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Gaia view on young stellar clusters

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Abstract. Gaia mission is going to provide a revolution in astronomy. Topics ranging from solar system to reference frames can be tackled. Gaia DR1 has provided a huge step forward, yet in Gaia terms it is only a taster for Gaia DR2 and future releases. For studies of young stellar clusters Gaia will not only improve our understanding of the young stars themselves, but also through kinematical studies the cluster formation and evolution can be addressed.

Key words. Stars: pre-main sequence – Astrometry

1. Introduction

Gaia is an ESA cornerstone mission, which is building on the Hipparcos heritage. Although astrometry is the unique capability of Gaia, and the reason to go to space, the satellite has also photometric and spectroscopic instruments. While photometry and spectroscopy in principle could be done from the ground, astrometry has to be done outside the Earth's atmosphere to achieve the required accuracies. Nevertheless, it is worth noting that the extent of both the photometric and the spectroscopic survey is such, that in practise they would never be conducted from the ground.

Gaia satellite, including all its instruments, has been constructed by industry. The prime contractor was Astrium (now Airbus DS). This is exceptional in the ESA science programme as usually scientific instrumentation is provided by research groups in the institutes at the ESA member states. In the case of Gaia the scientific community is heavily involved in the data processing effort. A consortium, DPAC (Gaia Data Processing and Analysis Consortium), has been formally selected to the task. The ESA role in Gaia is in the areas of overall management and spacecraft operations.

Gaia was launched 19 December 2013 with Soyuz rocket from Kourou. It took about one month to reach its operational trajectory around the L2 point. The launch was followed up by a commissioning phase lasting half a year. A more detailed description of the satellite can be found in Gaia Collaboration et al. (2016b).

2. Operations

The routine phase of Gaia consists of scanning the sky with a pre-defined pattern for the nominal 5 year operational period. This scanning law has been constructed to optimise the sky coverage for astrometric purposes within the operational and technical constraints. The nominal scanning law will provide on average 70 observations of each object. The spectroscopic field of view is narrower than that for astrometry and photometry and therefore an average number of transits is 40.

Gaia has been performing its routine phase operations since July 2014. The operations are generally speaking nominal with a normal level of maintenance activities required. At the time of the meeting (June 2017) Gaia had recorded 72 billion transits over the focal plane. On an average operational day Gaia transmits data down to the Earth from 70 million objects.

The on-board detection is tuned to detect astronomical point sources down to magnitude limit 20.7. The bright limit is between magnitudes 2 and 3 depending on which part of the focal plane the object crossed when transiting. Brighter objects will have too extended saturation plateau on the CCD chip for Gaia to recognise the source as point like. Gaia bundles astrometry and photometry together. This means that every object flagged for astrometric observations is also measured with the photometers. For spectroscopy an additional magnitude limit of 16.2 is imposed as for fainter objects the signal to noise would simply be too low even after adding all transit spectra of a source together. A more detailed description of the satellite operations can be found in Gaia Collaboration et al. (2016b).

3. Data release

The first Gaia data release (Gaia DR1) took place 14 September 2016, although access to data through Gaia science alerts has been possible already since 2014.

There are four key elements in Gaia DR1. A table of 1,140,622,719 sources with position and mean broad band (in Gaia called G-band) flux was made public. Due to the short time span of data used for Gaia DR1 it was not possible to deduce full five parameter astrometric solutions to the billion sources. This because with a short time interval parallax and proper motion give a mixed signature on the plane of the sky. It was possible to break this degeneracy by using the positions of Tycho stars from the Hipparcos mission. Given the long time span between Hipparcos and Gaia, the proper motion and parallax could be disentangled. A publishable solution could be found for 2,057,050 objects and this is in TGAS (Tycho-Gaia Astrometric Solution) part of Gaia DR1. TGAS is anticipated to be the most used entity of Gaia DR1.

The two remaining tables in Gaia DR1 are a separate position table for 2,152 ICRF quasars and light curves for 3,1194 Cepheids and RR Lyrae. The ICRF catalogue was produced with special priors to obtain better positions than available for the billion objects in the main catalogue. The pulsating star light curves could be extracted from the early mission data as the routine phase was started for calibration purposes with so called ecliptic pole scanning law. During this time the spin axis of Gaia was kept in the ecliptic plane ensuring every scan covering regions close to the ecliptic poles. This high cadence coverage allowed production of well sampled light curves in these selected regions. A more detailed description of Gaia DR1 can be found in Gaia Collaboration et al. (2016a).

