Report on the GREAT-ESF supported meeting

The Milky Way: Stars, Gas, Dust and Magnetic Fields in 3D

held at the
Haus der Astronomie, Max Planck Institute for Astronomy, Heidelberg
18-20 June 2012

The presentation slides are available from the meeting website
http://www.astra-gaia.eu/meetings/

Context and summary of the meeting

By combining the observational data from the Planck foreground maps with Gaia distances and stellar extinction measurements, a 3D map of the dust distribution within a few kpc can in principle be constructed. Combining this with radio observations of molecular and neutral hydrogen clouds can ultimately provide a picture of the distribution of those non-stellar components in our Galaxy that play a major role in, and reflect the consequences of, star formation and evolution. This is traced further through stellar chemical composition analysis, as provided in part by the Gaia data and in part by ground-based data (e.g. the Gaia-ESO spectroscopic survey). This workshop brought together scientists with expertise in different types of data - optical, infrared, radio - and in different components of the Galaxy - stars, dust, magnetic fields - in order to investigate scientific and technical ways in which we can fruitfully combine these data sets for a better understanding of the Milky Way.

Scientific Organising Committee

Paul Alexander, Cavendish Laboratory, Cambridge, UK
Coryn Bailer-Jones, Max Planck Institute for Astronomy, Heidelberg, Germany *(co-chair)*
Rosine Lallement, Observatoire de Paris, France
Floor van Leeuwen, Institute of Astronomy, Cambridge, UK
Steven Newhouse, European Grid Infrastructure, The Netherlands
Nikolai Piskunov, Uppsala, Sweden
Franck Le Petit, Observatoire de Paris, France
Nicholas Walton, Institute of Astronomy, Cambridge, UK *(co-chair)*
Patricia Whitelock, South African Astronomical Observatory, South Africa

Summary of the scientific content of presentations/discussions

Walton. Overview of the Gaia mission: science goals, capabilities, data processing, data release schedule. Summary of the project ASTRA (Advanced Systems Transforming Research Astronomy), of which this meeting is essentially the kick-off.

Boulanger. Overview of the Planck mission. For a physical interpretation, data need to be decomposed in terms of ISM components. Gas-dust correlation, HI-H_2 transition, disk-halo connection, dust polarization (magnetized ISM).

Rejkuba. VVV survey, using Vista to study variable stars in the Galactic bulge. Looking at red clump stars.

Farnhill (given by Drew). Exploring the outer Galaxy with IPHAS. One no-going project is to identify (reddened) A/F stars to then measure the rotation curve via RVs (out to about 10 kpc from the Sun). Another project is density mapping through star counts.

Hanson. 3D extinction mapping with a Bayesian method, using SDSS+UKIDSS photometry. Inference of effective temperature and line-of-sight extinction on a star-by-star basis.

Worley. AMBRE project to determine abundances and effective temperatures from ESO archive spectra (FEROS, UVES, HARPS), using the MATISSE algorithm. Can then get extinction from comparison with theoretical colours and using Hipparcos. Metallicity distribution for local neighbourhood stars (mostly dwarfs) from FEROS. Rix pointed out that doing a population study with archive data must be difficult, as there is no well-defined selection function.

Nieva. Measuring cosmic abundances using late O and early B-type stars, in particular alpha elements. This constrains both present-day and birth-place abundances. By measuring products of CNO-burning, we get constraints on stellar evolution.

Gilmore. Review of stellar populations and the evolution of the Milky Way. Cosmology not consistent: formation of pure disk a problem. No chemical evolution seen over last 8 Gyr. Why? We see abundance distributions much narrower than they ought to be. We see no young globular clusters in the MW, but we do in the MW satellites. Why? Halo MDF is consistent with in-situ monolithic formation, which seems to contradict ΛCDM.

Magrini. Open clusters and what they tell us about Galaxy evolution. Powerful tool for chemical evolution. Bimodal shape in metallicity gradient and a possible flattening with time of the inner gradient. Combining data from Gaia and Gaia-ESO surveys. van Leeuwen: we must be careful about inferring ages and distances for clusters with just one star (e.g. Hipparcos showed that some such stars were not even cluster members). What selection/obscuration biases are there in the open cluster sample?

Feltzing. Dwarfs in the solar neighbourhood. Edvardsson et al. 1993 showed that abundance trends are tight. Individual element abundances from a newer sample of 700 stars from Bensby et al. (in preparation). [Ti/Fe] seems to be an age proxy, although with a large uncertainty. Role of radial migration.

