RevMexAA (Serie de Conferencias), **50**, 7–10 (2018)

THE OVERTURE TO A NEW ERA IN GALACTIC SCIENCE: GAIA'S FIRST DATA RELEASE

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RESUMEN

A menos de tres años del lanzamiento de Gaia, la ambiciosa misión astrométrica de la ESA, la primera publicación de datos (Gaia DR1) fue dada a conocer en septiembre de 2016. Gran parte del Gaia DR1 es un catálogo de posiciones y fotometría de banda ancha para 1143 millones de estrellas. De mayor valor científico, sin embargo, será la publicación de la Tycho Gaia Astrometric Solution (TGAS), que incluye los 5 parámetros astrométricos considerablemente mejorados para dos millones de estrellas del Hipparcos y del Tycho2. Reporto sobre esta publicación, mostrando su potencial científico con algunos ejemplos, y doy una perspectiva sobre la siguiente publicación de datos, que incluirá los 5 parámetros astrometricos, pero ahora para todas las estrellas de Gaia.

ABSTRACT

Less than 3 years after ESA's ambitious astrometric space mission, Gaia, had been launched, the first data release (Gaia DR1) appeared in September 2016. The largest part of the Gaia DR1 is a catalogue of positions and broad band photometry for 1143 million stars - of greater scientific relevance will however be the Tycho Gaia Astrometric Solution (TGAS), which includes significantly improved full 5-parameter astrometry for the 2 million Hipparcos and Tycho2 stars. I will report on this release demonstrating its scientific potential with examples, as well as giving an outlook on the upcoming release, which will then include all 5 parameters for all Gaia stars.

Key Words: astrometry — Galaxy: structure — space: vehicles — stars: kinematics and dynamics

1. INTRODUCTION

On September 14, 2016, the first Gaia catalogue was released. While this release, covering about 14 months between July 2014 and September 2015 (∼11 months net) is rather preliminary in nature and only gives a taste of what is yet to come, it already shows the potential of Gaia. This is especially true for TGAS (Tycho Gaia Astrometric Solution), a subset of 2 million stars, which are also part of the Tycho 2 catalogue (Høg et al. 2000), allowing the derivation of full 5 parameter astrometry, i.e. positions, parallaxes and proper motions, to a precision significantly greater than that of previous catalogues.

The Gaia DR1 has been released with a comprehensive set of accompanying literature, see e.g. Gaia Collaboration (2016a) and Gaia Collaboration (2016b). Since these articles contain all the information required for putting the data into good use, including their restrictions and limitations, I will here only cover the most important issues, and refer to the documentation in the aforementioned publications for more details, including all-sky maps etc. This paper focusses on a hands-on approach, giving examples of how the astrometry is improved by Gaia DR1 and the TGAS subset. The main focus of this paper will be on examples, i.e. showing a number of real life situations and the impact of Gaia DR1 data on these. I will also briefly outline the coming releases, especially the upcoming DR2. Finally, rounding up the data package of Gaia DR1 is a catalogue of variable stars (mainly RR Lyraes and δ Cepheids) located in the Southern Ecliptic Pole field, and their photometric data. This field, lying in the outskirts of the Large Magellanic Cloud (thus containing a significant number of these objects) was – along with its northern counterpart – extensively observed during Gaia's commissioning phase in the first half of 2014. Gaia DR1 also contains a catalogue of QSOs serving as ICRF2 sources. Both of these parts will not be further dealt with in this paper.

2. TGAS - MORE THAN 2 MILLION STARS WITH FULL ASTROMETRY

The 14 month stretch of data is not sufficient to separate proper motions and parallaxes. Therefore,

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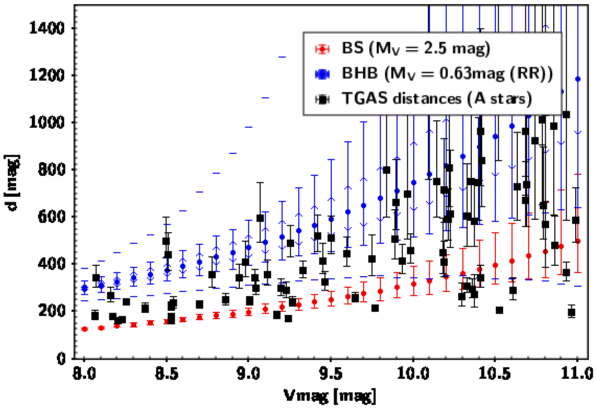

