

Report on the outcomes of a Virtual Mobility¹

Action number: CA18104

Grantee name: Lola Balaguer-Núñez

Virtual Mobility Details

Title: MW-Gaia Legacy in Gaiaverse

Start and end date: 01/08/2023 to 31/08/2023

Description of the work carried out during the VM

Description of the virtual collaboration and activities carried out during the VM, with focus on the work carried out by the grantee. Any deviations from the initial working plan shall also be described in this section.

(max. 500 words)

The main objective is to create a legacy webpage for the COST project in Gaiaverse, the official outreach website for MW-Gaia, where we add a new page dedicated to each of the activities done in the framework of COST (STSMs, Workshops, VM grants...) in the style of what it was done in the first three VM grants (e.g. https://gaiaverse.eu/fre_news/public-resources-for-stellar-spectroscopic-analysis/) from the reports presented by the different people involved. That will give more visibility to all the activities done by the COST project and also to the people and work done.

I have contacted the CSUC and asked for a budget to include all the STSMs, Workshops, VM grants as pages in the Gaiaverse webpage. To that end they will dedicate 25 hours with a cost of 1250,00€(+21%VAT) that will be covered with this grant. At the same time, I have collected and improved/normalised/completed all the reports for the 17 workshops that had taken place during the Action. All these reports include now some complete statistics on gender and country of origin and all of them follow the same pattern for publication. From the four schools only one report is actually available. From the 33 STSMs, I have asked for permission to all of the authors that could be located and only 18 have answered favourably to the publication and updating their previous reports. We hope the remaining will answer in the following days.

Description of the VM main achievements and planned follow-up activities



¹ This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.



Description and assessment of whether the VM achieved its planned goals and expected outcomes, including specific contribution to Action objective and deliverables, or publications resulting from the VM. Agreed plans for future follow-up collaborations shall also be described in this section.

(max. 500 words)

The work that has been implemented covered the following steps:

 Compilation of all the reports of all the activities (STSMs, Workshops, VMgrants) done in the COST Action since the beginning.

- Design and adaption of each report to a public news page for the Gaiaverse website

- Contact each author for corrections and agreements

- Implement them in the Gaiaverse webpage

- Creation of a Legacy webpage for the COST project in Gaiaverse portal (https://gaiaverse.eu/) with an overview of all the activities including some demographic statistics (work in progress, depending on the finalisation of the last reports)

The main achievement is the recollection of the reports and their completion and updating. There are still some reports that will be finished as soon as the authors give permission and the schools need to be processed in the same style as the workshops, and that will be finished in the following weeks. We attach to this report all the reports that are already finished. They will be available on the Gaiaverse webpage in the following weeks, as the permissions for publication arrive,



MW-Gaia WG1 Workshop The Gaia Treasure Hunt Cambridge (UK), 3rd-5th September 2019

To mark the beginning of the MW-Gaia COST Action, a three-day workshop <u>The Gaia</u> <u>Treasure Hunt</u> took place in Cambridge.

Scientific motivation of the workshop

The format was reviews and contributed talks, together with break-out sessions to tackle problems. The days are focussed around problems, in which we wanted to make progress during the meeting. The workshop was limited to a maximum of 45 participants.

Day One

The Galactic Bulge and Bar (Coordinator, Jason Sanders): What is the structure of the Galactic Bulge/Bar? What is the pattern speed? How do proper motions change our understanding of the X-shaped structure or the high velocity peaks? What is the role of ages and chemical data in the modelling?

The first morning was devoted to the structure of the Bulge and saw invited talks by Francesca Fragkoudi (Munich) and Christopher Wegg (Munich) as well as a contributed talk by Jason Sanders (Cambridge), who coordinated the session. Outstanding questions include the age and pattern speed of the bar, as well as its formation mechanism. In the afternoon, the discussion moved to the nearby disk, spiral structure and the local open clusters with contributions from Eugene Vasiliev (Cambridge) and Daisuke Kanata (MSSL).

Day two

The Galactic Disk (Coordinator, Justin Read): What is local dark matter density? How should the kinematics of the local disk be modelled? What is the origin of the phase space spiral (the Gaia snail)? What is the role of mergers? What are the mechanisms that drive the warp and bending modes in the disk?

The second day concentrated on the disk, and was organised by Justin Read (Surrey). It began with a stimulating invited talk by Misha Haywood (Paris) on how the thick disk, thin disk and the splash or plume stars are related.

Chervin Laporte (Victoria) gave an invited talk on how the Gaia phase space spiral may have been caused by the impact of the Sagittarius dwarf. A different viewpoint was advocated by Sergey Khoperskov (Munich), who attributed it to the epoch of bar formation and buckling. After lunch, the focus was on the local dark matter density, and how Gaia may pin this quantity down. It is of great importance in astroparticle physics, and Axel Widmark (Stockholm) gave a nice talk on this. The day concluded with Anthony Brown of ESA giving an update on perspectives for Gaia Data Release 3.

Day three

The Galactic Halo (Coordinator, Wyn Evans): What are the best statistical measures of substructure in configuration/phase space to describe the clustering in the stellar halo and disk? What physical processes are imprinted in the correlation functions? How should the data be compared to simulations? What is the mass of the Milky Way, and its escape speed?

The third day was organised by Wyn Evans (Cambridge) on the halo. Sergey Koposov (Carnegie-Mellon) and Lachlan Lancaster (Princeton) gave invited talks on how the structure in the halo may be analysed with modern astrostatistical techniques. Andrea Font (Liverpool) provided a perspective on how the in situ and accreted halo can be distinguished using numerical simulations. James Lane (Toronto) gave an interesting talk on how the shape of the dark halo may be measured using APOGEE stars. In the afternoon, the topic switched to the overall mass of the Milky Way with contributions from Marius Cautun (Leiden) and Denis Erkal (Surrey).

A particularly nice feature of the workshop was the very high standard of contributions from early stage researchers who gave some of the best talks.



The workshop in numbers

The workshop was attended by 45 researchers, 21% of them female. The SOC and LOC both had a 38% of female researchers (3 out of 8). From the total, 28 participants (62%, including invited speakers) had financial support by the COST Action.



There were researchers from 14 different countries: Europe (mostly UK), the United States, Canada and Mexico.

There were 26 presentations. 44% of the female participants presented something while 35% of male participants did. There were 7 Invited talks (29% female) and 19 Contributed talks (11% female).

Images:

https://en.wikipedia.org/wiki/Institute of Astronomy, Cambridge#/media/File:IoA-Cambridge-Obs-Building.jpg

https://en.wikipedia.org/wiki/Institute of Astronomy, Cambridge#/media/File:IoA-Cambridge-Obs-Building.jpg

Report prepared by Wyn Evans and Lola Balaguer-Núñez.



MW-Gaia WG3 Workshop Exoplanets in the era of *Gaia* Porto (Portugal), 18th-20th November 2019

The workshop <u>Exoplanets in the era of Gaia</u> took place in Porto from 18th to 20th November 2019. This was the second workshop of the CA18104 COST Action MW-Gaia and the first workshop of the Working Group 3 (WG3).

Scientific motivation of the workshop

With ultra-precise astrometric and photometric observations of more than 1 billion stars, *Gaia* is revolutionizing our view of the Solar System, extrasolar planetary systems, the Milky Way as a Galaxy, distant extra-galactic objects, and many other fields of astronomy. The aim of this workshop was to bring together exoplanet and stellar astrophysicists to discuss how *Gaia* is revolutionizing our understanding of exoplanet formation and evolution, and what are the future perspectives.

The scientific program of the workshop was organized as follows:

- ✓ Gaia and exoplanets: Overview of the Gaia mission; Exoplanet detection with Gaia; Overview of Exoplanet research
- ✓ Exoplanetary systems: Physical properties of exoplanets and their orbital architecture
- ✓ Exoplanet surveys: synergies between Gaia and ground-based RV exoplanet surveys
- Exoplanet surveys: synergies between Gaia and other ongoing/upcoming space missions and ground-based exoplanet surveys (e.g. Transit, Direct Imaging)
- Star-planet connection: Exoplanet host stars as an instrument to study planet formation and evolution in different environments

In each session there were review and contributed talks, followed by open discussion between the participants.



Day one

Gaia and exoplanets: Overview of the *Gaia* mission; Exoplanet detection with *Gaia*; Overview of Exoplanet research

This very first session of the workshop started with the introductory talk of Nicholas Walton (Cambridge), who gave an overview of the COST action presenting its aim and available opportunities. The session continued with the invited review talks by Berry Holl (Geneva) and Alessandro Sozzetti (Torino) who presented the current status of Gaia mission and its potential for detecting exoplanets. The expectations are rather exciting. About 15000 massive jupiters and about 30000 Brown Dwarfs (BDs) are expected to be discovered with Gaia's ultra-high precision astrometry. Photometric power of Gaia to detect transiting planets is expected to be strong to: ~1000 jupiters and ~9000 BDs for the 5-year mission of Gaia. Gaia DR3 will already provide non-single star solutions (binaries and perhaps lower mass objects!). The aforementioned large number of newly discovered planets are expected to help us to significantly improve our understanding of formation and evolution of giant planets especially at intermediate orbits. Among many scientific open questions, Gaia will help us to answer: What is the actual [Fe/H] limit for giant planet formation? Do low-[Fe/H] stars host longer-period companions? Are more massive planets preferentially found around more massive primaries? Do higher-mass star only host longer-period companions? Are orbital elements distribution of planets in binaries and around single stars the same? How do frequencies depend on binary separation? Many of this questions will be answered thanks to the synergies between Gaia and other surveys. As discussed by Antoine Grandjean (Grenoble), synergies between Gaia astrometric measurements, high contrast imaging, and radial velocity gives direct constraints on the orbit and on the dynamical masses of sub-stellar companions (planets, brown dwarfs). This masses then can be used to calibrate the evolutionary models. The synergies between Gaia and other missions/surveys was discussed in more details during the next sessions.

Exoplanetary systems: Physical properties of exoplanets and their orbital architecture

This afternoon session started with the review talk of Lars Buchhave (Denmark) about the statistical properties of exoplanets. In particular, he discussed the dependence of orbital properties (orbital periods and eccentricities) and occurrence rates of different types of exoplanets on the metallicity of the host star. The results suggest that jupiteranalogs (cold giant planets in circular orbits) are mostly found around solar-metallicity

stars, while cold giant planets in eccentric orbits are found to be around metallic stars. It is proposed that in high metallicity environments many giant planets can be formed which will lead to excitement of the eccentricities due to gravitational interactions between planets. This talk was followed by Elke Pilat-Lohinger (Vienna) who spoke about the planetary architectures in binary stars. After discussing the terrestrial planet formation using gravitational N-body simulations an online-tool "SHaDoS" was presented which identifies the location of secular resonances in circumstellar planetary systems. The last two speakers of the day, Solène Ulmer-Moll and Sérgio Sousa (Porto), spoke about "Forecasting exoplanet radii with machine learning" and "The metallicity-period-mass diagram of low-mass exoplanets", respectively. The results of Solène Ulmer-Moll (Porto) suggest that the random forest algorithm constrains the exoplanet radius, with higher accuracy than the previous methods. It derives reliable radii for planets between 4 and 20 R⊕, with a relative error smaller than 25%. Sérgio Sousa presented the SWEET-Cat - The Stellar parameters for stars with ExoplanETs CATalogue, a unique compilation of precise stellar parameters for planet-host stars provided to the exoplanet community. By using the precise parameters from SWEET-Cat he studied the exoplanets with minimum mass below 30 M to and found a correlation in the metallicity-period-mass diagram where the mass of the planet increases with both metallicity and period.

The first day of the workshop finished with one-hour open discussion coordinated by Alessandro Sozzetti (Torino). The discussion touched the topics such as "*Gaia* and exoplanet diversities", "How *Gaia* should help us to understand the orbital 'peculiarity' of Solar System - Cold Jupiter and no close-in super-Earth", and finally the "problems" with *Gaia* performance – currently estimated errors are larger than the formal errors. The general agreement was that DR3 results will be much better.

Day two

Exoplanet surveys: synergies between Gaia and ground-based RV exoplanet surveys

The first session of the second they opened Oscar Barragán (Oxford) with his invited talk on "The needle in the haystack: disentangling planetary and stellar activity signals in RV time series". In the presentation he presented different methods (Fourier decomposition, Float Chunk Offset, Gaussian Process, Multi-dimensional GP) to detect planets using Radial Velocity (RV) observations under the presence of stellar activity 'noise'. For each method the "pros" and "cons" have been provided. The main conclusion was that there is no "magic recipe" to disentangle planets from stellar activity signals and one has to treat this problem in a star by star basis. The next two speakers, Nuno Santos and Hugo Tabernero (Porto), described two state-of-the-art spectrographs - ESPRESSO and CARMENES – operating in the visible and visible+nIR wavelengths. ESPRESSO's high and ultra-high resolution, and long-term super-stability allows to reach a 10-20 cm/s precision in RV – enough to detect (if the stellar activity allows) earth-like planets in the habitable zone around sun-like stars. CARMENES's RV precision reaches to 1 m/s level for the visible arm and a bit less for the nIR arm. As stressed by Hugo, CARMENES's nIR spectrograph does well, it is us (researchers) who cannot take the full advantage of this spectrograph, mostly because of the heavy telluric contamination. Afterwards, Domenico Barbato (Torino) presented the first results of their new statistical analysis of cold companions of transiting hot Jupiters based on a 5-yr high precision radial velocity survey conducted with the HARPS-N spectrograph, AO imaging and proper motions taken from Hipparcos and Gaia. Elisa Delgado Mena (Porto) in her talk also stressed the need to carefully consider the stellar noise when looking for RV planets around evolved stars in open clusters. In particular, she discussed about the different origins of RV variability in these stars. She concluded that long term observations are essential to cover several rotational periods of these giant stars.

Exoplanet surveys: synergies between *Gaia* and other ongoing/upcoming space missions and ground-based exoplanet surveys (e.g. Transit, Direct Imaging)

The afternoon session of the second day started with the invited talk by Mariangela Bonavita (Edinburgh) who (remotely) spoke about the current and future efforts aimed at exploiting the emerging synergy between astrometry and direct imaging. This synergy will help to develop a framework to obtain the most precise model-independent measurement of the mass of directly imaged young giant planets. In her talk "Weighing young giants: tracing a path to precise dynamical masses for directly imaged exoplanets", she explained how to directly detect and characterize young giants in the outermost regions of planetary systems. It seems that Gaia's astrometric measurements are accurate enough to constrain the masses of the imaged companions (which was not possible before e.g. with Hipparcos). Maksym Lisogorskyi (Hertfordshire) in his talk explained how to use PEXO (Precision EXOplanetology) as a global modelling framework for nanosecond timing, microsecond astrometry, and µm/s radial velocities. This tool simultaneously models the classical and relativistic effects for Solar System and the Target System. This was followed by Paolo Giacobbe's (Torino) talk on the detection and characterization of giant planets combining Gaia astrometry, radial velocities and transit information. K2 mission detected large number of mono-transit planet candidates with transit duration of several hours. To confirm the planetary nature of these signals one needs to look at the astrometric data from Gaia which can provide useful mass upper limits or actual astrometric detection, particularly in the regime of orbital separations 1-4 AU, for which Gaia achieves maximum sensitivity. The session ended with the talk of Ozgur Basturk (Ankara) who presented the observation facilities in Turkey that can be used for exoplanet sciences. In Turkey they have several facilities and some are soon-to-come. They are open for collaboration.

