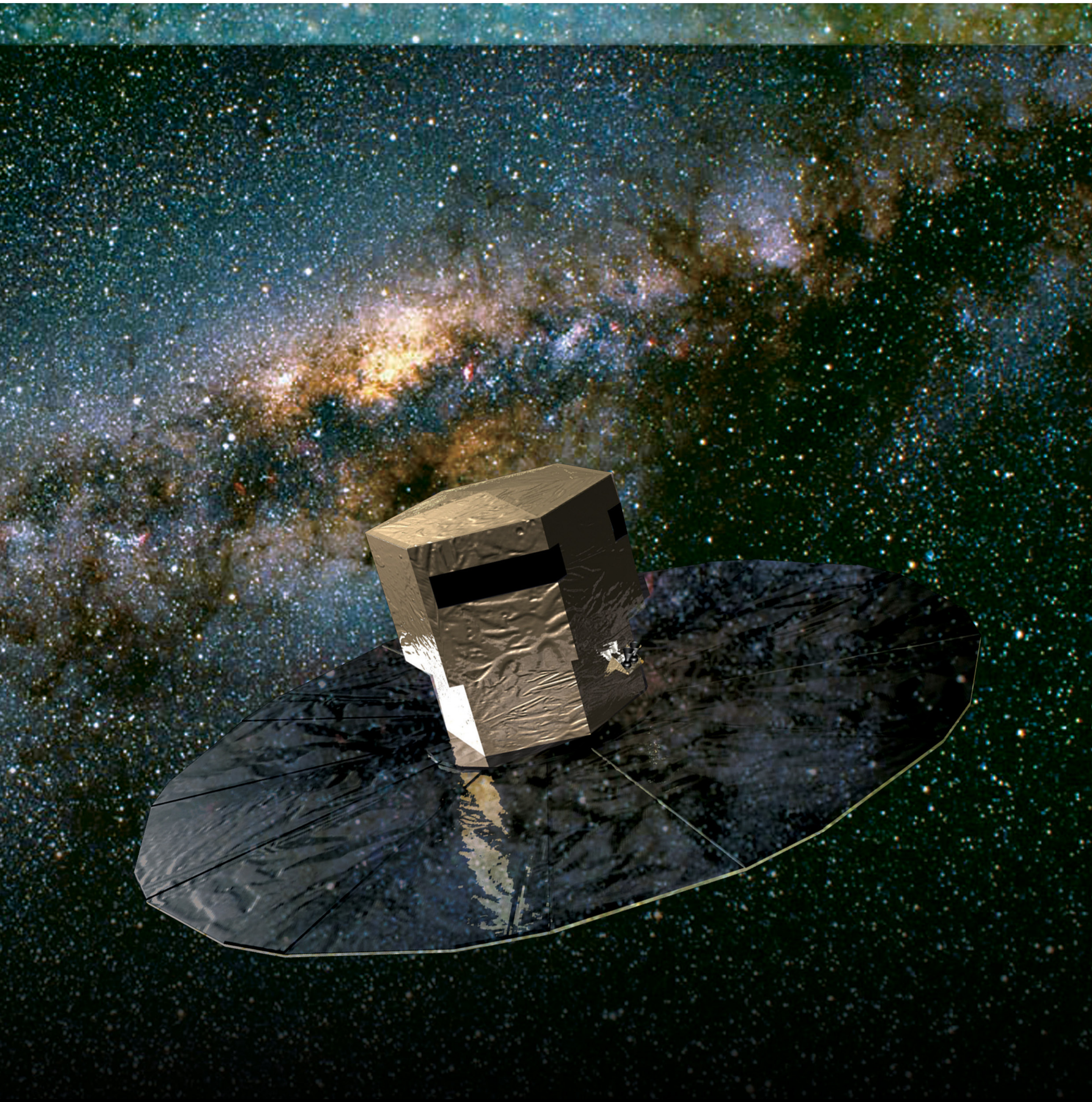
EUROPEAN SCIENCE FOUNDATION

SETTING SCIENCE AGENDAS FOR EUROPE

GREAT

GREAT: Gaia Research for European Astronomy Training



http://www.great-esf.eu

Introduction

The European Science Foundation (ESF) is an independent, non-governmental organisation, the members of which are 80 national funding agencies, research performing agencies, academies and learned societies from 30 countries.