Fig. 1. Example of the improvement of TGAS distances with respect to those of Hipparcos. The blue circular symbols denote theoretical calculations taken from Michalik et al. (2015) for HBA stars, having an absolute magnitude of V=0.63 mag, the red triangles show those for blue straggler stars (late A main sequence) with an absolute magnitude of 2.5 mag. The red error bars (connected to the triangles) only show the error according TGAS. The blue error bars (connected to the circular symbols) show the Hipparcos error (error caps without bars), the TGAS error for Tycho2 stars (outer error bars) and the TGAS errors for Hipparcos stars. The differences can be clearly seen. The black square symbols show actual candidate objects, namely high-proper motion A and B stars, with their distance derived directly from the TGAS parallaxes. This shows that the theoretical assumptions are realistic. The color figure can be viewed online.

in general, the DR1 does not contain them, only positions. However for a subset of ca. 2 million objects, namely those stars which are in the Hipparcos ESA 1997, or its improved version, by van Leeuwen 2007) or Tycho 2 catalogues (Høg et al. 2000), a method was found to separate the two, with the positions in those two catalogues serving as a first epoch with an epoch date of 1991.25. This leads to a baseline of almost 24 years, good enough to determine proper motions to great precision and thus to separate the two quantities. The feasibility of this approach has been analysed and is described in Michalik et al. (2015). Fig.1 shows the distances (and their errors) computed for a sample of high proper motion and high galactic latitude A and B stars, which are candidates for Blue Horizontal Branch (BHB) or Blue Straggler (BS) stars in the Galactic Halo, superposed on theoretical values for both star types (assuming an absolute magnitude of M_V=0.63 mag for BHB stars[3] and M_V=2.5 mag for the BS candidates[4] using the results of Michalik et al. (2015). The assumed improvement of the TGAS parallaxes (especially for Hipparcos stars) with respect to the Hipparcos improved reduction, by van Leeuwen (2007) parallaxes can be very clearly seen in this figure. While it will not be possible to classify the stars into the two categories, mainly due to the fact that the absolute magnitudes of both types are by far not as uniform as in this idealised representation, the data points indicate that the pre-release assumptions on the parallax and thus position errors[5] are very realistic, and thus present a significant improvement with respect to older data. The TGAS catalogue has not only improved both proper motions and parallaxes significantly, as demonstrated, but also increased the number of available parallaxes by a factor of 20, since the Tycho2 catalogue does not have parallaxes, leaving only the ≈120,000 Hipparcos parallaxes[6]. Another example of what is possible is the derivation of not only the proper motion of the Large Magellanic cloud, but also its planar rotation (van der Marel & Sahlmann 2016).

3. THE 1+ BILLION CATALOGUE OF POSITIONS

The 1.143 billion object catalogue of positions and Gaia broad band G-magnitudes forms the second part of this release. Since it lacks both proper motions and parallaxes, its astrophysical use is limited: for science, TGAS is clearly the more important part. However, the high object density, and the unprecedented precision and accuracy of this dataset has a significant impact on ground based astrometry, as shown in Figs. 2 and 3. These figures show some examples of measurements made by the GBOT team (Ground Based Optical Tracking, Altmann et al. 2014, see also contribution by S. Bouquillon to this conference's proceedings), whose responsibility it is to optically track Gaia with ground-based 2 m class telescopes on a daily basis. GBOT's observations are required to reach the maximum accuracy even for those stars which have the most precise data, and for solar system objects (see Altmann et

[3]Which is the value close to the RR Lyrae edge.

[4]Value taken from Santucci et al. (2015), corresponding to late A stars.

[5]The reader is made aware that the simple transformation from parallaxes to distances via the relation $d = 1/\pi$ is not unproblematic, given the resulting asymmetries of the error regions, possibly resulting in statistical biases. Here this simple approach was chosen for demonstrative purposes only. For the proper treatment of these issues, see textbooks of astrometry, such as van Altena (2013).

[6]All other parallax sources feature far fewer objects.