After-presentations discussion of the second day was led by Shay Zucker (Tel Aviv) and was focused on two main important points: what are the main limitations for the RV precision and can we use the *Gaia* observations to estimate the upper mass limits of planets not-detected by *Gaia*. It was concluded that although it is still possible to improve the methods of the RV determinations of stars, a real breakthrough is expected only if/when we understand the physics that is behind the impact of stellar activity on the formation and profiles of spectral lines. The discussion also led to a conclusion that *Gaia's* detection and non-detections of planets will help us to significantly improve our understanding of giant planet formation and evolution, and to estimate the occurrence rates of massive planets.

Day three

Star-planet connection: Exoplanet host stars as an instrument to study planet formation and evolution in different environments

The last day stared with the invited talk of Tiago Campante (Porto) who gave a review on the synergy between asteroseismology and exoplanet science. He explained that asteroseismology can provide high precision mass and age determination for planet host stars. At the same time asteroseismology needs improved luminosity to constrain the models. It was interesting to realize that the radii determined from *Gaia* in general is in good agreement with the asteroseismic ones. After this talk, Jacob Hamer (Baltimore) demonstrated that hot-Jupiters are tidally destroyed while their hosts are on the main sequence. He found that stars hosting hot-jupiters are younger than the stars without hot-Jupiters. Interestingly, ultra-short period (P < 1d) planets do not show the same effect as hot-Jupiters. The main limitation (discussed after the talk) was that he uses stellar velocity dispersion as a proxy for age. Dolev Bashi (Tel Aviv) gave a nice review on the exoplanet formation in the galactic context. He used Kepler-*Gaia*-LAMOST sample to study the occurrence rate of small-sized planets and its dependence on [Fe/H] and total velocity (Vtot - galactic space velocity) of the stars. The results suggested that planets are located in some favoured regions in the [Fe/H]-Vrot diagram: around metallic stars and in case of low-[Fe/H] planets tend to appear more around high Vtot. The latter trend is not easy to explain. Later on, Vardan Adibekyan (Porto) spoke about the dependence of the occurrence rate of different planets on the host star metallicity. He showed that it is still not clear whether there is a correlation between low mass planets and metallicity or not. The results are sensitive to the samples considered. It was also shown that stars hosting super-massive planets (Mp > 4Mjupiter) tend to appear around less metallic, but massive stars than field stars.

After these invited/contributed talks, Ana Ulla-Miguel (Vigo), Alan Alves (Aveiro), and Nicolas Unger (Geneve) presented their posters in short talks. Ana Ulla-Miguel spoke about the stellar cosmic rays and potential exoplanet habitability explaining that the cosmic rays can be bad for habitability of planets. Alan Alves explained that resonance trapping is a natural outcome of planetary migration processes due to planet-disk interactions. In particular, he explained the dynamics of the 3:1 planetary mean-motion resonance on the example of HD60532 b-c planetary system. Finally, Nicolas Unger showed the results of the re-analysis of the radial velocities data of HD40307 with the evidence estimator PolyChord: a Bayesian interface to determine number of existing planets. Alexandre Correia (Coimbra, "Exoplanets and the Cradle of Life with the SKA") and Ema Valente (Coimbra, "Dynamics and Habitability of Multi-Planet Systems") also presented their results but only in poster forms.

The workshop ended with a discussion and wrap-up led by the chair of the action Nicholas Walton (Cambridge). We briefly discussed the main questions that have arisen during the last session and continued with more general discussion about the potential of *Gaia* for exoplanet research, and how to be prepared for the *Gaia* DR3 and DR4. Nicholas Walton reminded the audience the structure of the Cost Action, opportunities it provides and the upcoming events organized within the action.



The workshop in numbers

The workshop was attended by 36 researchers (one remotely), 17% of them female.

The SOC and LOC both had a 33% of female researchers (3 out of 9).

From the total, 14 participants (39%, including invited speakers) had financial support by the COST Action.



There were researchers from 13 different countries: Europe (mostly Portugal), the United States, Israel and North Macedonia.

There were 26 presentations. All female participants presented something while only 55% of male participants did. There were 6 Invited talks (only 17% female, as one had to cancel), 15 Contributed talks (20% female) and 5 Posters (40% female).

Regarding career stage there were 11 PhD students and 7 Early Career Researchers (47% of young researchers).

Report prepared by Vardan Adibekyan and Lola Balaguer-Núñez.



MW-Gaia WG4 Workshop A dynamical view of the sky Nice (France), 4th-6th December 2019

The workshop <u>A dynamical view of the sky</u> took place in the Observatoire de la Côte d'Azur, Mont Gros site, Nice, France, from 4th to 6th December 2019.

This was the third workshop of the CA18104 COST Action MW-Gaia and the first workshop of the Working Group 4 (WG4). The format of the workshop was based on invited reviews and contributed talks.

Scientific motivation of the workshop

The scientific program of the workshop was focused on the following topics:

- ✓ Binary stars: Gaia astrometry of binary stars allow precise determination of stellar masses, an essential ingredient in astronomy, as well as the precise calibration of the first steps of the cosmic distance ladder. When applied to wide binaries, it also allows testing gravity theories.
- Black holes: Binary super-massive black holes (SMBH) are important in the framework of galaxy evolution models, but also as potential gravitational wave emitters. Recent analysis of the superb astrometry by VLBI and Gaia found an offset between their centroids in super massive black holes (SMBH). Binary SMBH, recoiling SMBH, VLBI jet components are candidate explanations.
- ✓ Galactic dynamics: Gaia changed our understanding of the dynamical interactions of the Galactic disc and halo, revealing their rich history. The impact of satellite accretion on the disc and the interpretation of the disc complex kinematic signatures are crucial challenges for Galactic dynamical studies.
- ✓ Solar System: The accuracy of asteroid astrometry by Gaia and its peculiar properties challenge the traditional approach to orbit computation, but can give access to measurements of Yarkovsky in the Main Belt and a better determination of asteroid masses, providing new constraints to the evolution of the population of small bodies.

The feedback from the widely different communities involved was excellent, and most participants were present over different sessions, not concerning specifically their own expertise. This allowed fruitful exchanges and sharing of knowledge beyond the usual perimeter of each of the topics.

Despite a large strike in France right in the middle of the workshop, in the end only 4 participants were not able to travel, and one did not came for other reasons. Among those, three of them were able to attend the sessions remotely and also give their presentation in a very effective way. We can thus say that we succeeded in minimizing the impact of these particular circumstances.

Day One

Milky way

This first session was mostly devoted to the formation of the Milky Way components. We allowed plenty of time for questions (all talks got several questions) and the discussions were extremely useful. There were two invited talks. The first one by Davide Massari (The Gaia view of the Milky Way Halo and its satellites) was an excellent review of the revelations of the Gaia data on globular clusters, dwarf galaxies and accretions events in the Milky Way. There was discussion on how precise is the estimation of masses of the progenitors of past accretions events and on the association of globular clusters to the different progenitors. The second invited talk was by Carme Gallart (The evolutionary history of the Milky Way disk(s) and halo from *Gaia* DR2 colour-magnitude diagram fitting) where she described their method of deriving age distributions from the observed CMD, the application to Gaia DR2 and the results obtained so far (e.g. star formation peaks at the Sagittarius pericenter times). There was an interesting discussion on how to explain the ages found for different disk vertical layers and the possible implications on the top-bottom disk formation. The contributed talks were by 1) Paola Re Fiorentin (Relics of the Formation of the Galactic Halo from Gaia and APOGEE) on the structures they find in the space of integrals of motion of a sample of halo stars. Among others, we discussed how the chemistry can help to distinguish the identity of the different structures. 2) Alessandro Spagna (The origin of the thick disc rotation-metallicity correlation) where he explained the different theories for the explanation of this relation and their work with cosmological simulations where an initially negative correlation ends up being positive at current times. There was discussion on the paradox that leads to a positive correlation while being negative for the individual mono-age populations.

The afternoon presentations were devoted to the study of different chemodynamical features of the Galactic disc and the bulge. First of all, Santiago Torres presented an analysis of the white dwarf population in different disc moving groups. The study shows that white dwarfs are reliable cosmochronometers, carrying important information about the Galactic history and structure. Gaia DR2 has provided astrometric and photometric information for about 300 000 white dwarf candidates, being a complete sample up to 100 pc. Thanks to this sample, the Hercules stream has been detected for the first time in the white dwarf population. Secondly, Eloisa Poggio presented an analysis of the Galactic warp in which Gaia DR2 data are fitted with a model allowing a warp precession. The new model solves different problems of the static warp interpretation. An unexpectedly high precession rate is needed to explain the data. In the future, a more detailed model, allowing radial variations of the warp precession needs to be implemented. Marco Giammaria presented an analysis of the Milky Way rotational curve using a relativistic Balasin & Grumiller model and a classical model. He showed that both models fit the data, being statistically equivalent. Finally, two presentations explored the nature of the Galactic bulge populations. It has been recalled that one third of the galactic baryonic mass is located within 5 kpc from the Galactic centre. Chris Wegg presented a chemodynamical study of the Milky Way bar population using VLT/FLAMES data. The analysis shows that the bar population seems to be more metal-rich than the surrounding bulge population. Finally, Felipe Gran described the new discoveries of globular clusters in the central regions of the Galaxy thanks to VVV. Combined studies using follow up spectroscopic observations and Gaia proper motions have already allowed to confirm several cluster candidates, revealing a rich cluster population in the bulge.

Day two

Binary stars

The binary star session started with Dimitri Pourbaix presenting a status of the processing of binaries in Gaia and what to be expected in Gaia DR3, scheduled for the second half of 2021. He started by cautioning that if there are about 2600 papers citing Gaia DR2 for now, some of them may have to be reviewed in line of DR3, when binaries will be taken account in the astrometric solution. Indeed, the inclusion of binaries could affect either the proper motions or the parallaxes, compared to a single star solution. However, tests done with a small subset of objects that show large RUWE values indicate that the effects may be limited to a range of parameters, for example for those binaries with orbital periods between 400 and 500 days and small parallaxes. It is also important to understand that the binary analysis of DR3 will be based on solely 1000 days of Gaia data, and not on the whole set of data available by then. Thus, DR3 will not be able to probe binaries with orbital periods below 200 days, nor those longer than 600 days. Still, we can expect 11,000 double-lined binaries, half a million astrometric binaries and more than a million eclipsing binaries. Enough to revolutionise the field! Flavien Keifer presented how we have now entered an era where it is possible to measure stellar masses - one of the most fundamental properties of a star – with precision better than 1 percent. This can only be done using binaries. Using precise radial velocities from the SOPHIE spectrograph for a sample of double-lined binaries, and sophisticated techniques involving two-dimensional cross-correlation and least-square spectral matching, it is possible to derive the minimum masses of the components with great precision. To get the stellar masses, however, a key ingredient is missing: the orbital inclination, which is generally unknown. This is where Gaia comes in play as by computing an astrometric orbit for these binaries, it will provide the missing piece of the puzzle. The technique has been tested using interferometric measurements to determine the inclination and thus the stellar masses for 11 systems. These will serve as useful benchmarks to validate the Gaia parallax when orbital elements are taken into account. A sample of about 70 double-lined systems has been followed up over more than 10 years and will allow, with Gaia DR3, determining stellar masses to better than 1%. Following this, Henri Boffin showed how one can use *Gaia* DR2 to study the mass ratio distribution of spectroscopic binaries. He showed that the mass ratio distribution is generally flat, with a weak dependence on the primary mass. An excess of twins is seen, and these are mostly belonging to a subsample of systems that have an A-type primary and an orbital period below 50 days. The most important conclusion is that given the large number of low-mass stars hidden as secondaries in binaries, the majority of stars belong to binary systems. Fran Jimenez-Esteban presented a study of wide binaries. Earlier results based on Gaia DR1 and Tycho-2 had shown the possibility of wide, stable systems, but also ultra-wide (separation larger than ~50,000 au) unstable systems that are challenging to binary star formation models. The use of Gaia DR2 clearly shows that ultra-wide binaries are likely rare, given the very high contamination rates from chance alignments. On the other hand, the method allowed to detect more than thousand highly reliable wide binary systems. Finally, Sahar Shahaf introduced the astrometric mass ratio function and showed how this simplistic, first-order approach can help select the most interesting systems, such as those containing compact stars and black holes, in a way that uses resources wisely, especially when many astrometric binaries will be found by Gaia. It is therefore possible that Gaia will be able to reveal dormant (that is, nonaccreting) black holes. In line of some recent discoveries, this is undoubtedly of very great interest.

Black holes

There was a session dedicated to the role of *Gaia* on point-like sources that are not stars, that is, galaxies harbouring super massive black holes, usually known as AGNs, which are an important fraction of the detected sources (exceeding 1 million). The main covered subjects discussed were (1) binary super massive black holes (SMBH) and methods to detect them, (2) the core-shift between the optical and radio centroids among AGNs. There were 2 invited talks, from Stefanie Komossa, from Max Planck Institute fur Radioastronomie (Germany), an expert in SMBH, and Yuri Kovalev, from Astro Space Center (Russia). Komossa presented a review talk on binary SMBH, an excellent and thoroughly presentation, where she explained the most accepted galaxy evolution models, where galaxy mergers and binary SMBH are drivers of galaxy evolution. Komossa also presented an excellent description of the methods used so far to detect binary SMBH. Komossa finished by highlighting the different areas for which Gaia data will have a major impact, considering its superb astrometry, its whole sky coverage and multi-epoch nature, ideal characteristics to obtain a large, homogeneous binary sample. Kovalev presented and discussed recent work comparing radio and Gaia positions of VLBI sources, a subject that is relevant per se, but also in terms of alignment between ICRF and Gaia Reference frame. Lukas Popovic presented work on the relevance of the complex quasar central structure (accretion disc and tours) to photocenter quasar variability. Their models indicate that there might be a significant variability in the photocenter structure due to outbursts in the accretion disc, and also super-massive binary black holes can affect the photocenter, the later expected to be pinpointed as the variability (light curve) has periodicity caused by dynamical effects, and that may be explored form Gaia data. Sonia Anton presented their efforts to find binary SMBH, via existent radio interferometers (VLA and emerlin) and Gaia, and she showed some of the best BSMBH candidates obtained by their team so far. Anton also discussed the impact of the new coming radio infrastructure SKA, that in combination with VLBI (ie SKA-VLBI) and Gaia will be a very powerful tool to find these (so far very scarce) systems.