The strength of ESF lies in the influential membership and in its ability to bring together the different domains of European science in order to meet the challenges of the future.

Since its establishment in 1974, ESF, which has its headquarters in Strasbourg with offices in Brussels and Ostend, has assembled a host of organisations that span all disciplines of science, to create a common platform for cross-border cooperation in Europe. ESF is dedicated to promote collaboration in scientific research, funding of research and science policy across Europe. Through its activities and instruments ESF has made major contributions to science in a global context. The ESF covers the following scientific domains:

- **Humanities**
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- **Physical and Engineering Sciences**
- **Social Sciences**
- **Marine Sciences**
- **Nuclear Physics**
- **Polar Sciences**
- **Radio Astronomy Frequencies**
- **Space Sciences**

The front page displays an artist's impression of the Gaia Spacecraft. Credit: ESA

The next ESA 'Cornerstone' mission Gaia is scheduled for launch in late 2012. It is designed to map over one billion stars with three instruments to collect astrometric, photometric and spectroscopic data on stars in the Milky Way and in galaxies belonging to the Local Group, distant galaxies, quasars and solar system objects. Gaia builds on the expertise established in Europe through the successful ESA Hipparcos mission. A broad community of nearly 400 European scientists and engineers are working together to prepare and carry out the extremely challenging mission data processing.

The overall objective of GREAT is to prepare the wider community for the science exploitation of the Gaia mission by supporting a science-oriented network which will address the key issues in which Gaia will have a major impact. This network will fund community training events, workshops and major conferences, proceedings, grants for short and exchange visits, and outreach material. It will help build essential collaborative scientific cooperation across Europe and the wider world in turn delivering major advances in science around the main objectives of Gaia. Over 550 researchers in some 90 groups from 17 European countries and the European Space Agency (ESA), and covering all the science areas addressed by Gaia have committed to participating in this network. GREAT is a pan European science driven research infrastructure which will facilitate, through focused interaction on a European scale, the fullest exploitation of this ESA cornerstone astronomy mission, enabling the European astronomy community to provide answers to the key challenges in our understanding of the Galaxy and Universe.

For further details and to respond to GREAT funding calls, in any scientific area within the remit of the GREAT programme, visit the website at **http://www.great-esf.eu**

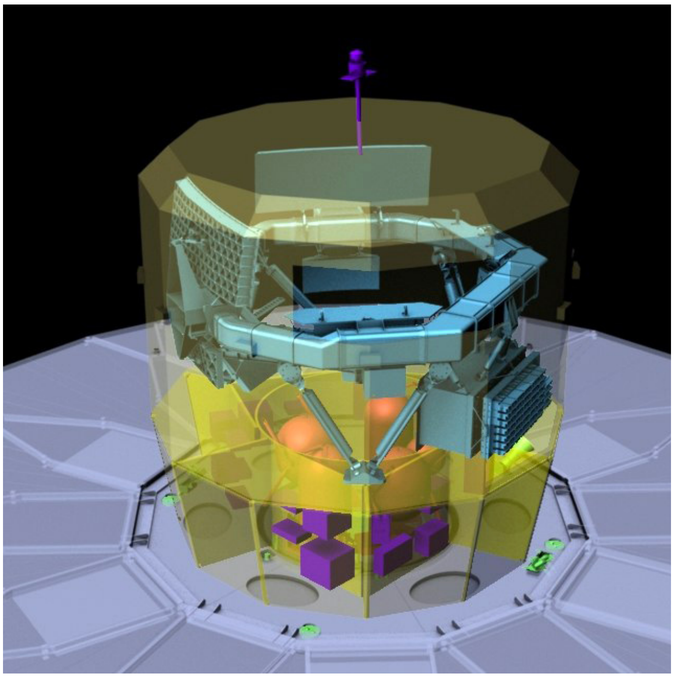
Understanding the formation and evolution of galaxies is a topic central to modern astrophysics. Observation of very distant galaxies allows us to probe the times when these systems were formed, but it is only our own Galaxy that provides a fossil record detailed enough to unravel its complete formation history. Current cosmological models envisage the formation of large galaxies through the merging of smaller structures. Deciphering the assembly history of our Galaxy requires a detailed mapping of the structure, dynamics, chemical composition, and age distribution of its stellar populations. Ideally one would like to "tag" individual stars to each of the progenitor building blocks.