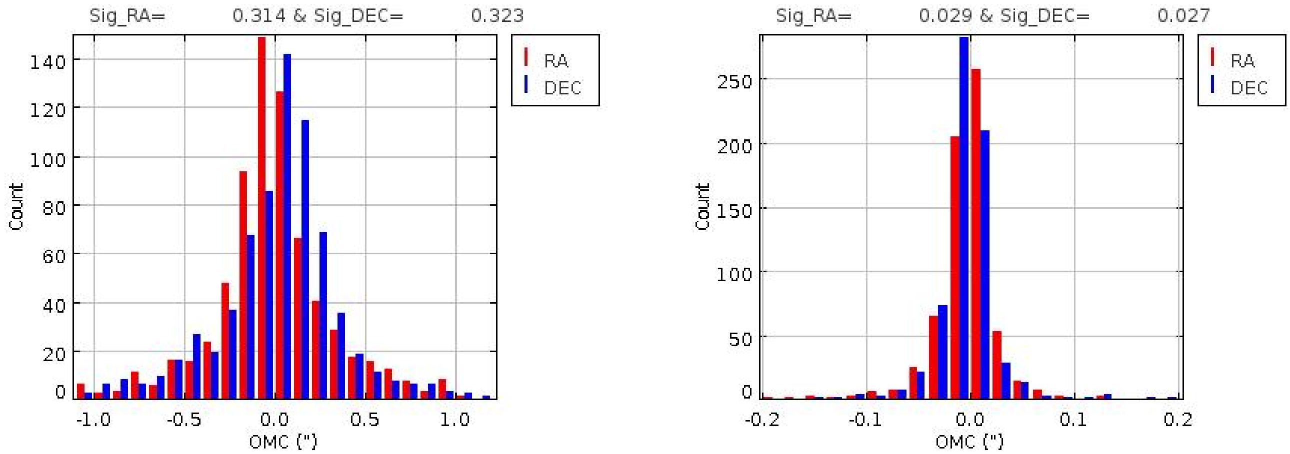

Fig. 2. This figure shows the improvement of astrometry of star fields with Gaia DR1 as reference catalogue. Both panels show the residuals after astrometric reduction between the positions derived from an image taken with the ESO-VST and Omegacam on July, 22, 2014 and the according entries in the reference catalogue. Red and blue denote Declination and Right ascension. The left panel shows the residuals when using the PPMXL (Roeser et al. 2010) as reference material, and the right panel, those using Gaia DR1. The improvement is clearly to be seen. Please note that the scale of the x-axis is 5×larger on the right panel. The color figure can be viewed online.

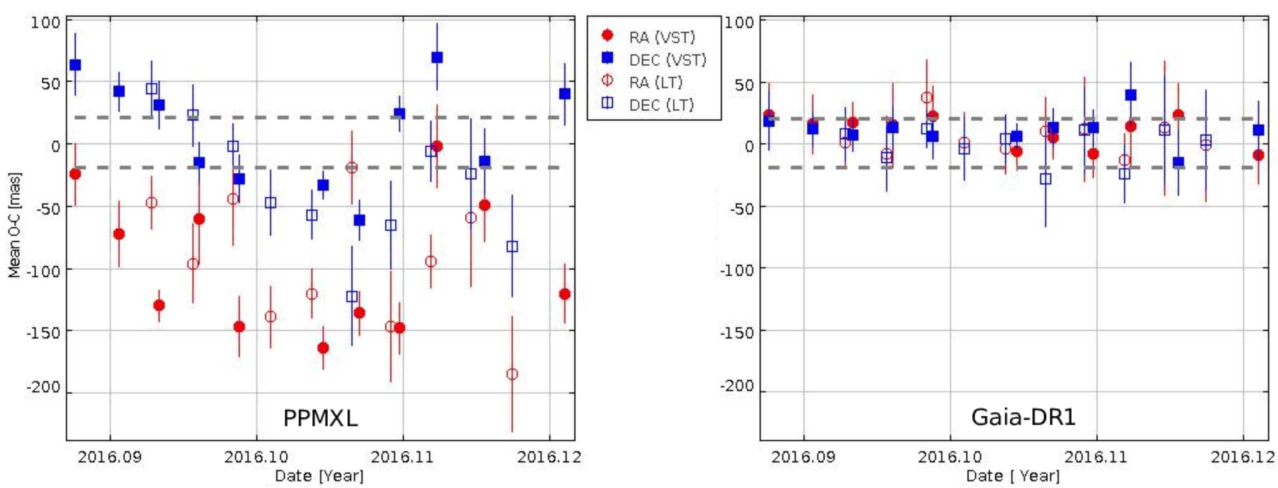

Fig. 3. GBOT astrometric results for the position of Gaia in the sky, observed during February 2016. Shown is the difference of the celestial positions as derived by the GBOT group and the orbit reconstruction performed by the flight dynamics group at MOC at ESOC (Darmstadt, Germany). Each symbol presents a daily observing sequence (of 10 images for the ESO-VST, and 20 for the Liverpool telescope, gaps due to bad weather) Full symbols show data from the ESO-VST, open symbols those for the Liverpool telescope. Red dots shows the residuals in right ascension, blue dots those in declination. The left panel shows the situation before Gaia DR1, when the PPMXL catalogue (Roeser et al. 2010) was used as reference catalogue, and the right panel shows the improvement when Gaia DR1 data is used (despite the lack of proper motions). The color figure can be viewed online.