Day three

Solar System

This last session was devoted to minor planets of the Solar System. The first talk, by Federica Spoto, was a rather complete review of the impact of Gaia on asteroid science, in particular by using DR2 data. The properties of DR2 with respect to this category of objects, and the last results in term of orbit computation and Yarkovsky effect determination, were presented. The presentations by Agnes Fienga and Lauri Siltala stressed the importance of Gaia DR2 data for the computation of planetary ephemeris and the determination of unknown masses in the Solar System. Interestingly, Fienga finds a rather large, unexpected impact of the exact definition of the Solar System barycenter on the orbital fit residuals. Large, distant TNOs are capable of shifting the barycenter of an amount large enough to cause trouble, not only for the exploitation of Gaia astrometry, but for the data reduction itself. An interesting debate on the topic followed the presentation. Siltala showed mass determinations for the asteroid 16 Psyche, with an interesting final result and some emphasis put on the need to use better error models and debiasing of archive data. Benoit Carry presented the mission Hera to the asteroid Dydimos, with a connection to the broader context offered by Gaia to the understanding of the origin of the Earth crossers. The importance of Gaia data for other missions to asteroids was discussed. Data mining of the daily data flow was presented by Francois Mignard, illustrating the strategy required to identify unknown moving objects. This is a very complex task that illustrates also the complexity of *Gaia* observations. Eventually Toni Santana concluded the session by reviewing other observational approaches that are complementary to *Gaia* data for the modelling of asteroid physical properties (mainly size, shape, and surface scattering). This broader perspective has been complementary to the previous talks, with a welcome opening to the interactions of *Gaia* data with ground-based observations.



The workshop in numbers

The workshop was attended by 41 researchers (3 remotely), 29% of them female.

The SOC and LOC had a 38 and a 40% of female researchers respectively.

From the total, 14 participants (34%, including invited speakers) had financial support by the COST Action.



There were researchers from 14 different countries in Europe (mostly French), Chile and Israel.

There were 25 presentations. 75% of female participants presented while 55% of male participants did. There were 7 Invited talks (43% female) and 18 Contributed talks (33% female).

Regarding career stage there were 6 PhD students and 10 Early Career Researchers (39% of young researchers).

Report prepared by Paolo Tanga and Lola Balaguer-Núñez.



MW-Gaia WG2/WG3 Workshop

Frontiers of Stellar Physics: the Theory-Observation Interface

Zagreb (Croatia), 21st-23rd January 2020

The workshop was <u>Frontiers of Stellar Physics: the Theory-Observation Interface</u> held at the Palace of Matica Hrvatska in Zagreb, Croatia, from 21st to 23rd January 2020.

This was the fourth workshop of the CA18104 COST Action MW-Gaia and the first (joint) WG2 and WG3 workshop.



Scientific motivation for the workshop

The recent data releases by the European Space Agency's Gaia survey reinvigorated the interest in stellar physics. Gaia's state-of-the-art astrometry and photometry combined with contemporary spectroscopic surveys and high-cadence photometric space missions allow stringent tests of the stellar evolution, pulsation and population synthesis models.

The aim of this workshop is to address the open questions related to the uncertainties in the theoretical models through a comparison with the observational data. The topics of the workshop include:

- ✓ Population synthesis: simulations of star counts, dependence on the uncertainties of the stellar models

- ✓ Stellar rotation: effects on the stellar evolution
- ✓ Stellar pulsations: comparison between the observational values and the theoretical light curves, luminosities, ages and colour
- ✓ High-cadence space missions: combining the Kepler, TESS and PLATO missions with Gaia and spectroscopic surveys to lift the degeneracies and provide key modelling parameters
- ✓ Spectroscopy: obtaining atmospheric parameters as a key ingredient of the models; Gaia benchmark stars
- ✓ Stellar ages: uncertainties in the models and their impact on the determination of ages
- ✓ Asteroseismology: importance of obtaining dynamical masses
- ✓ Distance scale: systematic errors in the determination of the distance scale as a result of the theoretical assumptions, ultimately affecting the determination of the Hubble constant

Day One

First day of the workshop started with the introductory talk of Nicolas Walton (Cambridge). He gave an overview of the COST action activities so far, presented the MW-Gaia work plan and the plan for the future workshops and activities. Second speaker was Giorgia Busso (Cambridge) who presented Gaia DR3 update. Her talk was divided in three parts. In the first part she presented the update of the Gaia mission and future plans for the mission. Second part was about Gaia EDR3 and DR3 and what the improvements will it have. The final part of her talk was about Gaia and comparison with other surveys. Rosanna Sordo (Padova) continued with Gaia DR3 updates and focused her talk on astrophysical parameters. She explained APSIS (Astrophysical Parameters Inference System) in great detail. Also, she added that CU8 will publish ~300 parameters in DR3 and since they have many modules treating the same source, multiple versions of parameters will be provided. Rosanna also explained the database structure and pointed out how all Gaia product must be validated before publication (CU8 and CU9 validation). The session continued with the invited talk on variable stars in Gaia DR3 by Gisella Clementini (Bologna). She gave an overview of Gaia and variable stars in general, variable stars in DR1 and DR2 and she explained that DR3 will provide variable star classifications together with the epoch photometry for 5-10 million variable stars of different types, and also that it will provide a pencil beam survey with integrated epoch photometry of all sources centred on the Andromeda Galaxy. That cone with 5.5-degree radius contains in total about 1 million sources both in M31 and the Milky Way. Also, Gisella presented her results for Cepheids and RR Lyrae, distance and HO determinations she obtained using DR2.

After a short break, the session continued with another invited talk by Vardan Adibekyan (Porto) on frontiers of stellar spectroscopy and the precision – accuracy interface. At the beginning he explained the difference between precision and accuracy, why the accurate/precise parameters/abundances are important and he described main and less popular spectroscopy techniques. After showing the results he concluded that high precision parameters and abundances can be determined for solar-type stars using high quality spectra. Accuracy of these stellar parameters and abundances can be off by a small factor. High-quality spectroscopic information can help to improve the models, which will in turn help to improve the accuracy of spectroscopically derived parameters. Next on was Andrea Miglio's (Birmingham) invited talk was on stellar physics with combined astrometric and asteroseismic constraints, opportunities and caveats. In the introduction he explained basic principles of seismic inference and continued with

availability of the data. He described *Gaia's* contribution in asteroseismology and gave three examples: testing seismic determination of radius – he pointed out that seismic mass and radius are strongly correlated, testing models of stellar evolution and calibrating model parameters. At the end he added *Gaia's* influence on adding information about the kinematics.

First talk of the afternoon session was given by Marica Valentini (Potsdam) who continued the topic with combining asteroseismology, spectroscopy and Gaia for metal poor stars. She introduced the method for obtaining the ages of metal poor stars and also explained the identification of the good candidates. She presented her latest results and explained Gaia's contribution in her research with distance and proper motion data. Marica concluded her talk with listing the future developments in the field. Next, Diego Bossini (Porto) presented the work Bayesian tool PARAM that was utilised in conjunction with the Gaia parallaxes in order to derive new constraints for stellar ages and masses. Next speaker was Felix lacob (Timisoara) whose topic was electron scattering in interstellar media. At the beginning, he gave a brief overview on plasma astrophysics and molecular species studied. He also pointed reasons why is the research in this field important and stressed importance of understanding the origin of matter, knowing the nature of the interstellar dust and chemical evolution. Felix also introduced methods and databases used. At the end he presented his results and announced the work in progress. Nicolina Pop's (Timisoara) was the final talk of the first day. Nicolina discussed the kinetic modelling in astrophysics. She presented her work on vibrational excitation and dissociative recombination of electrons with: H2 +, BeH+ and their isotopomers. First she introduced theoretical considerations, then continued with importance of rotational effects and later with H3+ dissociative recombination where she presented her latest work on three and two channel models. The first day was concluded with an open discussion of the topics that were presented.

Day Two

The first session of the second day was opened by Marcella Marconi (Naples) with her invited talk on theoretical constraints on the Hubble constant tension based on Cepheid models. She pointed out that the ESA Gaia mission will significantly contribute to reduce the uncertainties on the Cepheid-based local determinations of the Hubble Constant and the Hubble constant Tension and also for calibration of the extragalactic distance scale. Furthermore, she presented a theoretical approach to understand the residual systematics which is based on updated 1D nonlinear convective pulsation models. At the end of her talk she pointed another challenging aspect: the consistency between Cepheid and RR Lyrae distance scales. Richard Anderson (ESO) then presented his latest results related to the subject. He discussed the stellar association bias and how it affects H0. He concluded how there will be no solution to the discord related to H0 without improved systematic uncertainties. Next speaker was Louise Breuval (Paris) who presented her work on calibration of the Cepheid period-luminosity relation from Gaia DR2 visual binaries and its implications on the distance scale. She explained how, by using companion's parallaxes, it is possible to bypass the bias on Gaia DR2 Cepheid parallaxes and also calibrate the Leavitt law with non – HST (Hubble Space Telescope) parallaxes. Also, she described the re-scaling of H0 using Gaia DR2 parallaxes for Cepheid companions. In conclusion Louise added that they expect Gaia DR3 to provide a precise value of the parallaxes offset and also better Cepheids parallaxes. Last speaker before the short break was Giulia De Somma (Naples) whose talk was about modelling Galactic Cepheids in the Gaia photometric system. She explained how they obtained the individual distances and parallaxes from the Gaia light curves while obtaining the first theoretical PL, PLC, PW relations in the Gaia filters. At the end of her

talk she mentioned that these relations have been tested against *Gaia* DR2 parallaxes and that the results suggest a parallax offset for *Gaia* Cepheids consistent within the uncertainties with results published by other authors.

After a short break, Monika I. Jurković (Belgrade) gave a talk on Type II and Anomalous Cepheids in the Milky Way. She presented her results on Galactic kinematics for the Gaia DR2 sample of these types of stars where the results obtained for MW Bulge, Halo, Thick and Thin disc were presented separately. At the end she showed the distribution of Type II Cepheids in the Milky Way compared to their metallicity. Ivanka Stateva (Sofia) presented her results on modelling the binaries of W UMa type stars and Gaia distances. By using photometry and spectroscopy data together, they obtained simultaneous light curve and radial velocity curve solution which allowed them to determine the target distances from the global parameters of the targets. Calculated distances obtained of PHOEBE were compared to those of Gaia which proved the accuracy and adequacy of their model, used temperature and reliability of the PHOEBE itself. Last talk in the morning session was given by Krešimir Pavlovski (Zagreb) on quantitative spectroscopy of high mass stars in binary systems. His main topics were related to acquiring precise and accurate fundamental stellar quantities, discrepancy between dynamical and evolutionary mass of high-mass stars and the correlation with age and surface gravity. Furthermore, no pronounced changes in the surface CNO abundances are found, so far, for the high mass stars in binaries in a range of M = 8 - 22 MO, contrary to single stars. An important question was raised as to what is suppressing the internal mixing and transport of CNO products to the surface layers in binary components.

First talk of the afternoon session was given by Ewa Niemczura (Wroclaw) who presented her results on chemically peculiar Am stars in the observations of TESS. Ewa described how the peculiarities arise from segregation of chemical elements under the influence of atomic transport processes. She used the data from TESS for variability, different spectroscopic surveys and Gaia data for parallaxes. Pablo Santos (Nice) presented his results on high-precision magnesium abundances in the metal-rich Galactic disk. They developed a method not depending on the stellar parameters that allowed them to use strong saturated lines, increasing the line-to-line precision. They also found decreasing trend in [Mg/Fe] even at supersolar metallicities, observational evidence of radial migration and no correlation [Mg/Fe] vs. Age. Tomislav Jurkić (Rijeka) gave a talk on symbiotic binaries in the era of large surveys. He explained the importance of the symbiotic stars in general and how Gaia distances, stellar parameters, radial velocities and photometry will greatly improve the research in this field. Stefan Cikota (Zagreb) then gave a review talk on determination of stellar radii by observing asteroid occultations with MAGIC. He pointed out that observations of diffraction fringes enable a direct measurement of the angular size of the star, even though that may be far below the imaging angular resolution limit of the telescope. He also presented his results on diffraction pattern for monochromatic and polychromatic stellar light and also his progress in convolution with 1D kernel to the fringes. Last talk of the second day was given by Milan S. Dimitrijević (Belgrade) and the topic was Stark broadening data for better stellar atmospheres and interiors modelling. He explained the needs for large line broadening data set and presented databases for Spectral Line Shapes, specially he presented the STARK-B database. The second day was concluded with a discussion session related to the presented topics.

Day Three

Last day of the workshop started with the invited talk of Léo Girardi (Padova) on stellar population models for the star counts in *Gaia* catalogue. He gave an overview of the

models that reproduce the stellar content of the Milky Way and a comparison with the Gaia DR2 HR diagram. Léo concluded that it is possible to make quite good models for star counts in Gaia DR2. He commented that with better modelling of parallax errors, IMF and extinction it could be possible to get the agreement <20% everywhere. A discussion of the current state of the models followed. Some important issues were pointed out (e.g. overshooting, rotation and asteroseismology of stars in field and clusters). He also pointed out that for binary evolution and TP-AGB, there is a clear avenue for improvement – GDR2 + data from present wide-area surveys of nearby galaxies are already being used. Matko Milin (Zagreb) gave a nice review talk about open problems in stellar nuclear astrophysics and also covered topics like instrumentation and techniques. He explained stellar nucleosynthesis from hydrogen, helium and carbon burning to the synthesis of the elements heavier than iron (S and R processes). At the end he gave prospects for future research. Since the next speaker, Petar Zečević (Zagreb) had to unexpectedly leave, Lovro Palaversa (Zagreb) presented his talk on the AXS, a framework for fast astronomical data processing based on Apache Spark. Although Spark already provides a significant fraction of functionality needed, AXS adds additional methods to make astronomers lives easier. It has two extensions to make cross matching and processing fast: specific data partitioning scheme and sort-merge join optimization. A plan for future developments was also laid out. The final speaker was Fran Jiménez-Esteban (Madrid) with his talk on determination of stellar physical parameters using VOSA. He explained in great detail how Virtual Observatory and its interfaces can enhance the research and how can they be used in the most efficient manner.

After a short break, there was a hands on session that concluded the workshop. Fran showed how VOSA works in practice. The participants followed a set of exercises that showcased the capabilities of VOSA.



The workshop in numbers

The workshop was attended by 37 researchers, 46% of them female.

The SOC and LOC had a 44 and a 50% of female researchers respectively.

From the total, 17 participants (46%, including invited speakers) had financial support by the COST Action.



There were researchers from 12 different countries in Europe (mostly Croatia).

There were 26 presentations. All female participants presented while 65% of male participants did. There were 6 Invited talks (33% female) and 20 Contributed talks (55% female).

Regarding career stage there were 10 PhD students and 6 Early Career Researchers (43% of young researchers).

Report prepared by Lovro Palaversa, Marta Fatović and Lola Balaguer-Núñez.



The workshop <u>The Galactic Centre and the Inner Galaxy</u> took place online organised by the Center for Astronomy of Heidelberg University, from 10th to 12th February 2021.

This was the fifth workshop of the CA18104 COST Action MW-Gaia and the first, which was held completely online due to the COVID-19 restrictions. It was the second workshop of the Working Groups 1 and 4. The format of the workshop was based on invited key presentations and contributed talks, e-posters, a practical hands-on session for EDR3, and dedicated discussions.

A main channel in Zoom was defined for plenary sessions and breakout channels for additional focussed discussions and meetings. Slack Channels were set up for dedicated chats.

