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Added-value interfaces to asteroid photometric and spectroscopic data in the Gaia database

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Abstract

We present two added-value interfaces (AVIs) for analyzing photometric and spectroscopic data observed by the Gaia satellite. The Gaia Added-Value Interface for Temporal Analysis (GAVITEA) is used to calculate an estimate for the spin state and shape of an asteroid from its photometric data, and the Gaia Added-Value Interface for Spectral Classification (GAVISC) provides tools to define the taxonomic type and surface absorption coefficient based on spectroscopic asteroid data. Computations are mainly carried out using well-known methods of asteroid data analysis but the AVIs also offer the possibility to test novel methods that are specifically developed for analyzing temporally sparse photometric data, typical for Gaia.
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Keywords: Gaia; Asteroid; Photometry; Spectroscopy; AVI

1. Introduction

The European Space Agency's (ESA) astrometric cornerstone mission Gaia was launched in December 2013 from ESA's space port in Kourou in the French Guiana (Gaia Collaboration et al., 2016b). After a commissioning phase it started its science operations in August 2014. The first data release (DR1) in September 2016 did not contain data on solar system objects (SSOs; Gaia Collaboration et al., 2016a), but the subsequent data releases, starting with DR2, will contain gradually more extensive and more complex data sets on SSOs. Although Gaia is expected to discover tens of thousands of new SSOs, Gaia's strength is in the extremely precise astrometry and photometry, and low-resolution spectroscopy of previously known SSOs. These data will enable numerous science investigations focusing on SSO properties such as asteroid shapes and spectral classification (Mignard et al., 2007). Gaia's original estimate for the cut-off magnitude is $G = 20.7$, where G is comparable to the Johnson-Cousins V magnitude (Jordi et al., 2010). This suggests that some hundreds of thousands of SSOs will be detected during the nominal 5-year Gaia survey (Mignard et al., 2007). The actual number will most likely be closer to half a million, because the limiting magnitude for transmission to ground is higher than expected.

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An extension to the nominal survey would not substantially increase the number of objects detected (unless the cut-off magnitude is increased) but will provide more frequent detection of each SSO. Studies concerning the performance of Gaia in terms of the number of observed asteroids and the quality of photometric and spectroscopic observations have been carried out by, for instance, Tanga and Mignard (2012) and Delbo et al. (2012).

In 2006, the Gaia Data Processing and Analysis Consortium (DPAC) was formed and it was selected to provide the ground segment of Gaia. The role of the Gaia DPAC is to provide the software and computational infrastructure needed for the scientific processing of the Gaia data and the production of the Gaia catalogue (e.g., Cellino et al. (2015), Santana-Ros et al. (2015) and Delbo et al. (2012)). DPAC is composed of about 450 expert scientists across Europe with well-defined responsibilities. It is noteworthy that the DPAC members have no privileged access to Gaia data apart from limited science verification studies that are published simultaneously (or near-simultaneously) with a particular data release. The lack of a proprietary period implies that everybody (that is, also a scientist outside DPAC) has identical opportunities to publish novel results based on the Gaia data as soon as it becomes public. To enable efficient data analysis and publication following each data release, the data-analysis software should be ready, well documented and in most cases close, if not integrated, to the Gaia database to allow rapid processing of large quantities of data. Software for analyses that require active expert interference should be available to the scientific community so that a large number of research groups can contribute to the data analysis.

The Gaia database, developed by DPAC, is limited to basic analysis, and there has been no opportunity for non-members to contribute to the analysis software. The Gaia Added-Value Interface (Gaia AVI) project was initiated by ESA in 2015 to establish a platform for added-value interfaces to Gaia data. Gaia AVIs allow users to analyze and visualize various types of Gaia data with tools that are not planned to be part of the Gaia database. In addition to the platform, called the Gaia added-value interface platform (GAVIP; http://gavip.esac.esa.int; Vagg et al., 2016), ESA also funded the development of three science AVIs. The programmatic goal for the science AVIs was to use them as case studies that would guide the development of GAVIP, so that it would evolve into flexible and user-friendly portal that would inspire other scientists to develop their own AVIs. In the future, Gaia AVIs can be provided by anyone with interest in further processing or analysis of Gaia data. Two of the science AVIs, developed by Space Systems Finland Ltd. and the University of Helsinki, are presented in this paper: Gaia Added Value Interface for Temporal Analysis (GAVITEA) is a tool for analyzing the temporal variation of observed asteroid brightness in order to gather information on their spin state and shape, and Gaia Added Value Interface for Spectral Classification (GAVISC) is a tool for analyzing asteroid spectra for defining their taxonomic type and surface absorption properties. The information provided by GAVITEA and GAVISC is complementary to that to be provided by DPAC. While DPAC will deliver information on asteroid shapes using tri-axial ellipsoids at the end of the Gaia mission, GAVITEA focuses on providing convex shape models with uncertainty estimates based on the limited data available earlier during the mission. Similarly, while DPAC will provide a new spectral classification for asteroids for which there exists low-resolution spectra obtained by Gaia, GAVISC will provide the most likely spectral type for each asteroid in the Bus-DeMeo (B-DM) classification. Virtually all the observed asteroids can be analyzed with GAVITEA and GAVISC.

An alert service worth mentioning, developed in the framework of DPAC, is the Gaia Follow-Up Network for Solar System Objects (Gaia-FUN-SSO, https://gaiafunsso.imcce.fr/) developed as part of task DU459 of the Coordination Unit 4 (Object processing) of DPAC. Astrometric alerts are submitted to the Gaia-FUN-SSO from the Solar System short-term processing pipeline (Tanga et al., 2016) and can be used to schedule complementary observations to aid the analysis of Gaia data. This is useful especially considering GAVITEA; defining the rotation period for an asteroid using Gaia data alone is extremely tedious, since not a single full rotation cycle is covered but only single brightness observations about one month apart. Even one longer (hours) continuous sequence of observations would be helpful to constrain the rotation period and reduce the computation time.

In what follows we first describe the asteroid data that will eventually be available through the Gaia database. Then we continue with a description of the GAVITEA and GAVISC algorithms and their theoretical foundations, and describe the implementation in the Gaia AVI framework. Finally, we present our validation approach and validation results, and finish with conclusions including some potential future developments.

2. Gaia data of asteroids

Gaia DPAC will publish Gaia data in the Gaia archive and submit astrometry of asteroid discoveries to the Minor Planet Center. Submission to other repositories, such as PDS and asteroid lightcurve databases, will likely be up to members of the community at large. The Gaia data releases (DR; intermediate and final) will contain astrometric, photometric and spectroscopic data on asteroids, although the exact schedule and contents for DRs have not yet been decided upon (apart from DR2 which has been released on April 25, 2018). ESA Cosmos web pages for the Gaia mission (https://www.cosmos.esa.int/web/-gaia) are, at the time of writing this paper, the best public constantly updated source of information on the schedule of the data releases and contents of the Gaia archive. The astrometric data—uncertainty at the milliarcsecond (mas) level or even below for the brightest, non-saturated

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