The Gaia satellite (**http://www.rssd.esa.int/gaia**), a fully funded ESA 'Cornerstone' mission, scheduled for launch towards the end of 2012, will provide the required data in the form of distances (parallaxes), space velocities (proper motions and radial velocities) and astrophysical characterization (through multi-wavelength photometry) for more than one billion stars throughout most of the Galaxy.

Gaia builds on the expertise in astrometry established in Europe through the successful Hipparcos mission. This satellite produced a reference catalogue (published in 1997) of some 120,000 stars with an astrometric accuracy of ~1mas. Gaia will produce results which are orders of magnitudes better than those from Hipparcos. Gaia will map a billion stars, with astrometric accuracies of less than 10µas for the brighter stars. Thus, Gaia will allow for distance determinations out to 10kpc of better than 10%, thus direct measurements of the distance to stars throughout our Galaxy and beyond.

Gaia will have a major impact across all areas of astronomy and astrophysics, and at all scales.

- Mapping the Milky Way in three dimensions (parallaxes, positions, extinction)
- Galactic kinematics and disk heating (proper motions and radial velocities)
- Formation and evolution of the Milky Way
- Star formation and evolution (ages, star formation histories (SFH), initial mass functions (IMF) in the field and clusters)
- Stellar physics (classification, M, L, log g, T_{eff} [Fe/H], ages)
- Distance scale (geometric distances to Cepheids and RR Lyrae stars)
- Age of the Universe (galactic globular cluster diagrams, PLC-metallicity relation, distances, luminosities)
- Dark matter (stars as tracers of gravitational potential)
- Reference frame (quasars, absolute astrometry)
- Extrasolar planet detection (~M_J, astrometry and photometric transits)
- Fundamental physics (relativistic parameters $\gamma \sim 5x10^{-7}$, $\beta \sim 5x10^{-4}$)
- Solar system science (taxonomy, masses, orbits for $5x10^5$ bodies)



Artist's impression of the Gaia spacecraft. Several components are made transparent to reveal other sections. Credits: ESA/AOES Medialab

GREAT collaborations are thus essential in the following areas:

Origin, structure, and evolution of the Milky Way: unravelling the complexities of the Milky Way with its mix of stars and planets, gas, dust, radiation, dark matter and dark energy, is one of the major challenges for astrophysicists. These components show wide distributions: in age (when did the stars form?), in chemistry (how did the stars form?), in spatial location (reflecting the formation processes of the Galaxy, and subsequent history, in for instance accreting other galaxies), in their orbits (measuring the distribution of matter, dark matter). Measuring these distributions allows a mapping of formation, structure and evolution of the Galaxy and a better understanding of the sub structure of the Milky Way.