Girardi. Using the infrared for stellar population studies. Good IR facilities are now or soon will be available, not just wide-field surveys, but also high resolution imaging (adaptive optics, JWST) and high resolution spectroscopy (APOGEE, NIRSPEC). 2MASS studies of the LMC and SMC. PHAT: HST survey of M31 to perform detailed stellar population studies. Surveys confirm smooth - but not featureless - morphology of old (>1 Gyr) populations.

Pasetto. Producing synthetic CMDs for N-body simulations, e.g. for modelling Gaia data. Goal is a fast code for large number of stars and parameters.

Bonifacio. Metal-weak tail of the Galactic halo: the first generation stars (< 0.8 Msol). X-shooter discovery of lowest metallicity star yet known. Theory of Bromm & Lob said it should not be able to form (due to lack of carbon).

Gibson. Simulated galaxies and real galaxies often look quite different. Why? Disks modelled by MaGICC code are *not* structurally two-component disks, but they do show discontinuities. So this might be consistent with the recent work of Bovy et al., which suggests there is no distinct thick disk.

Steinacker. A technique to get 3D structure from (2D) images, used to probe molecular cloud cores (star progenitors). 3D challenging, as you need a lot more parameters (so more data/constraints), and it's much more time consuming. E.g. 3D modelling of one core (L183) showed that grain size larger than assumed, explaining observed "coreshine" (light scattering) at 3.6µm. Idea is to build a parametrized model and solve using data at different wavelengths (which probe to different depths of the structure).

Dubernet. Generation and provision of atomic and molecular data. VAMDC consortium of 21 partners. An overview of what tools there are and what they can do. System to be made publicly available to any producers and users from end June 2012.

Sipos. European Grid Infrastructure (EGI): network of resources, including, e.g., CPU, storage, data, which can be accessed by users external to the resource providers. Currently comprises over 300 sites (270 000 CPUs), mostly but not only in Europe. Main users so far (94% of CPU time) are those processing LHC data.

van Leeuwen. Organizing and accessing data streams in the context of the ASTRA proposal. Ideas coming out of work done in Gaia-DPAC CU5. Demonstration of interactive data interrogation/plotting tool (written in Java using NetBeans) on Hipparcos catalogue, supplemented with cross-matched photometry. It's primarily a data viewing and selection system: selected data can then be exported for statistical analysis.

Haverkorn. Magnetic fields using radio. Upcoming facilities: LOFAR, ASKAP-POSSUM, SKA. Polarization (Faraday rotation). Many different studies use essentially the same data to come up with quite different best-fitting models of the Galactic magnetic field. This is partly due to confusion from small scale structure. Can use polarized pulsars to measure magnetic field strength in ISM, as the latter delays the radio pulses (20 000 polarized pulsars expected with SKA).

Penades Ordaz. Advantages of using massive stars (spectroscopy) to study the ISM: numerous; easy to identify; distant to many kpc; numerous ISM and DIB lines. But it limits us to the disk, and there's not much information beyond 3-5 kpc.

Kerp. HI 21cm line. Most of Galaxy is optically thin. Probes both cold neutral medium (300 K, 5 cm^{-3}) and warm neutral medium (10 000 K, 0.1 cm^{-3}). It now seems as though the local hot bubble, an interpretation of ROSAT data, is actually an artefact from the interaction of the sun with the geomagnetic field. This means that HI data now agree better with X-ray observations of the ISM. (There is still a bubble, but not filled with 10^6 K gas.)

Beuther. MW structure using the ATLASGAS with the APEX telescope (875 μm). A stripe covering -1 to +1 deg in latitude from -60 to +60 deg longitude. This region also covered by Spitzer (GLIMPSE survey). First analysed density in 1 deg bins in longitude: cold gas density is enhanced towards Galactic centre, but star formation activity (GLIMPSE) not. Conclusion: reduced star formation efficiency towards the Galactic centre.

Drew. Galactic plane surveys: EGAPS (IPHAS, UVEX, VPHAS+). Mapping Halpha emission down to 20th magnitude. This helps to reduce T_{eff}-extinction degeneracy (Halpha is probably the best choice of a narrow filter for this, independent of its other uses). Merging/matching catalogues to do 3D extinction mapping.

Gerin. MHD (magneto-hydrodynamic) simulations of the ISM using a photon dissociation model, with the goal of coupling the chemical processes with MHD. Spectral line observations crucial. Diffuse ISM best studied in absorption. Selected molecular lines for studying H2 in diffuse ISM.