Scientific motivation of the workshop

The inner regions of our Milky Way are dominated by the Galactic bar and a classical bulge. The barred potential causes gas to flow inwards and form stars in the central few 100 parsecs. Over time this process may have built up the nuclear stellar disk, also found at these radii. At the very centre, the nuclear star cluster surrounds the Galactic supermassive black hole, Sgr A*. The larger inner bulge region also contains the highest-density parts of the Milky Way's stellar halo, and perhaps a classical bulge component.

After this workshop, the Gaia data release EDR3 was released on Dec. 3, 2020, based on 34 months of observations. Compared to DR2 improvements in completeness and astrometry (20% in parallaxes, factor of two in proper motion) were expected. Additionally, more information on the parallax zero point was going to be included and the basis of the Celestial Reference Frame (CRF) extended to 1.5 million objects, a factor of three more.

This three-day workshop in (virtual) Heidelberg, was focused on the impact of the ultraprecise Gaia astrometry on our understanding of the structure and dynamics of the Galactic bar and bulge region including the interrelation with the inner halo, the nuclear stellar disc and the central star cluster. Chemical enrichment, ages and the assembly history were also covered. The celestial reference frame, zero points of parallaxes and proper motions, as well as questions of fundamental physics were discussed. Also first results based on EDR3 were presented.

Topics Covered

- ✓ Gaia EDR3: overview, completeness
- ✓ Gaia Ref Frame: zero points in parallax and proper motion, fundamental physics and relativistic effects using Gaia and VLBI, Sgr A* and testing GR
- ✓ Bulge, Bar and Inner Halo: kinematics, dynamics, mass distribution
- ✓ Bulge, Bar, Inner Halo: metallicity-orbit distribution and stellar ages
- ✓ Bulge, Bar, Inner Halo: critical discussion on stellar ages in Bulge, assembly history from (hydro-)dynamical and cosmological simulations
- ✓ Nuclear Disk, Gas Inflow and Star Formation

In each session there were invited review and contributed talks followed by a general discussion. Additionally, we offered short presentations of e-Posters and a hands-on session to learn how to use the Gaia EDR3 data.

Online Mode of Workshop

Since the workshop was fully online, we accepted more than 200 participants. This workshop was run online via Zoom with a number of parallel channels:

- One main channel for plenary sessions
- One channel for EDR3 hand-on sessions
- Three breakout channels for presentations (oral and e-Posters) for additional focused discussions and meetings.
- One additional free channel for spontaneous meetings (appointments via Slack or email).

Additional Slack Channels were set up for dedicated chats and a repository of questions and answers concerning the presentations.

A dedicated workshop website was setup to accompany the workshop. This website

- Summarized the mission statement of this workshop
- Provided the current workshop program which linked talks to abstracts and video recordings
- Presented workshop representatives in the SOC/LOC to the participants
- Gave instructions to participants regarding presentations, ZOOM issues, e-Poster presentations
- Linked Talks and Abstracts
- Provided access to video recordings of presentations more or less immediately after each session
- Informed about workshop news and current changes

Overview and summary of workshop sessions

Day One

Session 1: Gaia and EDR3

The first session started with an overview over the COST action MW-Gaia by Nicolas Walton, followed by an introduction by Carine Babusiaux (Paris) on the "Gaia satellite & EDR3: Status, Overview, Completeness.". The great interest and importance of the new Gaia data release EDR3 was demonstrated by three contributed talks, which show first results already a few weeks after the data release: Céline Reyle discussed "The solar neighborhood kinematics from Gaia EDR3" based on the Gaia Catalogue of Nearby Stars (GCNS); Vikrant Jadhav identified about 2000 blue (and yellow) stragglers in 300 open cluster by "A search for Blue Stragglers in Galactic Open Clusters"; Eugene Vasiliev used the "Gaia EDR3 view on Galactic globular clusters", especially the kinematic structure, in order to demonstrate that the formal uncertainties of Proper motions in EDR3 are underestimated by 10-20%.

Anthony Brown (Leiden) led a question-and-answer session on Gaia EDR3, where a lot of interesting aspects were discussed. Session 1 was completed by the Hands-on to EDR3 hold by Hendrik HeinI and Stefan Jordan (Heidelberg), which was also planned as part of the plenary sessions, because about 2/3 of all participants had registered for this course (about 90 people joined the course). An introduction to the usage of the EDR3 data and Topcat (a convenient tool for quick and also complex investigations) was given. A homework was posed for the next day, which was discussed in the lunch break of day 2.

Session 2: Reference Frame and fundamental Physics

In session 2, Mario G. Lattanzi (Torino) gave an excellent overview over fundamentals, i.e. "Reference frame, zero points, and relativistic effects; The impact of full GR solutions at the Milky Way scale: from the inner Galaxy outward"; Complementary to standard physics Sankha Chakrabarty discussed in a contributed talk alternative gravity by "Probing MOND with hypervelocity stars.". The result is still inconclusive, but more precise observations in the future can exclude the QUMOND theory, if the predicted limit of tangential velocities is exceeded.

The series of 11 e-Poster presentations (in machine gun style: 1 slide, 2 minutes each) proves in an impressive manner the variety of potential applications of Gaia data:

- Aaron Bryan "Far Infrared view of the Galactic Centre Circumnuclear Disk"
- Frances Cashmen "3D Structure of the ISM around the Galactic Center"
- Chirag Chawla "Gaia may detect hundreds of black holes"
- Paola Re Fiorentin "Icarus: a Flat and Fast Prograde Stellar Stream in the Milky Way disk" (also as contributed talk: Paola was able to jump in and replace a canceled talk over night)
- Francesco Conte "Gamma-gamma absorption in the Galactic Center2"
- Kosmas Gazeas "CoBiToM Project Contact Binaries Towards Merging"
- Priya Hasan "New Insights in Mass Segregation using Gaia"
- Mercedes Mollá "The rapid time evolution of the abundance gradient: the flattening due to gas mixing"
- Sara Ortega-Martinez "Inner discs? An insight on the inner region of simulated disc galaxies"
- Mohammad J. Shahhoseini "A detailed study of Radio-IR correlation in Dwarf irregular galaxies (Magellanic clouds)"

• Lukasz Wyrzykowski "Invisible population of remnants in the Galactic Centre revealed with microlensing"

After coffee break two invited talks on the additional value of other instruments were highlighted: Mark J. Reid (Cambridge MA) showed based on absolute "Parallaxes and Proper Motions from VLBI" that SgrA* is at rest and must be supermassive and Frank Eisenhauer (Garching) presented "Relativistic effects in the orbit of star S2 from GRAVITY". Then Paola Re Fiorentin jumped in for a cancelled talk presenting the discovery of "Icarus: a Flat and Fast Prograde Stellar Stream in the Milky Way disk". Session 2 was finalized by a general discussion led by Anthony Brown (Leiden).

Day Two

Session 3: Bulge, Bar and Inner Halo I

The morning started with a review talk of Juntai Shen (Shanghai) on "Bulge, Bar and Inner Halo: Kinematics, dynamics, and mass distribution" to provide a comprehensive basis for the following sessions. Angeles Perez-Villegas (Sao Paulo) was invited to speak on the usage of "Globular clusters and their orbits in the bulge" to derive properties of the inner halo. Jonathan Clarke gave a contributed talk on "Global Parameters of the Milky Way - Sun System; Insights from VIRAC and Gaia", which was focused on the determination of the bar pattern speed combining VIRAC proper motions of red clump stars with the Gaia reference system. After lunch Andrea Kunder (US) talked about the "RR Lyrae distribution and kinematics: what do these stars represent?" She showed that 25% of the sample are halo interloopers and the rest is a combination of bulge/bar stars and a centrally concentrated population. More properties of the bar structure and kinematics were discussed in contributed talks by Dongwook Lim on "A new view on the double red clump in the Milky Way bulge through luminosity and color distribution", Mercè Romero-Gomez (Barcelona) by "Dissecting the kinematics of the Galactic bar", and Rain Kipper with "Measuring torque of bar from Solar Neighbourhood". Ortwin Gerhard (Munich) chaired the final discussion of this section.

The tutorial of the hands-on session by Henrik Heinl and Stefan Jordan (Heidelberg) in the lunch break was visited by about 1/3 of those, who joined the hand-on course.

Session 4: Bulge, Bar and Inner Halo II

This session, which was focusing on ages and metallicities, was the largest session of the workshop. In four invited talks different aspects of age distributions, correlations to kinematics and abundances were discussed: Anna Barbara Queiroz (Postdam) on the "Metallicity-orbit distribution in the inner Galaxy"; Thomas Bensby (Lund) on "Ages from microlensed stars"; Elena Valenti (Garching) on "Ages of bulge stars from colour-magnitude diagrams and globular clusters"; and Diane Feuillet (Lund) on the "Distribution of stellar ages in the bulge". This was complemented by contributed talks of Carme Gallart (Tenerife) on "Unbiased age distributions for the Milky Way inner halo and disk through colour-magnitude diagram fitting", Anke Arentsen on "Finding the most metal-poor stars in the inner Galaxy with PIGS", Andreas Koch-Hansen on "Chemodynamics of stellar oddballs in the bulge", and Shola Wylie on "Abundance maps of the Milky Way's b/p bulge and long bar using the combined A2A and APOGEE surveys".

This session was not finished on Thursday and continued on day 3.

Day Three

Session 4 was finalized by a contributed talk of Henrique Reggiani on "A Thermonuclear Explosion in the inner Bulge Slides" to explain the odd abundance pattern of a metal poor bulge star, and the general discussion led by Andreas Burkert.

Session 5: Bulge, Bar and Inner Halo

Session 5 was also on ages but illuminating the assembly history of the inner Galaxy. Andrea Miglio (Birmingham) started with an invited talk on a "Critical Discussion of Stellar Ages in the Bulge" critically comparing different methods of age determination. Li Zhi introduced the kinematics of the ISM in a contributed on "Gas Dynamics in the Galaxy: Mass distribution and Bar Pattern Speed". Then Françoise Combes (Paris) was invited to present the "Assembly history from (hydro)dynamical and cosmological simulations", which was supplemented by a contributed talk of Francesca Fragkoudi (Garching) on "The formation and properties of the Milky Way's bar and bulge according to cosmological simulations". Two more contributed talks by Horta Danny on "The galaxy within the Galaxy: Evidence from APOGEE for the presence of a major building block of the Milky Way halo buried in the inner Galaxy" and by Diederik Kruijssen on "A sleeping giant in the inner Galaxy - the merger history of the Milky Way reconstructed with cosmological simulations of the globular cluster population" together with the general discussion chaired by Lia Athanassoula finalized this session.

Session 6: Nuclear Disc and Star Cluster

The last session focused on the very centre of the Milky Way. Francisco Nogueras-Lara (Heidelberg) was invited to talk on "The Nuclear Disc" and Anja Feldmeier-Krause (Chicago) on "The Nuclear Star Cluster". In two contributed talks Brian Thorsbro on "Clues to galaxy evolution from chemical abundances of stars in the Galactic centre" and Sergey Khoperskov on "Bar-spirals coupling in the Milky Way: fuelling galactic nuclei and multiple populations in the chemical abundance space" discussed the formation of the Galactic nucleus. Mattia Sormani (Heidelberg) was invited to discuss the "Galactic Centre: Gas Inflow and Star Formation". Then, two contributed talks by Jason Sanders on "Kinematics of long period variables in the central nuclear disc" and Alessandra Mastrobuono on "Star formation at the Galactic Centre: coevolution of multiple young stellar discs" completed the presentations of the workshop. Rainer Schödel led the final Discussion on session 6.

The workshop in numbers



The workshop was attended by 203 researchers (online), 29% of them female. The SOC and LOC had a 44 and a 40% of female researchers respectively.



There were researchers from 30 different countries in Europe (mostly Germany), US, Chile, Argentina, Mexico, Canada, Brazil, China, India, Nepal, Taiwan e Iran.

There were 51 presentations. 38% of female participants presented while 20% of male participants did. There were 18 Invited talks (44% female), 22 Contributed talks (41% female) and 11 eposters (45% female).

Report prepared by Andreas Just, Guido Thimm and Lola Balaguer-Núñez.



MW-Gaia WG5 Workshop Bringing the Milky Way to schools online, 2nd-4th June 2021

The workshop <u>Bringing the Milky Way to schools</u> took place virtually hosted by Instituto de Astrofísica e Ciências do Espaço (Porto, Portugal) and Vilnius University (Lithuania), from 2nd to 4th June 2021.

This was the first workshop of the Working Group 5 of the MW-Gaia COST Action CA. The submission of talks and poster presentations on all topics was encouraged. We also encouraged posters from schools, astronomy clubs or astronomy enthusiasts to tell the success story of educational activities. Two poster prizes were issued to the best poster and the best poster from school.

A main channel in Zoom was defined for plenary sessions and breakout channels for additional focussed discussions and meetings. Slack Channels were set up for dedicated chats.



Scientific motivation of the workshop

MW-GAIA main purpose is to provide a better understanding of the Galaxy, its stars and planets, to enhance the potential of the community in its scientific exploitation of the observations of more than a billion stars with the European Space Agency's *Gaia* satellite, and to enhance the development of the next steps in astrometry and space astrometry missions.

During this three-day workshop we brought together the research, the teaching and the science communication communities. This was done by presenting the work that has been done throughout the years on the exploration of our Milky Way, but also the attempts of turning this knowledge into useful and powerful tools for teaching, astronomy outreach and communicating science in general.

This workshop fits the Action by aiming to leave a significant legacy, creating a dynamic and vibrant network of researchers with expertise in the study of the Milky Way and teachers that aim to make their classrooms more engaging by using the Milky Way as a learning tool. The participation in this workshop aims to be inclusive, irrespective of gender or location.

Topics Covered

- ✓ The Milky Way as a Galaxy: the science and research background
- ✓ Dissemination of the GAIA science
- ✓ Bringing the research closer to the public
- ✓ Teaching the Milky Way in schools
- ✓ How to make teaching and science communication more inclusive



The workshop in numbers

The workshop was attended virtually by 190 researchers, 59% of them female (3% unknown).

The SOC and LOC had a 100% (6 out of 6) and a 20% of female researchers (1 out of 5).



There were researchers from all continents and 39 different countries: Europe (mostly PT), the Americas (United States, Mexico, Argentina, Colombia, Canada), Middle East (Syria, Iraq) Asia (Bangladesh, Pakistan, Japan, India, Azerbaijan, Vietnam, Indonesia, Malaysia), Africa (South Africa, Ethiopia, Madagascar).

There were 32 presentations. 14% of the female participants presented something while 22% of male participants did. There were 6 Invited talks (67% female), 13 Contributed talks (46% female) and 13 Posters (46% female).

Report prepared by Lola Balaguer-Núñez.

MW-Gaia WG3 Workshop



Asteroids and comets: revealing the history of the Solar System

Helsinki (Finland), 28th-29th September 2021

The workshop <u>Asteroids and comets: revealing the history of the Solar System</u> took place hybrid, hosted by department of Physics of University of Helsinki, from 28th to 29th September 2021.