4. Publications

Gaia DR1 has been extensively used by astronomers in various topics. Many papers deal with comparisons of Gaia parallaxes to other distance indicators. While Cepheids and RR Lyrae data seem to bring no surprises, except for possible TGAS having too conservative errors, asteroseismology distances are not fully consistent with parallaxes. Both the conservative errors and possible parallax zero point bias may be related to certain statistical properties of TGAS, which are difficult to handle correctly. Gaia DR2 will clarify these issues much better.

Reference frames have been addressed in several papers as Gaia finally provided an accurate optical catalogue and an assessment of radio and optical frame matching can be addressed. With Gaia DR1 accuracy the matching is good, but in some sources there are indications of an astrophysical reason for small differences between the radio and optical positions.

The accuracy of positions has also triggered production of several proper motion catalogues. The Gaia position has been used as the current best estimate of the position and earlier positions are taken from catalogues based on old photographs and CCD measurements. It is expected that Gaia DR2 will provide more accurate data making these proper motion catalogues obsolete within one year.

Magellanic Clouds have been studied in several papers and both the rotation of the Large Magellanic Cloud and the stellar bridges between the Clouds have been addressed with Gaia data.

The scientific issues related to the structure and evolution of our Milky Way Galaxy were the main drivers for Gaia performance requirements. Therefore it is not surprising that many studies have appeared in the literature using Gaia DR1 data to look in detail the Solar neighbourhood, Milky Way disk warping and the halo. It is worth noting that the anticipated combination of ground-based spectroscopic data with Gaia data is indeed taking place. All major spectroscopic surveys (e.g. RAVE, LAMOST, Gaia-ESO) are utilised in combination with Gaia DR1.

The topics related to young stars have not gained that much attention yet. Main reason is that many of the well studied star forming regions are at distances beyond 140 pc. It turns out that only slightly more members are available through TGAS in comparison with Hipparcos and the uncertainties are only somewhat better. With reasonably well known distances the TGAS improvement is often in smaller error bars, but without a fundamental change in the actual distance estimate. However, there are exceptions. Voirin et al. (2017) find the well studied Chamaeleon I star forming region 20 to 30 pc further away than the earlier consensus.

5. Future data releases

Gaia DR2 has been scheduled for release on April 2018. It will be a major step forward also in view of Gaia DR1. Instead of 2 million parallaxes, there will be more than a billion. More precisely, more than billion 5 parameter (position, proper motion and parallax) astrometric solutions will be published together with broad-band G-fluxes and with integrated photometry in red and blue band of the photometric instrument. For sources brighter than magnitude 12, radial velocities will be released. For sources brighter than 17 magnitude, an estimate of the effective temperature, and extinction, if possible, will be provided. In addition light curves for variable objects and astrometry for more than 10,000 asteroids will be made public.

For young stars Gaia DR2 and future releases provide great possibilities. Distances to all close by regions will be well determined even to the level that differences within a star forming complex can be studied. Parallax information combined with proper motions will enable much better discrimination between field and member stars. The full sky coverage of Gaia makes it also possible to look for members far away from the central regions for stars already escaping from their birth cluster.

The kinematics and dynamics of young stellar clusters are almost always based on studies using radial velocities. With Gaia proper motions much higher velocity accuracies can be achieved within regions closer than about 1 kpc. Furthermore, this can be achieved in two rather than one dimension.

After Gaia DR2 two more releases are anticipated for the nominal mission. These are planned for 2020 and 2022. The latter one is intended to contain all data, including all epoch measurements.

At the moment the estimated end of Gaia operations is mid-2024. This due to exhaustion of cold gas used to keep the spin of the satellite within requirements. This means doubling of the original 5-year nominal period to 10 years. In order to continue the mission beyond the nominal period, additional funding both at ESA side for spacecraft operations and at member states for DPAC work is needed. This process has been initiated in the standard ESA process for mission extensions.

6. Conclusions

Gaia satellite is operational and performing its nominal mission. Gaia DR1 is a major step forward, yet a dwarf with respect to Gaia DR2. Gaia is well on its way to deliver ”the promise of Gaia”.

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