Marshall. Dust in the Galactic plane. Tracing dust temperature and density in spiral arms using H1. Tracing Galactic extinction using Besancon Galaxy model. Extinction vs. distance, as a way of inferring distances. 3D extinction mapping using Hipparcos, and later with Gaia. But 3D stellar maps so derived affected by extinction. Gamma rays produced by cosmic rays impacting ISM (inverse Compton scattering) also provide a probe. Planck and Herschel reveal cold ISM. Gaia gives distances. Must extend Galactic studies to the plane.

Sale. Improved 3D extinction mapping using hierarchical Bayes. Nuisance parameters (stellar temperature, metallicity etc), on which data are dependent but are not of immediate interest. Adopt prior including the IMF, stellar density distribution and dependence of extinction on distance, A(d). Grid the sky. Combine data (photometry, spectroscopy, astrometry). Infer posterior PDF of A(d), for different lines of sights. Then take into account correlation of dust in adjacent lines of sight: gives smoother 3D map, of course. Ideally look at variation of extinction law (R) along the line of sight.

Lallement. Determining extinction using interstellar lines and diffuse bands in cool star spectra. Conclusion: this can be done, but need very good models of stars (i.e. stellar parameters to good accuracy); DIBs varying with reddening as you'd expect, but further work needed. Soon available: TAPAS (Transmissions of the atmosphere for astronomical data), a tool to infer the Earth's atmospheric transmission spectrum at the time of your observations from your site, using weather data.

Rix. Multi-wavelength approaches to MW studies: extinction is a major issue. We need A (l,b,d) to high precision. What are the (other) limiting issues in trying to do "precision" 3D dynamics? Selection biases and systematics become increasingly important in large samples, e.g. in the determination of $F_z(R)$. 5-10% photometric distances (best possible prior to Gaia, or for distant/faint stars) possible for stars of assumed logg, but only if we have known/zero extinction. Suggestion: rather than trying to do 3D modelling for whole MW, select a few fields in which we have (or acquire) good data, and apply the various methods (presented at this workshop) here. Assess strengths and weakness of each.

Walton. Tying this all together: towards ASTRA. Demonstration of workflows (using Taverna) for spectral synthesis, as an example of ASTRA processing goals. Pilot studies defined to run on EGI infrastructure, to set up a virtual research community.

Results and impact of the event on the future directions of the field

The goal of this meeting was to bring together scientists from different parts of the astronomical research community: data or theory; different parts of the EM spectrum (and thus using very different instruments); different components of the Galaxy (stars, gas, dust, extinction, magnetic fields). As such, it represents an exploratory attempt to bring together a broad set of expertises to begin to think about how we can build self-consistent, 3D models of our Galaxy using new or upcoming large data sets, in particular Gaia. The meeting was a success simply from the point of view of bringing together these different communities and making each other aware of each others tools, data, progress and challenges. Being confronted with methods and ideas outside ones otherwise "usual" methods and ideas is always constructive in pushing science forwards.

In addition to this, it was clear from the discussions that participants picked up also on specific suggestions for their on-going work: problems to look out for, ideas to test, extra data to integrate, new tools to try out.

Already discussed at this workshop were the next steps on possible meetings and collaboration, both on a large scale, but also on a one-to-one level.

An important outcome of this meeting, both during the meeting itself and in preparation for it, was the decision to resubmit our highly-ranked, but ultimately unsuccessful, EU FP7 proposal "Advanced Systems Transforming Research for Astronomy" (ASTRA). The ASTRA project already exists, but only in terms of ideas and wishes, not in terms of concrete work and funding. The primary goal of ASTRA is to "reveal the 3-D structure of the Milky Way", in order to gain better understanding of the origin and evolution of our galaxy. Our current partial knowledge of the 3-D structure of the Milky Way, and the relationship between the 3-D distributions of the stars, gas, and magnetic fields, which shape the Milky Way, severely limit our current understanding of the structure, formation and evolution of the Galaxy. ASTRA will deliver a focussed research programme, with at its heart, solutions to fully leverage the wealth of new data and opportunities offered by the combined data from the Gaia mission, the Planck dust maps, and various sets of ground based observations, at optical, infrared and radio wavelengths. Ideas presented at the workshop fill feed directly into this, and several of the workshop participants will be co-applicants on the revised proposal.