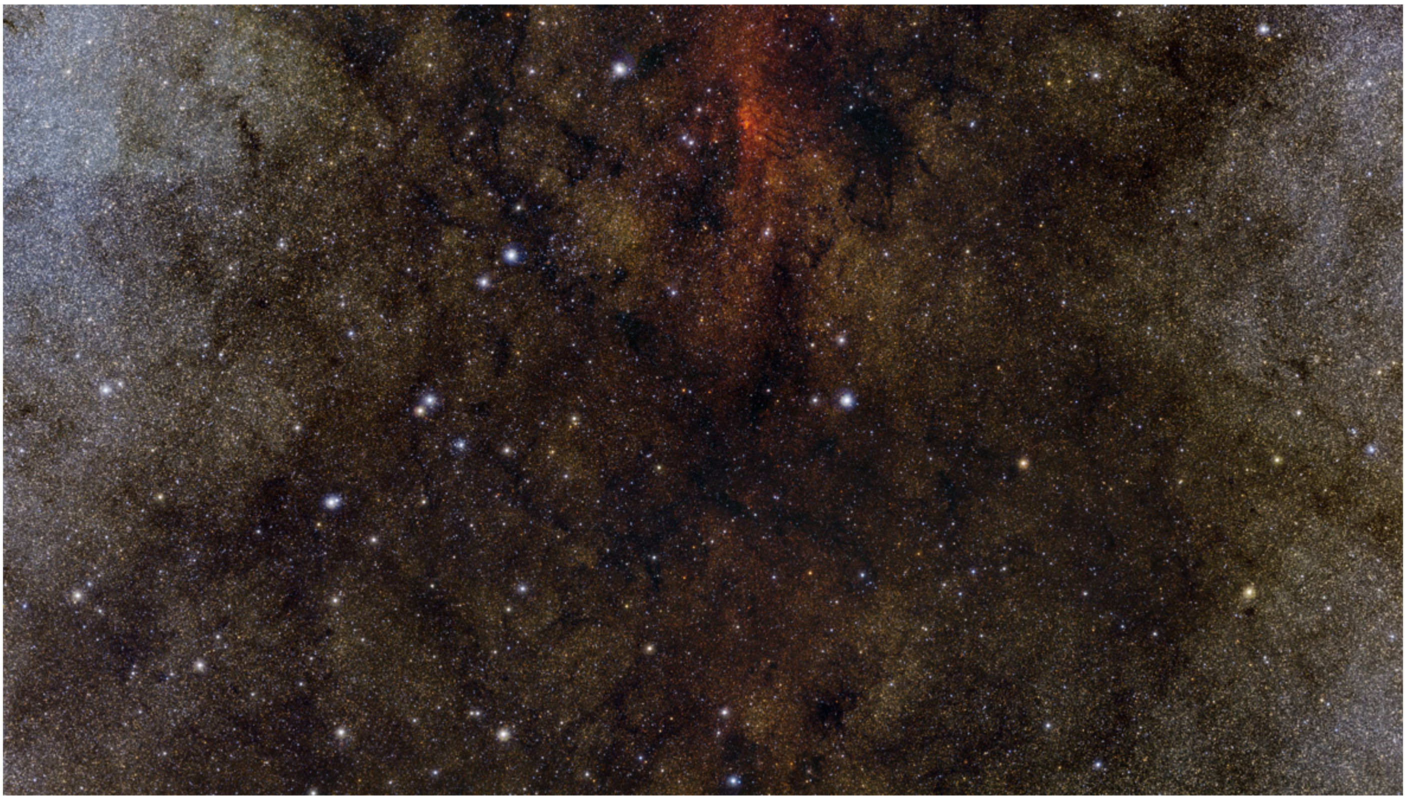
- The Galactic bulge
- The halo
- Large scale structure of the disk

Stellar astrophysics: Gaia will provide distances of unprecedented accuracy for all types of stars of all stellar populations, even those in the most rapid evolutionary phases which are very sparsely represented in the solar neighbourhood.

This extensive amount of data of extreme accuracy will stimulate a revolution in the exploration of stellar and Galactic formation and evolution, and the determination of the cosmic distance scale.

Galactic Dynamics is best traced by the motions of the Milky Way's stars and gas. Gaia will focus on stellar motions, which are key for uncovering the properties of the different stellar components of our Galaxy such as the size, mass, density of the thin and thick disk. Galactic dynamics are an excellent means of deriving the detailed mass distribution of the Milky Way and of constraining the distribution and amount of dark matter. Dynamics are also a vital tool for uncovering stellar streams in phase space and for finding signatures of ancient accretion events.

