high resolution projects can provide the individual chemical abundances of the targeted stars. The chemical tagging approach ((Freeman & Bland-Hawthorn 2002)) can be used to associate stars to common ancient star-forming aggregates with similar abundance patterns or to to disrupting satellites.

The SDSS Apache Point Observatory Galactic Evolution Experiment (APOGEE, (Eisenstein et al. 2011)) is obtaining high-resolution (R=30 000) high signal-to-noise, H-band (1.51μm $< \lambda <$ 1.70μm) spectra of 10^5 evolved, late-type stars. APOGEE will provide individual abundances for about 15 elements per star. Thanks to its infra-red observations, the APOGEE survey can probe Bulge and Thin Disc regions that are unaccesible to optical surveys. The spectrum analysis of the first APOGEE data are already producing the first scientific results ((Nidever et al. 2012)).

The Gaia-ESO Survey (GES, (Gilmore et al. 2012)) is a public spectroscopic survey began in January 2012 that will obtain high quality spectroscopy of some 100 000 Milky Way stars, in the field and open clusters, down to magnitude 19. GES employs the VLT FLAMES instrument to observe well-defined samples, based on current VISTA photometry for field stars. The survey will quantify the kinematic-multi-element abundance distribution functions of the Bulge, the Thick and the Thin Discs and the Halo stellar components, as well as a significant sample of 100 open star clusters, covering all accessible cluster ages and stellar masses. GIRAFFE spectra, with two settings (HR10 and HR21), will be obtained for statistically significant samples of stars in all major stellar populations. These will be supplemented by UVES spectra (R$\sim$40 0000) of an unbiased sample of G-stars within 2 kpc of the Sun, providing the abundance distribution function for the local Thin Disc and Thick Disc. As shown in Fig. 4, the implication of the French comunity in the Gaia-ESO survey is very strong and it concerns several key working groups and one person of the Steering Committee. This is also reflected in the GES data-flow scheeme (Fig. 5), where the working groups with a French coordination or strong French contribution are highlighted. More than 5 000 field stars and 7 open clusters have already been observed. The first semester data release will appear at the end of this year, including reduced 1-D spectra, associated variance spectra, radial velocities and variability information. In June 2013 is expected the firs advanced anual release with astrophysical parameters, element abundances, complementary data as appropriate, and uncertainties.

Finally, to begin observations in 2013, the Galactic Archaeology with AAO HERMES (GALAH) survey aims to obtain precision multi-element abundances for a milion stars with V<14, from high signal-to-noise, R=30 000 spectra. The HERMES-GALAH project will explore a chemical space of abundances of about 25 elements, with a dimensionality of 8 to 9. Most disc stars should inhabit a sub-region of this space.

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Target selection, Calibrators, FPOSS & OBs			
Open Clusters: membership analysis auxiliary data target selection	**WG1,2,4:** Alicante, Armagh, Torino, ETH, MSSL Vienna, MPIA, Palermo, Barcelona, Granada Bologna, Madrid (CAB), ESO, ESA, Geneva, AIP Herts, Arcetri, Uppsala, ROBelg, Leicester, Indiana, Graz, Lisbon, Grenoble Keele, IAC, Athens, Exeter, Birmingham Padova, Catania, Porto, Nice, ZAH	6	E. Alfaro (Sp) E. Paunzen (At) A. Bragaglia (I)
Galactic Plane & Field Selection	**WG3:** Camb, ZAH, ANU, MPIA, Paris, RUG, AIP, MSSL, Strasbourg, Oxford	4.5	C. Babusiaux (Fr)
Calibrators & Standards	**WG5:** AAO, AIP, Uppsala, Camb, Bordeaux Antwerp, Bologna, Madrid, Paris, MPA, ANU	1.5	E. Pancino (I)
OB/FPOSS generation: Field Survey Cluster Survey	**WG6:** Paris, ESO, Camb, Lund, AIP, ZAH Arcetri, Bologna, Catania, Padova, Palermo, IAC Exeter, Alicante, CAUP, ESO	2 2.5	T. Bensby (Se) E. Flaccomio (I)
Spectrum Extraction Pipelines			
Pipeline Raw Data: GIRAFFE Reduction UVES Reduction	**WG7:** CASU, Keele Arcetri	1 2	M. Irwin (UK) L. Morbidelli (I)
Radial Velocities	**WG8:** Camb, Keele, Arcetri, Antwerp, ZAH	2	Camb/Keele/Arcetri
Discrete Classification	**WG9:** Camb, MPIA, IAC, Madrid, MSSL, Porto, ZAH	2.5	S. Koposov (UK)
Spectrum analyses			
FGK Stars: GIRAFFE incl QC	**WG10:** Paris, MPA, Lund, Uppsala, Nice, Bordeaux Arcetri, Bologna, Liège, Geneva, Alicante Nice, ESO, Porto, ZAH, Arcetri, Naples Catania, Padova, Kaypten, IAC, ANU	17	A. Recio-Blanco (Fr) & C. Allende Prieto (Sp)
FGK Stars: UVES incl QC	**WG11:** Paris, MPA, Lund, Uppsala, Nice, Vilnius Arcetri, ANU, Bologna, AIP, Indiana, UCM, Herts Groningen, ESO, Naples, Porto, Catania, Alicante Catania, Padova, Liege, Bordeaux, ZAH, IAC, Chile	14	A. Korn (Se) & R. Smiljanic (ESO)
WG10/11 Interface	Recio-Blanco, Allende Prieto, Pasquini, Smiljanic, Korn, Hill	0.5	
Pre-Main-Sequence stars incl QC	**WG12:** Arcetri, Catania, IAA Naples, Palermo, ETH, CAUP Keele, Exeter, Madrid (UCM, CAB)	8	A. Lanzafame (I)
OBA Stars incl QC	**WG13:** Liege, RO Belg, AIP, OMA, Madrid, Paris Alicante, Uppsala, MPIA, ZAH, Leuven, Herts Calar Alto, Nice, IAA, Armagh	2	R. Blomme (Be)
Unusual Objects	**WG14:** SRON, Nijmegen, Warwick, Leuven	1	tbc
Survey Parameter Homogenisation	**WG15: & WG5:** all spectrum analysis groups	4	P. Francois (Fr)