Looking ahead, there was an exchange of ideas on how to analyse large data sets and how one might - and might not - combine different data sets in a useful way. Much has been promised, either implicitly or explicitly, about the enormous advances Gaia will provide in our knowledge of Galactic structure. Yet the Gaia data will not be perfect: It will still have noise, systematics, selection biases, source confusion etc. Some of these will be even more acute when we have such a large, precise set of data (as we become limited by systematics and selection effects, rather than random noise or sample size limitations). Data on the majority of the data (in terms of number of stars) will actually be quite “poor”, even though the number of stars with high quality astrometric data will far exceed what we currently have. This sense of a “reality check” of what Gaia can and cannot provide is important, as it will help focus efforts on exploiting what Gaia really can do well.

There was a general feeling that trying to map the entire Milky Way in 3D using all possible available data on all components is simply far too ambitious at this stage. What came out of the meeting was the feeling that we should probably focus on simpler projects at first, such as modelling just parts of the Galaxy, or limiting ourselves to a selection of data or components. This “bottom up” approach would complement the creation of a “top down” system into which such work can be integrated. ASTRA plans to integrated these by both building a system, and developing a number of pilot projects on which to test it.

Meeting participants

Surname	First name	Institute
Bailer-Jones	Coryn	MPIA, Heidelberg
Beuther	Henrik	MPIA, Heidelberg
Bonifacio	Piercarlo	Observatoire de Paris
Boulanger	Francois	IAS, U. Paris Sud
Butkevich	Alexey	TU Dresden
Caffu	Elisabetta	ZAH, U. Heidelberg
Davies	Melvyn	U. Lund
Drew	Janet	CAR/STRI, U. Hertfordshire
Dubernet	Marie-Lise	Observatoire de Paris
Eyer	Laurent	U. Geneva
Feast	Michael	U. Cape Town
Feltzing	Sofia	U. Lund
Font	Andreea	U. Birmingham
Gerin	Maryvonne	Observatoire de Paris
Gibson	Brad	U. Central Lancashire
Gilmore	Gerry	IoA, U. Cambridge
Girardi	Leo	INAF, Padova
Hanson	Richard	MPIA, Heidelberg
Haverkorn	Marijke	U. Nijmegen
Kalberla	Peter	U. Bonn
Kaltcheva	Nadia	U. Wisconsin Oshkosh
Kerp	Juergen	U. Bonn
Knude	Jens	NBI, U. Copenhagen
Lallement	Rosine	Observatoire de Paris
Magrini	Laura	INAF, Arcetri
Marshall	Douglas	IRAP, Toulouse
Nieva	Maria-Fernanda	U. Erlangen-Nuremberg
Pasetto	Stefano	MSSL, UCL, London
Penades Ordaz	Miguel	IAA-CSIC, Granada
Rejkuba	Marina	ESO, Garching
Rix	Hans-Walter	MPIA, Heidelberg
Sale	Stuart	U. Oxford
Sipos	Gergely	EGI.eu, Amsterdam
Skoog	Chris	U. Lund
Steinacker	Juergen	U. Grenoble
Stoeckle	Gabriel	ZAH, U. Heidelberg
van Leeuwen	Floor	IoA, U. Cambridge
Vickers	John	ZAH, U. Heidelberg
Walton	Nic	IoA, U. Cambridge
Worley	Clare	Obs. de la Cote d'Azur

Advanced Systems Transforming Research Astronomy

Richer use of the Gaia data

The Milky Way: Stars, Gas, Dust and Magnetic Fields in 3D

Programme

Invited (in bold) talks - 30 mins (23+7 mins discussion)

Contributed talks - 20 mins (15+5 mins discussion)