This was the second workshop of the Working Group 3 of the MW-Gaia COST Action. The program is composed of invited oral presentations with a duration of 20 min each (15 min for the talk, 5 min for questions, answers, and change of speaker). Additionally, there will be specific sessions for discussion. The workshop attendance was by invitation only, with the restriction of maximum 25 participants on site. The workshop was organized in hybrid mode with participants attending virtually and on site. Both modes of attendance involved scientific presentations via Zoom. Mankeliaitta of the Krapi Conference Center (Tuusula, Finland) served as the workshop venue, with accommodation at the Onnela premises.

Scientific motivation of the workshop

Asteroids and comets are the key to the evolution of the Solar System. These small Solar System objects (SSOs) are being systematically observed, with unprecedented precision in photometry, spectroscopy, and astrometry, by the ESA *Gaia* space mission. The workshop will cover the synergies and challenges in the combination of *Gaia* data and data from other sources, that is, from ground-based astronomical observations and space missions to small SSOs. The former includes astrometry, occultations, spectroscopy, polarimetry, and photometry, whereas the latter include the high-resolution observations of asteroid Ryugu by the Hayabusa2 mission (JAXA), of asteroid Bennu by the OSIRIS-REx mission (NASA), and of Comet 67P/Churyumov-Gerasimenko by the Rosetta mission (ESA). How *Gaia* relates to future SSO space missions, such as DART (NASA) and Hera (ESA), Comet Interceptor (ESA), and Destiny+ (JAXA), was addressed.

The workshop improves the understanding of the physics of small SSOs to draw inferences on their origin and formation. Topics covered, for example, exploitation of the extraordinary accuracy of, first, *Gaia* astrometry for orbit improvement, navigation to mission targets, and asteroid mass determination, and, second, *Gaia* photometry for the retrieval of asteroid phase curve parameters, shapes, and rotational characteristics. Tutorial sessions are organized using pre-recorded videos on data analysis techniques in astrometry and photometry, including applications of machine learning techniques to large samples of asteroid data.



The workshop in numbers



The workshop was attended by 33 researchers, 36% of them female.

The SOC and LOC had a 33% (1 out of 3) and 50% of female researchers (3 out of 6) respectively.

From the total, 14 participants (42%, including invited speakers) had financial support by the COST Action.



There were researchers from 12 different countries: Europe (mostly FI), the United States, China and Korea.

There were 31 presentations (42% female).
Report prepared by Lola Balaguer-Núñez.



The workshop <u>Star Clusters: The Gaia Revolution</u> took place online organised by the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) and the Institut d'Estudis Espacials de Catalunya (IEEC), from 5th to 7th October 2021.

This was the third workshop of Working Group 1 and the second workshop of the Working Groups 2 of the MW-Gaia COST Action. The format of the workshop was based on invited key presentation, contribution talks and short pitch poster talks.



Scientific motivation of the workshop

The ESA *Gaia* mission is having a tremendous impact on our knowledge and understanding of small-scale structures in the Milky Way. Stellar clusters are at the crossroads of multiple topics in astronomy and astrophysics, from the formation of stars to their dispersal throughout the Galaxy.

This joint WG1/2 workshop of the <u>EU COST action MW-Gaia</u> covered various topics such as stellar associations, open clusters in the Milky Way disc, globular clusters and streams in the halo, as well as synergies between *Gaia* and other missions and observational campaigns.

The sessions were distributed over three half days, and were entirely online.

Main topics and invited speakers were:

- ✓ Young stars and star forming regions (Phillip Galli)
- ✓ Stellar evolution and asteroseismology (Andrea Miglio)
- ✓ Data mining in the Gaia catalogue (Marina Kounkel)
- ✓ Cluster dynamics (Eugene Vasiliev)
- ✓ Chemistry and synergies with ground-based surveys (Laia Casamiquela)
- ✓ Clusters as tracers of the Galactic structure and history (Angela Bragaglia)



The workshop in numbers

The workshop was attended by 363 researchers, 36% of them female, and 5% unknown.

The SOC and LOC had a 38% (3 out of 8) and 75% of female researchers (3 out of 4).



There were researchers from 46 different countries: Europe (mostly ES and IT), the Americas (United States, Chile, Brazil, Mexico, Uruguay, Colombia, Peru, Canada, Argentina), Middle East (Iran, Israel) Asia (China, Bangladesh, Pakistan, Japan, India, Indonesia, Malaysia, Philippines, Nepal, Korea) and Australia.

There were 26 presentations. 44% of the female participants presented something while 35% of male participants did. There were 7 Invited talks (29% female) and 19 Contributed talks (11% female).

Report prepared by Lola Balaguer-Núñez.



The workshop <u>Breaking Barriers: Inspiring the Next Generation</u> in the University of Santiago de Compostela, Spain, from 23rd to 25th December 2022.

This was the ninth workshop of the CA18104 COST Action MW-Gaia and the second workshop of the Working Group 5 (WG5). The format of the workshop was based on invited reviews, contributed talks and posters.



Scientific motivation of the workshop

This three-day school covered topics related to improving inclusion in the science process, how this leads to better science, and more impactful science. In the school the MW-Gaia community discussed, with the help of professionals from several scientific and social disciplines, current best practice in inclusion and impact and learned about possible new initiatives and solutions.

Speakers showed how their Equality/Diversity/Inclusion commitment is fundamental in underpinning their research.

Topics for the School included:

- ✓ public engagement with research
- ✓ practical skills on engagement with different audiences (including policy-makers)
- ✓ practical development of a public engagement project about Gaia.
- ✓ training in social innovation
- ✓ applying scientific knowledge to tackle social issues
- ✓ gender and diversity training
- ✓ contribute to the UN's Sustainable Development Goals

The meeting was especially aimed at WG5 members of the project, who discussed the current state of their work and discussed the future decisions to be taken. Participants were mainly expected from countries that are part of the COST MW-Gaia Action, but the workshop was open to scientists from all over the world, an international participation that was encouraged. Researchers who are in the early stages of their careers and those from underrepresented countries played a key role. The presence of some of the leads of the MW Gaia project, scientists of recognized international prestige, was also expected; as well as high-level astronomers as guest speakers.

In order to enable participation by people who might be unable to attend physically due to travel or time zone constraints or through a wish to reduce the carbon footprint of the event, the meeting happened in hybrid format. There were Invited talks 30 min (25+5) and Contributed talks 15 min (12+3).

Day One

Day one focussed on EDI - what is equity, diversity and inclusion? Participants considered how they identify. How improving diversity, inclusion, in a project can increase the science impact of the project.

After the welcome talks, the first session was dedicated to the "Advances in our understanding of the Milky Way: WG1, WG2". There was a resume of the activities of WG1 by Despina Hatzidimitriou, followed by Danielle de Brito Silva with the talk "The accreted Galaxy: An overview of TESS metal-poor accreted stars candidates".

Gisella Clementini did the resume of the WG2 activities and Saniya Khan talked about "Gaia, stellar models, and asteroseismology", followed by the invited talk by Sara Vitali presenting "Unveil the Sagittarius dwarf galaxy with the Pristine survey". To finish session 1, Carlos Viscasillas explained us "Exploiting the abundances of neutron capture elements from the latest Gaia-ESO Survey (GES) data release".

Session two was dedicated to the "Advances in our understanding of the Milky Way: WG3, WG4". Alessandro Sozzetti gave a resume of the "Milky Way & Gaia: WG3 activities" and Barbara Soares presented "The Chemical link between stars and their rocky planets". Then Fernando Tinaut-Ruano explained "Exploring near-UV region for primitive asteroids using ground-based observations and Gaia".

Sonia Anton presented the resume of the "Milky Way & Gaia: WG4 activities". And there was contributed talks by William Beordo "Gravitational Astrometry & Fundamental Physics to test the dynamical evolution of our Galaxy and its place in cosmology"; Marta González "Galactic hierarchy of clustered stellar formation" and Javier Olivares "The

dynamical interaction of the Coma Berenices open cluster and the GroupX moving group".

After that there was the visit to the observatory and the group photo was taken.

Day Two

Day two considered the application to the case of Gaia. A distributed, Pan European project, with science impact across astronomy, across domains. How the project culture within Gaia aims to promote greater understanding between the team, leading to better science outputs?

Session 3 was dedicated to "MW Gaia inclusiveness and equal opportunities. Gender Balance". Alessandra Zanazzi, invited talk devoted to "An astronomy exhibition, inclusive also for blind and visually impaired people and other INAF inclusive activities". Then Edita Stonkute presented "Mentorship platform for early career researchers". And Paula Jofre gave an invited talk "Inclusiveness and equal opportunities. Gender Balance". And Josefina F. Ling presented "KastronomAs" A journey through the Universe by hand of hundreds of women"

Session 4 was dedicated to the posters:

- ✓ Tineke Roegiers "Female contribution to the Gaia DPAC consortium"
- ✓ Minia Manteiga "Two STEMBACH projects based on Gaia data: introducing Big Data Astronomy in Spanish High Schools"
- ✓ Antoaneta Avramova-Boncheva "Extracurricular activities for school students with special interest in astronomy"
- ✓ Tòfol Tobal "Star Analyser Spectroscopic Data Base. OAG-SVO Pro-Am project"
- ✓ Antoaneta Antonova "STELLAR: an EU twinning project on LOFAR data analysis and knowledge transfer"
- ✓ Judith Ardèvol Guillamón "Disseminating the rotation curve of our Galaxy and its implication on the Dark Matter content"
- ✓ Cecilia Doporto Regueira and Carlos Viscasillas Vázquez "The Museum of Lalin "Ramon Maria Aller Ulloa", the first astronomical observatory in Galicia"

Session 5 was dedicated to "Reaching out to the public with Gaia". First invited talk by Stefan Jordan "Reaching out to the public with Gaia" and then there were three contributed talks: Tineke Roegiers with "Outreach and community resources for Gaia", Pedro P. Campo "Astronomical outreach in the Ramón María Aller Astronomical Observatory" and Marusa Zerjal "A website dedicated to the nearby young open clusters as seen by Gaia".

That evening there was a public talk by Carme Jordi "Los secretos de la Vía Láctea" in Spanish for general public. Followed by the workshop dinner.

Day Three

Day three provided training in communication of ideas, and how this can help reinforce students' ability to actively participate in and promote the development of a positive and inclusive culture within the MW-Gaia network.

Session 6 dedicated to "Citizen science and amateur input" began with an invited talk by Sandor Kruk "From galaxies to asteroids: Citizen science as an efficient tool to explore large datasets". Followed by three contribution talks: Elsa Moreira "CoAstro: @an Astronomy Condo-a new possible path for GAIA's dissemination strategy"; Victor Tilve "Light pollution data from Galicia (Spain): measurements from the Earth" and Eduard Masana "Modelling the natural sky brightness with Gaia data".

Session 7 dedicated to "Bringing Milky Way to schools and universities" began with an invited talk by Jackie Faherty "Visualizing the Gaia enabled Milky Way for Science and Education" and followed by three contributed talks: Rosa M. Ros talking about NASE, an ambitious program of teaching astronomy for everybody "NASE, Astronomy for everybody"; Ederlinda Viñuales with "NASE: Using Demonstrators for Easier Training of Future Teachers" and Hristo Stoev "EAAE's Catch a Star Competition: helping teachers and students". To finish the session, an invited talk by Luis Aguilar about "The next generation of astrometry experts".

Session 8 was devoted to the debate and conclusions and was chaired by Šarūnas Mikolaitis. It was followed by a tourist guided visit to Pazo do Faramello.

The workshop in numbers



The workshop was attended by 85 researchers (55 remotely), 51% of them female.

From the total, 8 participants (9%, including invited speakers) had financial support by the COST Action.



There were researchers from 26 different countries in Europe (mostly Spain), Argentina, Colombia, Chile, Mexico, Brazil, Peru, Costa Rica, US, Nepal, Korea, China and India.

There were 37 presentations. 56% of female participants presented while 31% of male participants did. There were 11 Invited talks (64% female) and 25 Contributed talks (58% female) and 7 posters (86% female).

Report prepared by Lola Balaguer-Núñez.



MW-Gaia WG3-WG2 Workshop

Fundamental stellar parameters from asteroseismology: the connection with exoplanet studies in the era of Gaia

Aarhus (Denmark), 13th-15th June 2022

The workshop <u>Fundamental stellar parameters from asteroseismology: the connection</u> <u>with exoplanet studies in the era of Gaia</u> took place in Aarhus University, Denmark, from 13th to 15th June 2022.

This was the tenth workshop of the CA18104 COST Action MW-Gaia and the fourth/third workshop of the Working Group 3 and 2. The format of the workshop was based on invited reviews and contributed talks.

Scientific motivation of the workshop

The aim of this workshop was to bring together experts on asteroseismology, galactic archaeology, stellar evolution, exoplanets, and Gaia data. Participants discussed the synergies that combining Gaia data with datasets from Kepler and TESS offers, as well as the opportunities to eliminate the remaining stumbling blocks.



The workshop in numbers

The workshop was attended by 63 researchers, 27% of them female.

The SOC and LOC had a 22% (2 out of 9) and a 33% (2 out of 6) of female researchers respectively.



From the total, 6 participants (10%) had financial support by the COST Action.

There were researchers from 20 different countries in Europe (mostly Denmark), US, Australia, Brazil, India, Uganda and Canada.

There were 30 presentations. 47% of female participants presented while 48% of male participants did. There were 13 Invited talks (38% female) and 18 Contributed talks (18% female).

Report prepared by Lola Balaguer-Núñez.



The workshop <u>Stellar variability, stellar multiplicity: periodicity in time & motion</u> took place as hybrid in the Sofia Tech Park, Sofia, Bulgaria, from 6th to 8th June 2023.

This was the fourteenth workshop of the CA18104 COST Action MW-Gaia and the sixth workshop of the Working Group 2 (WG2). The format of the workshop was based on invited talks (25+5min), contributed talks (15+5 min) and poster presentations (2-3 min)

The number of (non-invited) participants was limited to about 40. The selection of participants was based on the relevance of the proposed abstract, the importance of the workshop for the advancement of the career of the applicant as well as diversity (in gender, country, etc). As with all COST actions, early-career scientists were given priority.

Scientific motivation of the workshop

Stellar variability, intrinsic as in pulsating stars and extrinsic as in binaries, plays a crucial role in many fields of astrophysics, from stellar evolution, to the distance scale, to the study of structure and formation of the Milky Way. Gaia DR3 published light curves and characteristic parameters for about 10.5 million variable sources. This number is expected to increase by an order of magnitude in DR4. The workshop will focus on the impact that Gaia is having on a number of different fields addressed by stellar variability

Day One

Session 1: Setting the scene had as a chair Gisella Clementini (Bologna). The first Invited talk by Berry Holl (Geneva, online) was "Gaia-DR3 papers on variable star classifications and light curves in the Gaia-DR3 Special Issue of A&A". Session 2: Classical pulsating stars (Cepheids, RR Lyrae stars) followed with an Invited talk by Marcella Marconi (Naples, in person) "Theoretical efforts in the modelling of Cepheid and RR Lyrae properties in the Gaia bands: from Gaia distances to stellar physics in pulsating stars"

After the coffee break, there were three contributed talks:

- ✓ "Stellar pulsation modeling of Classical Cepheids: new determinations of structural parameters and individual distance" by Roberto Molinaro (Naples, in person)
- ✓ "Constraints on evolutionary status of Cepheid variables from cluster membership" by Ignacio Negueruela (Alicante, online)

 ✓ "MUltiepoch Disparity Examination of H-Alpha and infraRed (MUDEHaR)" by Gonzalo Holgado (Tenerife, in person)

Then we had the invited talk "Metallicities of Gaia DR3 RR Lyrae stars" by Alessia Garofalo (Bologna, in person)

After the lunch break, Laurent Eyer (Geneva) was the chair and a contributed talk by Ranaivomanana Tahina Princy (Nijmegen, in person) "Classification of variable stars observed in multiple filters with MeerLICHT and BlackGEM" ended session 2.