al. 2014 for a detailed description). In order to reach the required precision of 20 mas for a daily sequence, the reference catalogue material needs to be of the highest accuracy possible. As can be seen in the left panel, the traditional ground based all-sky catalogues, such as the PPMXL catalogue (Roeser et al. 2010) used in this case, are by far not capable to deliver this kind of accuracy. In the GBOT results, there are day to day variations in the residuals of far more than 100 mas in some cases (see Fig. 3). Reducing the same data, this time using Gaia DR1 as reference catalogue, dramatically improves the situation. Now the aims in terms of error margin are met, as shown in the right panel (the stippled lines denote the 20 mas error budget limit). Perhaps of more interest to the average reader, who wants to do star field astrometry, is what is shown in Fig. 2, which depicts the scatter of the residuals between the reference catalogue and the data. Again the improvement is spectacular. Using PPMXL (Fig. 2, left panel) leads to a $\sigma_{\rm O-C}$ of about 300 mas for this particular image, while Gaia DR1 (right panel) leads to a $\sigma_{\rm O-C}$ of less than 30 mas - note the difference in the x-axis scale in Fig. 2. Here the limiting factor is now more and more the data themselves and not the reference astrometry. It is however to be noted that with increasing time with respect to Gaia DR1's epoch of 2015.0 the number of positions in the catalogue will decrease due to the lack of proper motions. This also applies to data which have a significantly earlier epoch than that of Gaia DR1, i.e. 2015.0. Fortunately this will be rectified by the next release, Gaia-DR2, which has both parallaxes and proper motions and will appear in April 2018.

In the meantime, as a stop-gap measure in order to remedy the lack of proper motions in the second part of Gaia DR1, an attempt has been made to combine the input data forming the PPMXL and Gaia DR1 positions, resulting in a catalogue of ∼583,000,000 stars with Gaia DR1 quality positions and vastly improved proper motions in contrast to the older PPMXL (Altmann et al. 2017). This catalogue, which recently became available in the GAVO database (`http://www.g-vo.org/` and links therein, TAP query only) is called HSOY ("Hot Stuff for ONE Year"). While certainly not being able to compete even remotely with the expected data quality of Gaia DR2, this catalogue does have the potential to lead to a number of new results, especially in the study of star clusters, before DR2 is released in a bit more than a year (at the time of writing, i.e. Dec. 2016), and it can also be used as testbed for projects to be tackled when the next set of Gaia data comes. Please note that HSOY does not contain parallaxes, only proper motions, the formal errors of which range from between $\ll 1$ mas for bright stars and 5 mas at the faint end. The short-lived HSOY catalogue is a powerful tool which increases the scientific value of the DR1 data (outside of TGAS); it should be seen as an appetizer for the next big and more complete Gaia release, DR2.

4. FUTURE RELEASES

The next release, Gaia DR2, is currently foreseen to appear in April 2018. In contrast to the current DR1, it will not only contain positions but full 5 parameter astrometry (positions, proper motions and parallaxes) for well behaved stars. In addition to the G-magnitudes, this release will contain the integrated photometry derived with the blue and red (spectro-)photometer (BP and RP), as well as radial velocities for bright stars. While certainly this release will not have the final precision (currently there are no error estimates available), it will be a significant improvement over anything currently in existence. Since this release is the first dataset with "complete" astrometry, it will make a major impact on Galactic science and beyond. After DR2, there will be further releases, adding more and more data for more and more objects and object classes (binaries, solar system objects, etc.), until the final release, which is currently foreseen for 2022.

The DR2 release and all coming releases are described in the "Gaia Data Release Scenario" (`http://www.cosmos.esa.int/web/gaia/release`), to which the reader is referred for up to date information on Gaia's releases.

Acknowledgements: The author wants to thank the ADeLA organising committee for the kind invitation, and financial support. The Gaia project is supported by many funding organisations in Europe. The author is part of the German contribution to Gaia which is supported by the German Space agency, DLR, on behalf of the German Ministry of Economy and Technology via grant 50 QG 1401.

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