Date/Time	Title	Speaker	Slides
Mon 18 Jun			
Session 1: Context and the Promise of Gaia (Chair: Bailer-Jones)			
14:00-14.10	**Welcome**	Coryn Bailer-Jones (MPIA, Heidelberg)	
14:10-15.00	**Introduction, Gaia and ASTRA**	Nicholas Walton (IoA, Cambridge)	
Session 2: The Milky Way in 3D: the picture now (Chair: Walton)			
15.00-15.30	**Planck and the Galactic Structure**	Francois Boulanger (IAS, U Paris Sud)	
15.30-15.50	The ESO public survey VVV: a new view of the Milky Way bulge	Marina Rejkuba (ESO)	
15.50-16.10	Exploring and exploiting IPHAS: Density mapping and the Galactic rotation curve	Hywel Farnhill (U Herts) [Presented by Janet Drew (U Herts)]	
16.10-16.40	*Coffee*		
16.40-17.00	3D Extinction Mapping	Richard Hanson (MPIA, Heidelberg)	
17.00-17.20	The AMBRE Project: Exploring the chemical and kinematic information in the ESO:FEROS archived spectra	Clare Worley (OCA, Nice)	
17.20-17.40	Present-day cosmic abundances in the solar neighbourhood and implications	Maria-Fernanda Nieva (Sternwarte, Bamberg)	
17.40-18.10	**The Evolution of the Milky Way**	Gerry Gilmore (IoA, Cambridge)	
Tues 19 Jun			
Session 3: The 3D chemo-kinematics of the Milky Way (Chair: Drew)			
09.00-09.30	**Open Clusters**	Laura Magrini (INAF-Arcetri)	
09.30-10.00	**Chemistry in the Disk**	Sofia Feltzing (Lund)	
10.00-10.30	**The IR view: Insights from M31 anf the Magellanic Clouds**	Leo Giradi (INAF-Padua)	
10.30-10.50	Synthetic CMD generator for N-body simulation: a novel technique to exploit Gaia photometric catalogue	Stefano Pasetto (MSSL, UCL)	
10.50-11.10	The metal-weak tail of the Galactic Halo	Piercarlo Bonifacio (Obs Paris)	
11.10-11.40	*Coffee*		
Session 4: Theoretical Challenges (Chair: van Leeuwen)			
11.40-12.10	**The Milky Way in 3-D, modelling challenges**	Brad Gibson (UCLan)	
12.10-12.30	Inverse radiative transfer to determine complex 3D structures from multi-wavelength images	Juergen Steinacker (Institut de Planetologie et d'Astrophysique de Grenoble/ MPIA, Heidelberg)	
12.30-12.50	*Workshop Photo*		
12.50-14.00	*Lunch*		
Session 5: New Opportunities from European IT and Data infrastructures (Chair: Le Petit)			
14.00-14.30	**New Advances in Atomic & Molecular Data Infrastructure**	Marie-Lise Dubernet (Obs Paris)	
14.30-15.00	**On-demand European Research Computing**	Gergely Sipos (EGI)	
15.00-15.30	**Gaia: Organising and Accessing the Multiple Data Streams**	Floor van Leeuwen (IoA, Cambridge)	
15.30-16.00	*Coffee*		
Session 6: The sub-mm/Radio view of the Milky Way (Chair: Feltzing)			

16.00-16.30	**Mapping Galactic Magnetic Fields**	Marijke Haverkorn (Radboud University, Nijmegen)	
16.30-16.50	Studying the ISM with large Galactic massive star spectroscopic surveys	Miguel Penades Ordaz (IAA-CSIC)	
16.50-17.10	The 3D structure of the Milky Way's neutral interstellar medium	Juergen Kerp (Universitaet Bonn)	
17.10-17.30	Milky Way Structure Derived from the 875um Galactic Plane Survey ATLASGAL	Henrik Beuther (MPIA, Heidelberg)	
19.30-22.30	***Workshop Dinner***	***Restaurant Thanner*** (http://thanner.net)	
Weds 20 Jun			
Session 7: Gas, Dust and Extinction in the Milky Way (Chair: Lallement)			
09.00-09.30	**Emission line surveys of the Milky Way**	Janet Drew (U Herts)	
09.30-10.00	**The Galactic ISM**	Maryvonne Gerin (Obs Paris)	
10.00-10.30	**Galactic Dust**	Douglas Marshall (IRAP, Toulouse)	
10.30-10.50	Improved 3D Extinction Mapping Using Hierarchical Bayesian Models	Stuart Sale (Oxford)	
10.50-11.20	*Coffee*		
Session 8: Novel techniques for 3D mapping and Workshop Summary (Chair: Bailer-Jones)			
11.20-11.40	Extracting interstellar lines and diffuse bands from cool star spectra: towards extinction proxies	Rosine Lallement (Obs Paris)	
11.40-12.10	**Combining Multi-Wavelength Data for the 3D Milky Way: a mere fashion, or a true goldmine?**	Hans-Walter Rix (MPIA, Heidelberg)	
12.10-12.40	**Towards ASTRA**	Nicholas Walton (IoA, Cambridge)	
12.40-13.00	**Discussion and Next Steps**	Led by Coryn Bailer-Jones (MPIA, Heidelberg	
13.00	**Meeting Close**		

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