Session 3: Structure of our Galaxy with RR Lyrae stars and Cepheids, began with two invited talks:

- ✓ "RR Lyrae stars as tracers of the structure and formation of the Milky Way halo" by Vasily Belokurov (Cambridge, online)
- ✓ "Cepheids to trace the disc and the spiral arms of the Milky Way" by Vincenzo Ripepi (Naples, in person)

And four contributed talks to finish the day

- ✓ "The distance scale of Type II Cepheids in the Magellanic Clouds" by Teresa Sicignano (Naples, in person)
- ✓ "Are the Ultra Long Period Cepheids standard candles?" by Ilaria Musella (Naples, in person)
- ✓ "Stellar variability for 145 million Gaia DR3 sources from photometric dispersions" Contributed talk, Jesús Maíz Apellániz, Centro de Astrobiología, Spain - In presence
- ✓ "Young, (metal-)rich ad not alone: formation of thin-disc RR Lyrae stars through binary evolution" by Giuliano Iorio (Padova, online)

Day Two

The morning chair was Svetla Tsvetkova (Sofia) and the Session 1: Classical pulsating stars (delta Scuti, Long Period Variables) began with one invited talk "Long Period Variables in the Gaia era" by Thomas Lebzelter (Vienna, in person). Followed by two contributed talks:

- ✓ "Variability study of galactic AGB stars with Gaia data" by Fran Jiménez-Esteban (Madrid, in person)
- ✓ "Magnetic field study in semi-regular pulsating giants" by Renada Konstantinova-Antova (Sofia, in person)

Session 2: Binaries, pulsating stars in eclipsing binary stars (e.g. binarity of Cepheids and RR Lyrae stars), disentangling methods, binaries in clusters, use of binary stars in astrophysics opened with two invited talks:

- ✓ "Binary stars, eclipses and pulsations" by John Southworth (Keele, in person)
- ✓ "Massive binaries in the Gaia era" by Laurent Mahy (Brussels, in person)

And the morning finished with two contributed talks:

 ✓ "The multiplicity fraction in 202 open clusters from Gaia" by Judit Donada Oliu (Barcelona, online) ✓ "The binary fraction in star clusters" by Priya Shah (Hyderabad, online)

The chair of the afternoon was Ivanka Stateva (Sofia) and began with an invited talk by Alexandre Gallenne (Concepción, in person) "Long-Baseline interferometry of binary stars". And two contributed talks to finish the session:

- ✓ "The new 1.5-meter robotic telescope for the Rozhen Observatory" by Evgeni Semkov (Sofia, in person)
- ✓ "Low-mass and sub-stellar eclipsing binaries in stellar clusters" by Nicolas Lodieu (Tenerife, online)

Session 3: Chemically peculiar stars - Early and late stages of evolution (magnetic CP stars, using BP/RP Gaia spectra; T Tau, FU Ori etc.) began with an invited talk by Ernst Paunzen (Masaryk, online) "CP stars using BP/RP Gaia spectra"

After the coffee break a contributed talk by Natalia Posiłek (Wrocław, in person) "The problem of variability of chemically peculiar Am stars" and an invited talk by Zsófia Nagy (Konkoly, in person) "Early and late stages of evolution".

Day Three

The chair of the morning was Fran Jimenez-Esteban (Madrid) on the Session 1: Chemically peculiar stars - Early and late stages of evolution (magnetic CP stars, using BP/RP Gaia spectra; T Tau, FU Ori etc.) with two contributed talks:

- ✓ "Broadening of Ga II spectral lines by collision with charged particles for research of variable stars" by Milan Dimitrijević (Belgrade, in person)
- ✓ "Mercury-manganese stars in the observations of TESS satellite" by Ewa Niemczura (Wrocław, in person)

And Session 2: Synergies and connections between Gaia and other surveys of variable stars – OGLE, LSST, ZTF with two invited talks:

- ✓ "Synergies and connection between the Gaia and OGLE catalogs of variable stars" by Igor Soszynski (Warsaw, in person)
- ✓ "Rubin's LSST as a large-scale time-domain photometric survey" by Zeliko Ivezic (Washington, in person)

After the coffee break, two contributed talks:

- ✓ "Generating LSST synthetic photometry from Gaia XP spectra" by Lovro Palaversa (Zagreb, in person)
- ✓ "Supercomputer 'Bura' as a computing facility for time-domain astrophysics" by Tomislav Jurkic (Rijeka, in person)

And an invited talk by Ashish Mahabal (Pasadena, in person) "Synergies and connections between Gaia and other surveys of variable stars"

The chair of the last session Carme Jordi (Barcelona) was the Poster session (Short presentations, 2-3 min per poster):

 ✓ "Distance - Luminosity discrepancy for binaries with the B[e] phenomenon" by Anatoly Miroshnichenko (Greensboro)

- ✓ "Searching for photometric variability of massive star candidates in IC342" by Antoniya Valcheva (Sofia)
- ✓ "Cepheid Metallicity in the Leavitt Law (C- MetaLL) survey: II.High-resolution spectroscopy of the most metal poor Galactic Cepheids" by Erasmo Trentin (Postdam)
- "Evidence of Hα periodicity in the Be/black hole binary MWC 656" by Kiril Stoyanov (Sofia)
- "Photometric observations of the Dwarf Novae stars DX And, AR And and RX And" by Luba Dankova (Sofia)
- "Variation of emission profile parameters, connected with the binarity of Pleione" by Lubomir Iliev (Sofia)
- ✓ "The classification intricacy of different type of Cepheid variable stars and the case of RU Camelopardalis" by Monika I. Jurkovic (Belgrade)
- ✓ "Reactive collisions between electrons H+ 2 and HD+ molecular cations in the Early Universe: Ro-vibrational transitions and dissociative recombination" by Nicolina Pop (Timisoara)
- "Identification and characterization of detached white dwarf red dwarf pairs using Gaia and ZTF" by Stefan Stefanov (Sofia)

And the workshop finished with a talk by Nic Walton (Cambridge, in person) about "MWGaia, the Action and Doctoral Network with an update on next steps" and the Concluding Remarks by Laurent Eyer (Geneva, in person).



The workshop in numbers

The workshop was attended by 67 researchers (XX remotely), 39% of them female.

The SOC and LOC had a 40 (4 out of 10) and a 67% (4 out of 6) of female researchers respectively.

There were 6 session chairs, 4 female (67%).

From the total, 28 participants (42%, including invited speakers) had financial support by the COST Action.



There were researchers from 20 different countries in Europe (mostly Bulgaria), also US, India and Chile.

There were 42 presentations. 46% of female participants presented while 73% of male participants did. There were 14 Invited talks (21% female), 19 Contributed talks (32% female) and 9 Posters (33% female)

Regarding career stage there were 3 PhD students (4% of young researchers).

Report prepared by Lola Balaguer-Núñez.



The workshop <u>Science and technology roadmap for µas studies of the Milky Way</u> took place as hybrid at the Lund Observatory, Sweden, from 18th to 20th July 2023.

This was the fifteenth workshop of the CA18104 COST Action MW-Gaia and the fifth workshop of the Working Group 4 (WG4). The format of the workshop was highly interactive with a preference of in person participation. All presentation can be found at the meeting webpage.

Scientific motivation of the workshop

This workshop presented the Action's science roadmap/case for sub-µas astrometry in delivering the next advances in our understanding of the Milky Way. The Action influence the future development of Astrometry in Europe. The White Paper to be developed through WG4, will define a science and technical roadmap for the development of next generation astrometry missions. This will be of significant use for exploitation by the European community when responding to opportunities in proposing future space missions, e.g. ESA calls. This workshop involved scientists with interests in next generation Astrometry.

Day One

Session 1: Next generation astrometry in the context of Voyage 2050, had David Hobbs (Lund) as chair and also gave the introductory talk "The GaiaNIR Mission", and three talks:

- ✓ "The JASMINE Mission" by Daisuke Kawata (London)
- ✓ "The Theia Mission" by Fabien Malbet (Grenoble)
- ✓ "A brief review of 70 years with astrometry. From meridian circles to Gaia and beyond" by Erik Høg (Lund)

Session 2: WG1: The Milky Way as a Galaxy: key issues for GaiaNIR, had Xavier Luri (Barcelona) as chair.

- ✓ "Stellar populations in the Galactic bulge: orbital-chemical analysis" by Cristina Chiappini (Potsdam)
- ✓ "GaiaNIR mock catalogues to study the capabilities towards the inner disc" by Mercè Romero-Gómez & Teresa Antoja (Barcelona)
- ✓ "The Milky Way Halo with GaiaNIR" by Alis Deason (Durham, online)
- ✓ "Massive young open clusters" by Ignacio Negueruela (Alicante)

✓ "Galactic Archaeology to its limits" by Else Starkenburg (Groningen, online)

Day two

Session 3: WG2: The Life and Death of Stars: key issues for GaiaNIR with Gisella Clementini (Bologna) as chair.

- ✓ "RR Lyrae stars as distance indicators and metallicity tracers: impact of Gaia and GaiaNIR" by Tatiana Muraveva (Bologna, online)
- ✓ "Star clusters and the Galactic mid-plane" by Tristan Cantat (Heidelberg)
- ✓ "Explore the population of metal-rich RR Lyrae stars with GaiaNIR" by Giuliano Iorio (Padova)

Session 4: WG3: Planetary Systems Near and Far: key issues for GaiaNIR with Santi Roca Fabrega (Lund) as chair.

- ✓ "The Solar System at mas and µas accuracy" by Paolo Tanga (Nice)
- ✓ "Exoplanet demographics in the 2050s: How does GaiaNIR fit in?" by Alessandro Sozzetti (Torino)
- ✓ "Inspection of exoplanetary system properties near and far" by René Heller (Göttingen, online)
- ✓ "Lessons learned from Gaia toward µas astrometry on small solar system bodies" by Daniel Hestroffer (Paris)

Session 5: WG5: Impact, Inclusiveness and Outreach: building the GaiaNIR community inclusively, with Sergei Klioner (Dresden) as chair.

- ✓ "Beyond the Data: Engaging the Public with Astrometry Missions through Visualisations and Fascinating Insights" by Stefan Jordan (Heidelberg)
- "Engaging minorities in science: A Latin American perspective" by Luis Aguilar (Mexico)
- ✓ "Gaia mission: challenges in communication for large data releases" by Tineke Roegiers (Leiden)

Session 6: WG4: Gaia Fundamentals: Space and Time: key issues for GaiaNIR with Sonia Anton (Coimbra) as chair.

- ✓ "A new experiment in near-field cosmology" by Joss Bland-Hawthorn (Sydney, online)
- ✓ "Developments of relativistic aspects of Gaia for next generation astrometry" by Sergei Klioner (Dresden)
- ✓ "Influence and detection of gravitational waves in Gaia-like astrometry" by Robin Geyer (Dresden)
- ✓ "The Gaia bright reference frame using binaries" by Eero Vaher (Lund)

Day three

Session 7: Technical challenges with Nic Walton (Cambridge) as chair.

- ✓ "NIR Detector options" by Guy Rixon (Cambridge)
- ✓ "GaiaNIR Photometric Systems" by Josep Manel Carrasco (Barcelona)
- ✓ "Infrared Full Sky Scanning Mission as a Data Processing Challenge" by Wolfgang Loeffler (Heidelberg)

- ✓ "Experiences from the Gaia in-flight instrument modelling and suggestions for GaiaNIR" by Nicholas Rowell (Edinburgh)
- ✓ "Detection of multiple stellar systems from modern-precision single-epoch photometry" by Gregor Traven (Ljubljana)

Session 8: GaiaNIR discussion, challenges, and next steps. Chairs of the session David Hobbs (Lund) & Nic Walton (Cambridge)

- ✓ How does GaiaNIR rank in national funding programs?
- ✓ Open discussion on who needs to do what first
- ✓ Roadmap towards an L5 proposal



The workshop in numbers

The workshop was attended by 91 researchers (41 remotely, 45%), 26% of them female (5% unknown).

The SOC and LOC had a 44 (4 out of 9) and a 20% (1 out of 5) of female researchers respectively.

There were 8 chairs, 2 (25%) of them female.

From the total, 5 participants (5%, including invited speakers) had financial support by the COST Action (40% female).



There were researchers from 24 different countries in Europe (mostly from Germany and Sweden) and China, Mexico, Japan, Chile, Australia, Canada, India, US and Israel.

There were 30 presentations (20% female). 25% of female participants presented while 38% of male participants did.

Report prepared by Lola Balaguer-Núñez.

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Group photo:

https://www.astro.lu.se/sites/astro.lu.se/files/styles/lu_wysiwyg_full_desktop/public/202 3-07/GroupPhoto.jpg.webp?itok=2lUgQH8L **MW-Gaia WGAll Workshop**



The Milky Way Revealed by Gaia: The Next frontier: MW-Gaia Final Conference

Barcelona (Spain), 5th-7th September 2023

The workshop <u>The Milky Way Revealed by Gaia: The Next frontier: MW-Gaia Final</u> <u>Conference</u> took place as hybrid in the University of Barcelona, Spain, from 5th to 7th September 2023.

This was the sixteenth workshop of the CA18104 COST Action MW-Gaia and the only one regarding all of the Working Groups. The format of the workshop was based on invited talks (25+5min), contributed talks (15+5 min) and poster presentations (2-3 min)

There was an effort to include as many talks as possible. The selection of participants was based on the relevance of the proposed abstract, the importance of the workshop for the advancement of the career of the applicant as well as diversity (in gender, country, etc). As with all COST actions, early-career scientists were given priority. Researchers who had granted STSMs, VMs and ITCs during the Action were encouraged to present their research resulting from the exchanges.

Scientific motivation of the workshop

This conference aimed to highlight the broad range of results based on Gaia data releases, including outputs from the Action working groups, covering the Milky Way and beyond, stars and stellar clusters, Solar system and exoplanets, Gaia fundamentals, and impact, inclusiveness and outreach. The conference also looked ahead to the next generation of astrometry surveys.

There were five sessions corresponding to the five working groups: a report from each WG, followed by an invited talk and contributed and posters contributions for each WG.

Day One

First day began with a "Welcome to the meeting and Goodbye to the MW Gaia Action" from Nic Walton (Cambridge) and a few logistics words from Carme Jordi (Barcelona and host of the Action).

