Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310011142

The Gaia astrometric survey

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Abstract. In its all-sky survey, the ESA global astrometry mission Gaia will perform high-precision astrometry and photometry for 1 billion stars down to $V = 20$ mag. The data collected in the Gaia catalogue, to be published by the end of the next decade, will likely revolutionize our understanding of many aspects of stellar and Galactic astrophysics. One of the relevant areas in which the Gaia observations will have great impact is the astrophysics of planetary systems. This summary focuses on a) the complex technical problems related to and challenges inherent in correctly modelling the signals of planetary systems present in measurements collected with a space-borne observatory poised to carry out precision astrometry at the micro-arcsecond (μas) level, and b) on the potential of Gaia μas astrometry for important contributions to the astrophysics of planetary systems.

1. Introduction

The Gaia all-sky survey, due to launch in Spring 2012, will monitor astrometrically, during its 5-yr nominal mission lifetime, all point sources (stars, asteroids, quasars, extragalactic supernovae, etc.) in the visual magnitude range $6 - 20$ mag, a huge database encompassing $\sim 10^9$ objects. Using the continuous scanning principle first adopted for Hipparcos, Gaia will determine the five basic astrometric parameters (two positional coordinates α and δ, two proper motion components μ_α and μ_δ, and the parallax ϖ) for all objects, with end-of-mission precision between 6 μas (at $V = 6$ mag) and 200 μas (at $V = 20$ mag).

Gaia astrometry, complemented by on-board spectrophotometry and (partial) radial velocity information, will have the precision necessary to quantify the early formation, and subsequent dynamical, chemical and star formation evolution of the Milky Way Galaxy. The broad range of crucial issues in astrophysics that can be addressed by the wealth of the Gaia data is summarized by Perryman *et al.* (2001). One of the relevant areas in which the Gaia observations will have great impact is the astrophysics of planetary systems (Casertano *et al.* 2008), in particular when seen as a complement to other techniques for planet detection and characterization (Sozzetti 2009).

2. Astrometric modelling of planetary systems

The problem of the correct determination of the astrometric orbits of planetary systems using Gaia data (highly non-linear orbital fitting procedures, with a large number of model parameters) will present many difficulties. For example, it will be necessary to assess the relative robustness and reliability of different procedures for orbital fits, together with a detailed understanding of the statistical properties of the uncertainties associated with the model parameters. For multiple systems, a trade-off will have to be found between accuracy in the determination of the mutual inclination angles between pairs of planetary orbits, single-measurement precision and redundancy in the number of observations with respect to the number of estimated model parameters. It will constitute a challenge to correctly identify signals with amplitude close to the measurement uncertainties, particularly in the presence of larger signals induced by other companions and/or sources of astrophysical noise of comparable magnitude. Finally, in cases of multiple-component systems where dynamical interactions are important (a situation experienced already by radial-velocity surveys), fully dynamical (Newtonian) fits involving an n-body code might have to be used to properly model the Gaia astrometric data and to ensure the short- and long-term stability of the solution (see Sozzetti 2005).

All the above issues could have a significant impact on Gaia's capability to detect and characterize planetary systems. For these reasons, within the pipeline of Coordination Unit 4 (object processing) of the Gaia Data Processing and Analysis Consortium (DPAC), in charge of the scientific processing of the Gaia data and production of the final Gaia catalogue to be released sometime in 2020, a Development Unit (DU) has been specifically devoted to the modelling of the astrometric signals produced by planetary systems. The DU is composed of several tasks, which implement multiple robust procedures for (single and multiple) astrometric orbit fitting (such as Markov Chain Monte Carlo and genetic algorithms) and the determination of the degree of dynamical stability of multiple-component systems.

3. The legacy of Gaia

Using Galaxy models, our current knowledge of exoplanet frequencies, and Gaia's estimated precision (~ 10 μas) on bright targets ($V < 13$), Casertano *et al.* (2008) have shown how Gaia's main strength will be its ability to measure astrometrically actual masses and orbital parameters for possibly thousands of giant planets, and to determine the degree of coplanarity in possibly hundreds of multiple-planet systems. Its useful horizon for planet detection (encompassing $\sim 3\times10^5$ stars) extends as far as the nearest star-forming regions (e.g. Taurus at $d \simeq 140$ pc) for systems with massive giant planets ($M_p \gtrsim 2-3\ M_{\rm J}$) on $1 < a < 4$ AU orbits around solar-type hosts, and out to $d \sim 30$ pc for Saturn-mass planets with similar orbital semi-major axes around late-type stars.

In summary, Gaia holds promise for crucial contributions to many aspects of planetary systems astrophysics, in combination with present-day and future extrasolar planet search programs. For example, the Gaia data, over the next decade, will allow us to a) significantly refine of our understanding of the statistical properties of extrasolar planets, b) carry out crucial tests of theoretical models of gas giant planet formation and migration, c) achieve key improvements in our comprehension of important aspects of the formation and dynamical evolution of multiple-planet systems, d) provide important contributions to the understanding of direct detections of giant extrasolar planets, and e) collect essential supplementary information for the optimization of the target lists of future observatories aiming at the direct detection and spectroscopic characterization of terrestrial, habitable planets in the vicinity of the Sun.

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https://doi.org/10.1017/S1743921310011142 Published online by Cambridge University Press