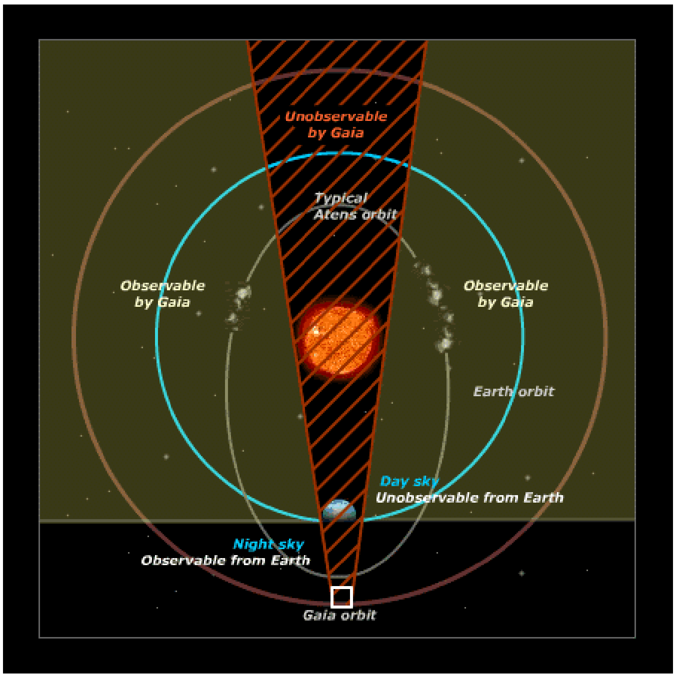
Galactic Archaeology uses the stellar fossil record to trace the evolutionary history of our Milky Way and its different components. Chemical tagging of individual stars, combined with their kinematics, is vital for understanding the assembly history of our Galaxy, for uncovering the dominant modes of star formation and the importance of different nucleosynthesis processes, for identifying streams of accreted satellites and constraining number, times, and importance of accretion events, and to test cosmological models of galaxy evolution.



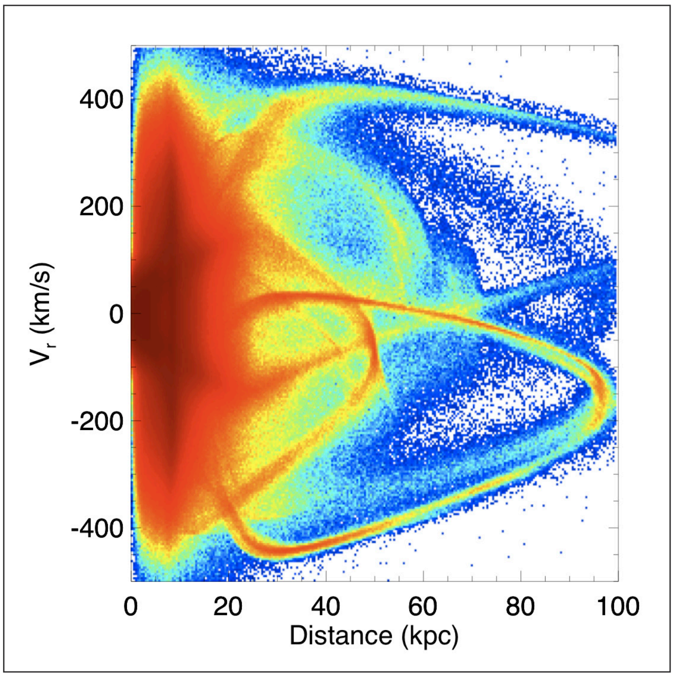
A remarkable ESO VISTA mosaic looking deep into the dusty heart of our own Milky Way galaxy in the constellation of Sagittarius (the Archer). About one million stars are revealed in this picture, most of them not seen in visible light pictures. Credits: ESO/VISTA. Acknowledgment: Cambridge Astronomical Survey Unit

Star Formation and evolution: The contribution of Gaia to star formation and evolution will be crucial and manifold, since it will provide key quantities such as luminosities and temperatures (and thus ages), extinction, as well as kinematic information for very large samples of stars in clusters and in the field. In the area of star formation (SF) this will allow studying in great detail two fundamental quantities: the IMF and SFH. The IMF is perhaps the most important outcome of the SF process and a detailed knowledge of its characteristics is required to understand Galaxy formation, chemical evolution of galaxies, the structure of the interstellar medium, and the nature of the baryonic dark matter. On the other hand, the SFH is also very critical, since it provides insights on the timescale to turn dense gas into stars within molecular clouds.

Specific issues include: does the IMF vary across different environments? Is there a lower limit to the IMF? Can a molecular cloud sustain or not the production of stars for a period of time comparable to its lifetime (>10Myr) and much longer than the typical free-fall time of dense gas (<1Myr)?. Presently there is no consensus on the prevalence of these two competing views. In the field of stellar evolution distances to open and globular clusters, along with kinematic information, will be fundamental not only to put tight constraints on evolutionary models of stars at all masses and in all evolutionary stages, but also to address several key topics such as cluster relative and absolute ages, the evolution of stellar properties, cluster internal dynamics and structure, cluster disruption processes, binary fraction.