Sonia Anton (Coimbra) presented the report for WG4: Gaia Fundamentals: Space and Time and the invited was "Close stellar interactions from Gaia) by Nadejda Blagorodnova (Barcelona). Then there were four contributed talks:

 ✓ "Dynamical formation of Gaia BH1 in a young star cluster" by Sara Rastello (Barcelona)

- ✓ "Young Star Clusters Dominate the Production of Detached Black Hole-Star Binaries" by Ugo Niccolò Di Carlo (Trieste)
- ✓ "Unveiling black holes in open clusters" by Stefano Torniamenti (Padova)
- ✓ Natal Kicks on Compact Objects: Insights from Gaia's Precision Astrometry" by Yue Zhao (Southampton)

And then three poster pitches:

- ✓ "Follow-up studies of Gaia transients with small and medium-sized telescopes: recent results and findings" by Vira Godunova (Kyiv)
- ✓ "Potential of Gaia BP/RP spectra and LDS sky surveys for study of high z Universe" by Rene Hudec (Ondrejov)
- Characterisation of Gaia alerts using the Virtual Observatory" (online) by Enrique Solano (Madrid)

Then the session dedicated to the WG2: The Life and Death of Stars, began with the report (online) by Gisella Clementini (Bologna), and the invited talk "Gaia RVS spectroscopy: do you really know it?" by Alejandra Recio-Blanco (Nice). Then we had six contributed talks

- ✓ "Young, (metal-)rich ad not alone: formation of thin-disc RR Lyrae stars through binary evolution" by Giuliano Iorio
- ✓ "A Multi-wavelength Study of the Galactic Point Sources in the MeerKAT Galactic Plane Survey with GAIA DR3" by Okwudili Daniel Egbo
- ✓ "The problem of variability of chemically peculiar Am stars" by Natalia Posiłek
- "The white dwarf population revealed by Gaia" by Santiago Torres Gil (Barcelona)
- ✓ "Kinematic study of the Orion Complex in the GAIA era" by Sergio Sánchez-Sanjuán
- "Fine structure in the Sigma Orionis cluster revealed by Gaia DR3" by Marusa Zerjal

And then ten poster pitches:

- ✓ "Analysis and Classification of Hot Subdwarfs Using Artificial Intelligence Techniques and Gaia DR3 data (online) by Carlos Viscasillas Vázquez (Vilnius)
- ✓ "Symbiotic stars in Gaia DR3" (online) by Jaroslav Merc (Prague)
- ✓ "Exploring chemical tagging limitations and feasibility with Gaia-ESO Survey" by Helio Perottoni (Warsaw)
- ✓ "Spectral Classification of Gaia White Dwarfs within 500 pc using a Random Forest Algorithm" by Enrique Miguel García Zamora (Barcelona)
- ✓ "Population synthesis study of the Gaia single and binary white dwarf population within 100 pc" by Alejandro Santos García (Barcelona)
- ✓ "White dwarfs with infrared excess: Gaia and the Virtual Observatory" by Raquel Murillo-Ojeda (Madrid)
- "The Gaia color-magnitude diagram revealing the physics of white dwarfs" by Maria Camisassa (Barcelona)
- ✓ "Reactive collisions of electrons with molecular cations of astrophysical interest: effects to H2+, HD+, H3+" by Nicolina Pop (Bucharest)
- ✓ "Peculiar radial velocities and action values of red supergiant stars in RSGC4" by Sang-Hyun Chun (Daejeon)
- ✓ "New O and Be runaways stars found with Gaia DR3" by Mar Carretero-Castrillo (Barcelona)

To finish the day, we had the report of "WG5: Impact, Inclusiveness and Outreach" by Elsa Moreira (Porto) and the invited talk "The billion ways of using Gaia data" by Tineke Roegiers (Leiden). And a very inspirational contributed talk:

 ✓ "Impact, Inclusiveness and Outreach: Outputs from the MW-Gaia WG5 School" by Dionysios Gakis (Patras)

Day Two

The second day dedicated to Open Clusters inside WG2 began with five contribution talks:

- ✓ "The bright future of open clusters" by Antonella Vallenari (Padova)
- "Detection of open cluster rotation fields from Gaia DR3 proper motions" by André Moitinho (Lisboa)
- ✓ "Mass loss in open clusters" by Duarte Almeida (Lisboa)
- ✓ The new detection of blue straggler stars in 50 open clusters using Gaia DR3" by ChuanYan Li (Shanghai)
- ✓ "Evolution of the Vertical Distribution of Open Clusters in the Milky Way" by Sandro Moreira

And six poster pitches:

- ✓ "On the determination of stellar mass and binary fraction of open clusters within 500 pc" by Yueyue Jiang (Shanghai)
- ✓ "Taking the census of star clusters in the Milky Way" by Ariana Dias (Lisboa)
- ✓ "Calibrating APs of Gaia DR3 with Open Clusters" by Tong Tang (Shanghai)
- ✓ "Hunting for Neighboring Open Clusters with Gaia DR3: 101 New Open Clusters within 500 pc" by Songmei Qin (Shanghai)
- ✓ "Building the largest sample of open cluster masses with Gaia DR3" by Andrija Zupic (Barcelona)
- ✓ "Metallicity determination in open star clusters by exploring Gaia--J-PLUS synergy" (online) by Eduardo Machado Pereira (Rio de Janeiro)

After the coffee break the report on WG3: Planetary Systems Near and Far was presented (online) by Joris de Ridder (Leuven) and the invited talk "Gaia DR3 and colors of the Solar System" by Dagmara Oszkiewicz (Poznan), followed by four contributed talks:

- ✓ "Estimating the Shapes and Spins of Asteroids from GAIA DR3 Photometry" (online) by Eric MacLennan (Helsinki)
- "The Photocenter-Barycenter Effect in Gaia astrometry and its Impact on Asteroid Orbit Determination" (online) by Karolina Dziadura (Poznan)
- ✓ "Shape modelling and spectral classification of asteroids using data from the AS Vidojevica and Gaia DR3" by Gordana Apostolovska (Skopje)
- ✓ "Gaia mission: the true time saver for asteroids shape modelling and spectral classification" by Elena Vchkova Bebekovska (Skopje)

After lunch, Despina Hatzidimitriou (Athens) presented the report on "WG1: The Milky Way as a Galaxy", followed by the invited talk "Chemodynamical models of the Milky Way" by Eugene Vasiliev (Cambridge). Then there were nine contributed talks:

- ✓ "Possible confirmation of the spiral density-wave structure in the solar neighborhood using about 650000 Gaia EDR3 stars" by Evgeny Griv (Be'er Sheva)
- ✓ "Spiral-like features in the disc revealed by Gaia DR3 radial actions" by Pedro Alonso Palicio (Nice)
- ✓ "Radial Wave in the Galactic Disk: New Clues to discriminate different Perturbations" by Chengye Cao (Shanghai)
- ✓ "Modeling the evolution of the Milky Way from Gaia DR3" by Annie Robin (Besançon)
- ✓ "Improving Galactic Disk simulations with Gaia" by Alessandro Mazzi (Padova)
- ✓ "GASTRO library: studying substructures of the Milky Way stellar halo with SPH
 + N-body single merger models" by João Antônio Silveira do Amarante (Barcelona)
- ✓ "Studying Jeans Equations in the Milky Way disk" by Orlin Koop (Groningen)
- ✓ "Gaia DR3 determination of the Galactic bar pattern speed" by Merce Romero-Gomez (Barcelona)
- ✓ "Unveiling the structure and kinematics of the Milky Way disk with A stars" by Judith Ardèvol (Barcelona)

And three poster pitches:

- ✓ "Measuring the Milky Way Potential with the Phase Snail in a Model Independent Way" by Rui Guo (Shanghai)
- "The star formation history of the Galactic disk from Gaia DR3 and the BGM FASt Galaxy model" by Marc del Alcázar i Julià (Barcelona)
- ✓ "Precise stellar ages for Galactic archaeology through machine learning" by Friedrich Anders (Barcelona)

Day Three

The third day we had eleven contributed talks:

- ✓ "Angular momentum of the Classical Cepheids and the spiral structure of the Milky Way" by Marcin Semczuk (Barcelona)
- ✓ "Structure, kinematics and time evolution of the Galactic Warp revealed by Classical Cepheids (online) by Mauro Cabrera (Montevideo)
- ✓ "The Outer Arm of the Milky Way from red clump stars" by Namita Uppal (Ahmedabad)
- ✓ "Beyond Gaia DR3: tracing the [α/M] − [M/H] bimodality from the Inner to the outer Milky Way disc with Gaia RVS and Convolutional Neural-Networks" by Guillaume Guiglion (Heidelberg)
- ✓ "Testing the Milky Way's age-metallicity-velocity dispersion relation and the lowmass star age-rotation-activity relation using white dwarf ages" by Alberto Rebassa-Mansergas (Barcelona)
- ✓ "The chemodynamical properties of the Galactic bulge" by Xiaojie Liao (Shanghai)

- ✓ "Precise abundances of Mg and neutron-capture elements in the Milky Way: chemodynamical relations using Gaia data and chemical evolution models" by Pablo Santos-Peral (Madrid)
- ✓ "Who is In, and Who is Not? Determining the Gaia Survey Selection Function" by Alfred Castro-Ginard (Leiden)
- ✓ "The mass-loss history of the Sagittarius dwarf galaxy" by Chervin Laporte et al. (Barcelona)
- ✓ "The Large Magellanic Cloud dynamics with high resolution glasses" by Óscar Jiménez Arranz (Barcelona)
- ✓ "Multiple phase spirals suggest multiple origins in Gaia DR3" (online) by Jason Hunt (New York)

And three poster pitches:

- ✓ "The Milky Way disc radial abundance gradient from planetary nebulae revealed by Gaia" (online) Oscar Cavichia (Itajubá)
- ✓ "Chemical footprints of the Galactic spiral arms revealed by Gaia DR3" (online) by Eloisa Poggio (Nice)
- ✓ "Where's Waldo? Unveiling a metal-poor extension of the Milky Way thin disc with Pristine-Gaia- synthetic" by Isaure Gonzalez Rivera (Nice)

And the conference concluded with the "Final remarks" by Nicholas Walton (Cambridge)



The workshop in numbers

The workshop was attended by 170 researchers (90 remotely, 8 combining both), 39% of them female.

The SOC and LOC had a 58 (7 out of 12) and a 88%(8 out of 9) of female researchers respectively. There were a 50% of female chairs of sessions (5 out of 10).

From the total, 21 participants (12%, including invited speakers) had financial support by the COST Action (52% female).



There were researchers from 35 different countries in Europe (mostly Spain), China, India, Chile, US, Brazil, Mexico, Canada, Vietnam, Korea, South Africa and Israel.

There were 70 presentations. 40% of female participants presented while 42% of male participants did. There were 5 Invited talks (80% female) and 41 Contributed talks (32% female) and 24 posters (42% female).

Regarding career stage there were 58 Early Career Researchers (34% of young researchers) and a 45% of them women.

Participation survey

After the conference a survey was sent to all participants and 54 answered (32%). In general, all the comments were positive from the participants in person and those online. The full set of answers can be found <u>here</u>.

More than 75% of those that answered thought the length of the meeting, the length of the sessions and of the breaks were fair. More than 85% of the answers said the distribution of the sessions, days and overall schedule was satisfactory, good or very good. **More than 85% though the quality** of the invited speakers, contributed talks, general contents and overall quality was **very good or excellent**.

Regarding the interaction with other participants: 80% agree or strongly agree that the questions after each talk were useful and effectively organised, 78% agree or strongly agree that the scientific discussion was interesting and 61% agree or strongly agree that there was enough social interaction between participants besides the talks.

Some said there were too many talks, some complain that it should have been longer time given. The participants in person suffered when the air conditioning broke and made it more uncomfortable but fortunately it did not disturb the normal cadence of the conference.

Regarding participation. The answers came from 78% in person and 37% online (15% from office and 12% from home). A 15% used both possibilities to attend different sessions online or in person. An 89% would have preferred to participate in person, so

an 11% that were online would have preferred to come, that is similar to the percentage of people who had to cancel their in person participation last minute. More than 66% would prefer hybrid for future meetings.

65% attended more than 80% of the sessions. 70% attended the sessions more than 7 hours per day. Most difficulties to attend the conference were due to external duties, and a 30% did not have any difficulties. More than 52% participated in Q&A after talks, discussions or social events. More than 94% felt comfortable or very comfortable when they asked questions. Nobody felt any kind of misconduct or harassment during the meeting. More than 64% presented something on the conference (talk, report or poster)

Regarding the COST Action, more than a 44% were first time participants in a COST activity, and 24% received some financial support from COST. More than 69% of the participants were from COST countries, 12% from ITC countries and 19% International Partner Countries.

From those who answered the survey 60% were male, so extremely similar to the general participants to the conference. 38% were still students and 21% finished in the last 5 years, so a total of 59% of the responders were ESR.

Report prepared by Lola Balaguer-Núñez.

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Revealed by Gaia: the central halo of the Milky Way

Cambridge (UK), 11th-13th September 2023

The workshop <u>Revealed by Gaia: the central halo of the Milky Way</u> took place as hybrid in the Lecture Theatre of the Hoyle Building at the Institute of Astronomy, Cambridge, UK, from 11th to 13th September 2023.

This was the fourteenth workshop of the CA18104 COST Action MW-Gaia and the sixth workshop of the Working Group 2 (WG2). The format of the workshop was based on invited talks (25+5min), contributed talks (15+5 min) and poster presentations (2-3 min)

The number of participants was limited. The selection of participants was based on the relevance of the proposed abstract, the importance of the workshop for the advancement of the career of the applicant as well as diversity (in gender, country, etc). As with all COST actions, early-career scientists were given priority.

Scientific motivation of the workshop

This MW-Gaia COST Action (<u>www.mw-gaia.org</u>) workshop focused on the central halo of the Milky Way (R<10 kpc). Given its proximity and high stellar density, the inner halo is an ideal target for stellar surveys. However, the central halo remains largely unstudied due to overwhelming contamination from the MW disc and high dust extinction. The inner accreted halo is predicted to host the earliest formed and the most primitive building blocks, but also to contain the strongest contribution from various in-situ components. While "unmixing" the inner halo would be ideal, relatively short dynamical timescales and strong perturbations from the Galactic bar make this incredibly difficult. In this workshop, we discussed the advances that have been made towards characterising the inner halo; focusing on both the accreted and in-situ components, past, present and future tracers of structure and the influence of the Galactic bar in reshaping halo dynamics. We also discussed what, as a community, we would like to focus on next, through synthesising the perspectives of simulators, theorists and observers.

This is an interactive meeting. Equal amount of time will be given to the planned presentations and the discussion sessions.

Topics of discussion:

- ✓ Accreted halo. Can we trace the accreted halo component? If so, in what space is it traced best, through chemistry, dynamics or a combination of both? How close to the Galactic Centre does the GS/E debris get? Is there evidence for additional large accretion events like Kraken/Heracles/Koala? Where are the primitive stars from the earliest accreted and smallest dwarfs?
- ✓ In-situ halo. While the exact formation channels contributing to the in-situ halo are still the subject of debate, three different in-situ channels have been proposed

to contribute to the inner halo of the Galaxy: the pre-disc Aurora/proto-Galaxy, the splashed disc induced by GS/E and earlier mergers and the star-burst. Can we trace and disentangle all three? What are their properties (total mass, shape, density distributions, metallicity distributions)? What is the contribution from disrupted globular clusters?