Fig. 4. Management structure of the Gaia-ESO Survey. The French working group coordinators and the Steering Committee member are marked in pink.

4 Halo spectroscopic surveys

Probing the Galactic Halo with high enough statistics faces the obstacle of the low stellar density of the targeted fields. To tackle this problem, the used spectroscopic facilities need to have access to a wide field of view. For this reason, most of the on-going projects are not optimized for the Halo exploration, where most of the fossil substructure of Galactic formation is still hidden. Fortunately, several starting and planned surveys can change this situation.

The LAMOST survey is in transition from commissioning to full operations. It operates at a resolution of R$\sim$1700, and will be able to observe very large numbers of Northern targets, including clusters, at intermediate magnitudes. It will provide radial velocities with a relatively low precision, but no element abundances.

In addition, several projects of multi-object spectrographs mounted in wide-field telecopes are today in a phase-A of study: the WHT Extreme Aperture Velocity Explorer (WEAVE, proposed for the William Herchel Telescope in La Palma); the 4-meter Multi-Object Spectroscopic Telescope (4-MOST, proposed for the NTT or VISTA) and the Multi-Object Optical and Near-infrared Spectrograph (MOONS, proposed for the Very Large Telescope).

5 Conclusions

Understanding how galaxies form and evolve in a ΛCDM universe needs both the observation of objects at high redshifts and the detailed examination of our Galaxy. The strenght of Galactic Archaeology relies in the possibility of analysing key physical processes that can not be accessed through the study of faint, poorly

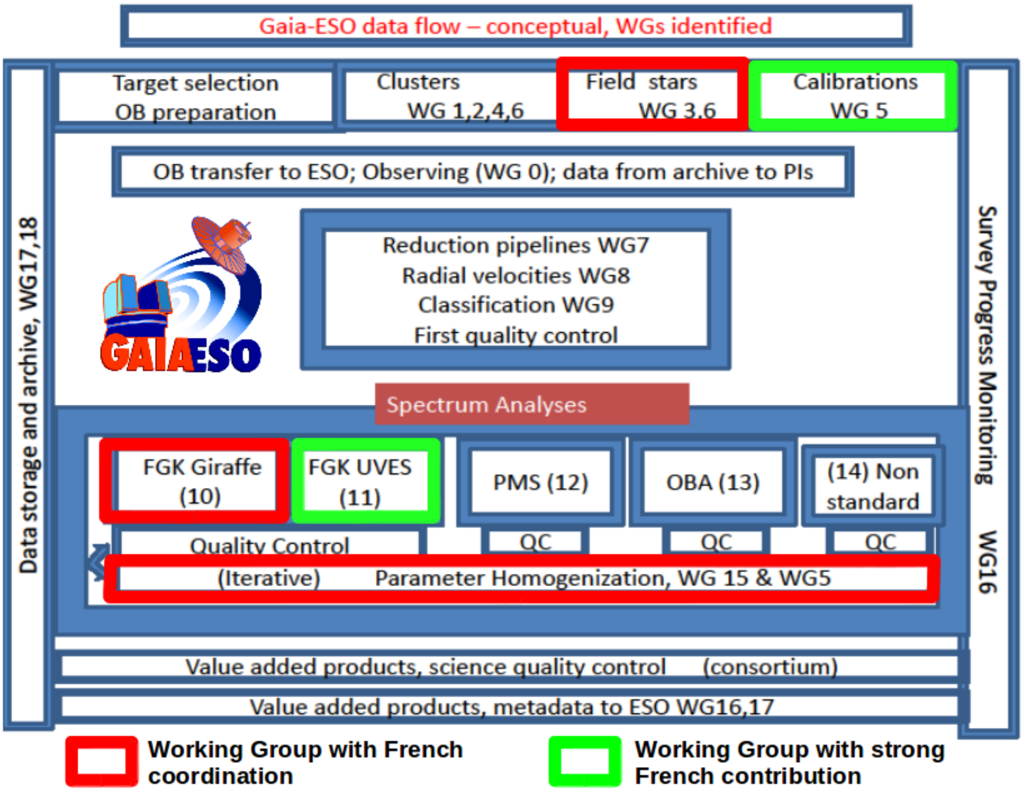

Fig. 5. Data flow of the Gaia-ESO Survey. The numbers of the corresponding working groups are indicated. The working groups with French coordination or important French contributions are highlighted.

resolved objects. In this sense, the contribution of the on going and planned spectroscopic surveys of the Milky Way is crucial for the fulfilment of the near-field cosmolgy approach.

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