Asteroids blind spot covered by Gaia. Credits: ESA & Medialab



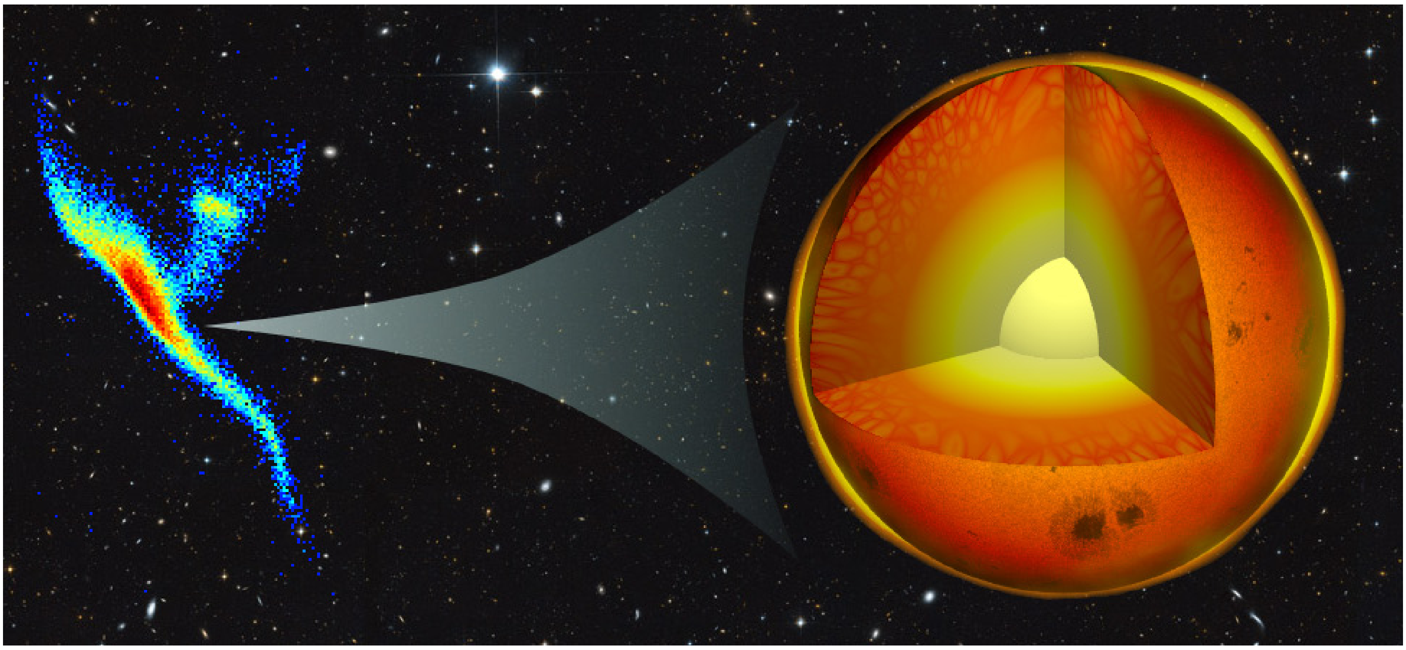
Disrupted dwarf galaxies in the Milky Way halo revealed by Gaia. Streams are revealed easily in the radial velocity - distance plane. Credits: Brown, Velazquez, Aguilar, University of Leiden

Fundamental physics and the Reference Frame: The unprecedented accuracy of Gaia observations and the complexity of relativistic effects appearing in those observations allow us to use Gaia data to test certain aspects of General Relativity, for example measurement of gravitational light deflection with a precision of about $5x10^{-7}$. Optimization of these complex and challenging tests requires close collaboration of several research groups in Europe.

Extrasolar planets: with its high astrometric accuracy, Gaia will be sensitive to perturbations on the orbits of stars by unseen companions. Thus tens of thousands of stars with Jupiter like planets orbiting them will be discovered. This will allow for detailed statistical studies, such as the impact of stellar environment (T, L, chemical abundance, single/binary) and how this correlates with the planets found in those systems.

Solar system: Gaia will have a major impact in surveying the asteroid population of our Solar system. This will be in finding new asteroids in previously 'difficult' locations, such as inside the Earth orbit and near to the Sun, but more importantly by determining the physical properties of many known asteroids in exquisite detail. This knowledge will enable us to better understand the conditions in the proto-Solar nebular out of which our Sun and solar system formed, based on the fossil signatures from the asteroids that we see now.

The IT Data Challenge from Gaia is an area which will stretch the community's ability to successfully integrate the new data with those from other large scale surveys. Efforts are underway to both access large compute grids to facilitate large computational modeling, for instance large scale simulations of Galactic Dynamics, and also to enable sophisticated workflow automation.



The interior structure of stars from accurate astrometry. Credit: A. Brown, University of Leiden

Facilitate, via community building, the development of optimum strategies for scientifically exploiting Gaia: arguably the most exciting European flagship mission of the coming decade. European astronomers need to be ready to make the best possible use of the scientific potential of Gaia to reap the highest possible returns and to maximize its impact. These will require a thorough knowledge of how to work with the astrometric, spectroscopic, and photometric data that Gaia will deliver. Also a readiness and ability to launch efficient follow-up observing campaigns where needed. This concerns specifically the spectroscopic follow-up needed for detailed abundance information, which may require specific planning for new wide-field multi-object spectrographs, covering the UV/blue, on 4 and 8 meter class telescopes. These issues all critically require European wide co-operation, the build-up of expert networks, the assembly of relevant tools. GREAT facilitates this by providing funds for travel, exchanges, workshops, and conferences which will provide the essential forums required to plan.

Develop multi-wavelength, multi-domain techniques, incorporating the information from Gaia, in addressing key science issues: In the initial phase of GREAT, a key objective will be to develop novel observational and modelling campaigns which, when combined with the data from Gaia, will be required to answer key science questions such as: the assembly history of the Milky Way, dark matter distribution in the local universe, mapping galactic structures using variable star populations, the formation of stars, star clusters, and so forth. GREAT will provide the European focus for research groups in these areas to formulate and carry out the significant observational and theoretical programmes required.

Transfer best practice in use of new computational techniques: this will include use of new Virtual Observatory techniques, and the development and deployment of high throughput statistical applications.

Foster collaboration between partners: a legacy of GREAT will be the enduring research collaborations built between research groups as a result of this network.

The GREAT programme is focussed around the following networking activities – where the community will be able to participate through open calls published by GREAT.

Conferences: major international meetings will be held during the ESF RNP. The conferences will be centred on “Grand Challenge’ themes, for example: ‘The fundamental cosmic distance scale’, ‘The formation of our Galaxy’, ‘Galactic Archaeology’.

Workshops – Science and Knowledge Transfer: these will address specific topics, bringing together leading experts to tackle the key issues. The format of the workshops will be such that, with typically 20-50 persons attending, intense interaction will be possible.

It is expected to organise some meetings with other groups working on large surveys, both in astronomy and other domains such as remote sensing, in order to identify synergies.

Training/ Schools: a range of training schools will occur during the GREAT programme, targeted at addressing key topics. Additionally, from year two, we plan to organise training schools which will directly result from preceding workshops, where the advances in knowledge gained at the workshops can be rapidly transferred to researchers through inclusion in the school programme.

Exchange Visits and GREAT Fellows: in order to seed the exchange of knowledge, short visits of noted experts will be supported. It is planned that outputs from these interactions will include the generation of proposals for future workshops and eventual training schools. Longer term visits for young researchers will be supported through GREAT Fellowships. These will allow for more intense knowledge transfer to these researchers. It is anticipated that GREAT Fellows would be involved in the organisation of a training school at the end of their fellowship, to further the spread of knowledge.

Outreach, Website and Networking: GREAT will produce accessible material for wider consumption addressing both the scientific community and the general public. These materials, will highlight the opportunities offered by participation in the GREAT network in advancing understanding of our Universe, noting successes achieved through the network, aiming to enthuse the community.

For further details, and to find out how you can benefit from the GREAT network, with support for your ideas, please visit the GREAT ESF RNP website at:
http://www.great-esf.eu

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For the latest information on this Research Networking Programme consult the ESF GREAT website:
www.esf.org/great

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