- ✓ Bar-halo interactions. How can we use bar-halo interactions to constrain the structure, dynamics and formation of the Galactic bar? When was the bar formed? Is there any connection to the GS/E merger? What are the signatures of the bar interaction in the stellar halo and its sub-structure: stream shepherding, chevron perturbations, spinning up, resonant trapping.
- Central MW tracers. RR Lyrae. Red Clump stars. Long Periodic Variables. Metalpoor stars.

Day One

The day began with the invited talk "Galactic halo and Gaia-Sausage-Enceladus main progenitors in cosmological simulations" Azedah Fattahi (Durham) and one contributed talk:

✓ "The diversity and similarity of Milky Way-like stellar haloes with radially anisotropic massive mergers" by Matthew Orkney (Barcelona)

Followed by 30 min discussion: What defines a MW analogue in simulations? Do we have close analogues of MW in any of the simulation suites? Do we need different simulations?

After coffee there were two more contributed talks:

- ✓ "GASTRO library: interpreting substructures of the Milky Way stellar halo with SPH + N-body single merger models" by João A. S. Amarante (Barcelona)
- ✓ "The early assembly history of the Milky Way" by Danny Horta (New York)

Followed by a discussion with topics: What defines the primordial MW? Is it possible to predict and recover the signature of the primordial MW in simulations and observations? What is in-situ?

After lunch there were three more contributed talks:

- ✓ "Mechanics of disk tilting as a result of satellite accretion" by Oren Slone (New York)
- ✓ "Dead man tells tales: MW stellar halo metallicity distribution reveals the past of the GSE-progenitor" by Sergey Khoperskov (Potsdam)
- ✓ "Mock surveys from cosmological simulations of Milky Way analogues" by Alex Riley (Durham)

Followed by a discussion on topics: What is left to be discovered when it comes to GS/E? Have we pinned down the properties of the GS/E-MW encounter? What role did the encounter play in reshaping the MW?

Day Two

The Morning Session began with the invited talk "Chemical signatures of in-situ and accreted stellar populations" (online) by Maria Bergemann (Heidelberg). Then two contributed talks:

- ✓ "Tidal debris from Omega Centauri discovered with chemo-kinematic tagging" by Kris Youakim (Stockholm)
- "Revealing the accretion that fuelled the formation of the Milky Way disk through chemical evolution" by Boquan Chen (Sydney)

It was followed by a discussion on the topics: Best chemical signatures to disentangle in-situ and accreted populations. Globular cluster chemical signatures.

After the coffee break the invited talk "Chemical tagging of the Galactic components: tracing the stellar populations in the inner Galaxy" by Anna Queiroz (Potsdam) was followed by a discussion: When does chemical tagging work best and why? Any new chemical tags that we did not know about?

After lunch the invited talk "Metal-poor stars in the centre of the Milky Way" by Anke Ardern-Arentsen (Cambridge) was followed by two contributed talks:

- ✓ "Chemodynamically Surveying the Ancient Heart of the Galaxy" (online) by Vedant Chandra (Harvard)
- ✓ "Tracing the Old, Metal-Poor Bulge: Milky Way Assembly through Observations of Old Stars" by Keith Hawkins (Austin)

With a discussion on topics: What are the primary drivers of chemical diversity in the lowmetallicity regime? What information is encoded in the chemical abundance scatter?

After the coffee two contributed talks:

- ✓ "Dissecting the Stellar Halo Using Chemistry, Extreme Deconvolution and Principal Component Analysis" by Nicole Buckley (Surrey)
- ✓ "Can we really pick and choose? Benchmarking various selections of Gaia Enceladus/Sausage stars in observations with simulations" by Andreia Carrillo (Durham)

Followed by a discussion on What chemical information is missing from cosmo sims to help us compare observations with models of MW formation? Or vice versa, what information is missing from observations?

Day Three

The Morning Session of the last day began with the invited talk "Stellar populations of the inner Galaxy: structure, kinematics, age and chemistry" by Jason Sanders (London) and two contributed talks:

- ✓ "Kinematic fractionation of the Milky Way boxy/peanut bulge seen in variable stars" by Marcin Semczuk (Barcelona)
- ✓ "CO in Cepheids A route to reduce the dispersion on the Cepheid Leavitt Law (LL) for the Milky Way, and to obtain metallicities for large numbers of Cepheids" by Steve Ardern (Bath)

Then followed by a discussion on: How does the structure and kinematics of the bar depend on chemistry and age? Is there a classical bulge in the MW?

After the coffee break the invited talk "Tracing the low-metallicity planar stars under a rapidly slowing down bar" Zhen Yuan (Strasbourg) and a contributed talk:

 ✓ "Trapped in the disk: constraining the galactic bar properties using planar metalpoor stars" by Akshara Viswanathan (Groningen)

Followed with a discussion on: Are there discernible trends in the sub-structure properties on moving from the outer halo to the inner MW and the disk?

The Afternoon Session brought the invited talk "Bulge/bar formation in numerical simulations" by Victor Debattista (Central Lancashire) and two contributed talks

- ✓ "Accelerated phase-mixing in the stellar halo due to a rotating bar" by Elliot Davies (Cambridge)
- ✓ "Stellar halo substructure generated by bar resonances" by Adam Dillamore (Cambridge)

Followed by a discussion on: When and how was the MW's bar created? Interactions between the bar and the stellar halo.

And a Final discussion after the coffee break to conclude the meeting.



The workshop in numbers

The workshop was attended by 41 researchers (2 remotely), 37% of them female.

The SOC and LOC had a 38% (3 out of 8) of female researchers.

From the total, XX participants (%, including invited speakers) had financial support by the COST Action.



There were researchers from 15 different countries in Europe (mostly UK), US, India and Australia.

There were 24 presentations. 47% of female participants presented while 68% of male participants did. There were 7 Invited talks (57% female) and 17 Contributed talks (18% female).

Regarding career stage there were 4 Early Career Researchers (10% of young researchers).

Report prepared by Lola Balaguer-Núñez.

MW-Gaia STSM



Corrections to Jeans equation in nonequilibrium systems using Gaia DR2

Žofia Chrobáková, PhD student at the Instituto de Astrofísica de Canarias (Tenerife) spent 15 days (01-15/11/2019) at the Instituto Dei Sistemi Complessi (Roma) thanks to a GP1 STSM grant to collaborate with Dr. Sylos Labini.

The Jeans equation (Binney and Tremaine, 1987, Ch. 4.2 (4-29a)) is a tool commonly used to determine rotational velocities of galaxies and subsequently their masses and density profiles. However, the Jeans equation assumes that the studied system is axisymmetric and in equilibrium, which we know is not the case of the Milky Way. The Gaia DR2 data has shown that there are large scale gradients in all components of the velocity field and there are clear deviations from axisymmetry (Gaia Collaboration (2018), López-Corredoira and Sylos Labini (2019)). In this project, she studied the validity of this assumption and aimed to quantify the corrections to the mass estimation for mock galactic system in configuration close to equilibrium.

During the STSM, they studied two different mock galactic systems. First system consists of a thin rotating self-gravitating disk embedded in a spherical dark matter halo with an isotropic velocity dispersion. The second system consists of a self-gravitating rotating disk embedded in a thick and rotating self-gravitating disk: this is obtained as a result of an out-of-equilibrium simulation. She studied the time evolution of the two systems, while they were subject to no external forces, just their internal gravity. She compared the kinematics of the two systems - the velocity components in cylindrical coordinates and their respective dispersions. We also studied the dependence of rotational velocity on galactic height. Then, she compared the probability distribution functions (PDF) of radial and azimuthal velocities, which is not very often studied in astrophysics, but it provides much insight into the behaviour of the systems and tells us much about the differences.

Žofia Chrobáková also studied the application of the Jeans equation to both systems. She calculated the gravitational force of each system and computed the rotational velocity from it. Next, she calculated the rotational velocity from the Jeans equation, under the assumption of axisymmetry and equilibrium and compared these two quantities.

Main achievements

The most important result is the comparison of the rotational velocity calculated by two independent, completely different ways. We find that the difference between these two approaches is negligible at small distances where both systems are close to an equilibrium configuration, and it starts to manifest at distances larger than 100 kpc, where the second system is out-of-equilibrium. At such large distances, the difference is extremely high, the velocity calculated from the Jeans equation reaches much higher values and cannot be substituted by the real rotational velocity, calculated from the force. This is in relationship with radial velocity - they found that when the average radial velocity begins to rise, the Jeans equation produces wrong results. This tells us, that at large distances, the Galaxy is not in equilibrium and we should not treat it in such way.

The comparison of the two different Galactic systems also yielded interesting results. Especially the comparison of PDFs showed that there are significant differences. However, comparison with observational data is necessary in order to better understand what produces the obtained behaviour.

 We published one paper from the STSM: Gaia-DR2 extended kinematical maps. III. Rotation curves analysis, dark matter, and MOND tests. Chrobáková, Ž.; López-Corredoira, M.; Sylos Labini, F.; Wang, H. F.; and Nagy, R. A&A, October 2020, 642, A95.

Following the STSM, a productive collaboration with the host and their research group has been maintained. They worked together on several projects using Gaia DR3 to explore the Milky Way kinematics.

We discovered that the rotation curve of the Milky Way is significantly decreasing:

✓ Mapping the Milky Way Disk with GAIA DR3: 3D extended kinematic maps and rotation curve to ≈ 30 kpc. Wang, H. -F.; Chrobáková, Ž.; López-Corredoira, M.; Sylos Labini, F. ApJ, 2023, 942, 12.

and explored mass models that could explain these observations:

 Mass Models of the Milky Way and Estimation of Its Mass from the Gaia DR3 Data Set. Sylos Labini, F.; Chrobáková, Ž.; Capuzzo-Dolcetta, R.; López-Corredoira, M. ApJ, 2023, 942, 3.

In the future, the collaboration continues, working mainly on the off-disk kinematics of the Milky Way and other related projects.

MW-Gaia STSM



Piecing together the puzzle: the interaction between the Sagittarius dSph and the Milky Way

Pau Ramos Ramirez, PhD student at the Institute of Cosmos Sciences of the University of Barcelona enjoyed a one month stay (November 2019) at the Kapteyn Astronomical Institute (Groningen) thanks to a GP1 STSM grant to collaborate with Dr. E. Balbinot.

The aim of this project was to learn about the Milky Way potential through cutting-edge simulations of the accretion history of the Sagittarius Dwarf Galaxy. To do so, we must explore the role of the different actors at play: Large Magellanic Clouds, Dynamical Friction and Mass Loss. And, most importantly, understand how the effect of these agents can modify (or not) our fit of the Milky Way gravitational potential.

The ultimate goal is to piece together the puzzle of the interaction between the Milky Way and Sagittarius, which can help us understand the substructure of both the Dwarf (streams, internal kinematics, ...) and our Galaxy (moving groups, phase-space spiral, outer disc structures, ...).

During the first week, Pau Ramos started working on a framework that would allow the production of accurate yet cheap simulations of the Sagittarius stream given a Milky Way potential and a set of initial conditions (at the present). In other words, the simulations would start at present and then populate the tidal tails based on the orbit that the progenitor (Sagittarius) had in the past.

This framework should allow for different parts of the simulation to be switch on and off:

- Interaction with the Large and Small Magellanic Clouds.
- Dynamical Friction.
- Mass loss.

The work was developed on top of an already existing framework for galaxy dynamics. This implies a lack of full freedom, since it has to comply with the logic of the underlying code, but it offers a set of auxiliary functions already implemented. So, by the end of the first week, Pau Ramos had basically reproduced the results of the Vera-Ciro&Helmi 2013 paper in the fiducial case where none of the above mechanisms were acting.

During the second week, in collaboration with Dr. E. Balbinot, they implemented the interaction with the Large Magellanic Clouds (and, in fact, any other satellite could be added) and compared their results with those in Vera-Ciro&Helmi 2013.

Once that the implementation was correct, the work on the Dynamical Friction part began. Following the approach described in Zentner et al. 2003 and introducing the equations in the framework, then they tested it thoroughly as to be certain that the results were quantitatively as expected. This required a careful treatment of the units and the transfer of data among modules in order to make it compatible with the pre-existing core of the framework.

In parallel, the implementation of the mass loss was being sketched. The loss of mass along the orbit is an effect caused by the tidal forces of the Milky Way acting on the
infalling satellite. An accurate treatment of the mass loss has been the interest of many studies and it is definitely not trivial if ones wants a general purpose simulator.

Therefore, the fourth week was devoted to the implementation of the mass loss. After exploring several recipes, a simple law was chosen: the mass is only lost at pericenter and in a fraction that depends only on the location within the host's potential. By doing so, even if the complexity of the dynamics of tidal stripping cannot be captured, this recipe is easily reversible in time and is accurate enough for the purpose of reconstructing the orbit of Sagittarius.

On the last week, the work was devoted on refining the code, started exploring the modules that allows populating the tails of the stream and also a first sketch of the Approximate Bayesian Computation algorithm to fit the Milky Way potential to the observations of the Sagittarius stream.

Main achievements

The development of a framework that can produce a prediction for the stream of Sagittarius given a set of parameters for the Milky Way potential, fast enough to use it within a fitting algorithm. Moreover, it can consider different effects acting on the infalling satellite, either all together, separately or in any permutation wanted.

 A paper was produced: "Full 5D characterisation of the Sagittarius stream with Gaia DR2 RR Lyrae" P.Ramos, C.Mateu, T.Antoja, A.Helmi, A.Castro-Ginard, E. Balbinot, J.M.Carrasco. A&A 638, A104 (2020) <u>https://arxiv.org/abs/2002.11142</u>

FUTURE COLLABORATIONS (if applicable)

After the visit they planned a second visit another visit to the Kaptyen Astronomical Institute for end of January – early February of 2020 In order to finish the project successfully. Furthermore, with the tools developed during this project, they could go one step further and start answering other questions about the observed morphology of other streams, which is an active line of research and also one of the main interests of Dr. E. Balbinot.

The STSM gave Pau Ramos the opportunity to start a new collaboration that he still maintains to this day. After the paper resulting from the STSM, they collaborated again in a couple other papers and, more importantly, they have a line of communication open for future research ideas.



Preparation for SCIP observations with the WEAVE multiobject

Dr. Maria Monguió from Universitat de Barcelona spent 13 days (19-22/11/2019) at the UCL (London) thanks to a GP1 STSM grant to collaborate with Prof. Janet Drew. The main purpose of the visit was to prepare the publication of the IGAPS survey, both in terms of the catalogue tables and the paper publication. IGAPS is a photometric catalogue of the northern Galactic plane developed with the Isaac Newton Telescope, that includes the five filters i, Halpha, r, g, U_RGO. It contains almost 300 million sources covering |b| < 5 and 30 <I<215 deg.

This catalogue is also being used for target selection for the forthcoming WEAVE survey. The grantee Dr. Monguio and the host Prof. Drew are respectively the Survey Working Group representative and the Science Team Lead of the Stellar Circumstellar and Interstellar Physics (SCIP) sub-survey of WEAVE, so they are responsible to coordinate and prepare the observations for SCIP. Work on the SCIP coordination and the input catalogue preparation was also in the plan for this short visit, having in mind that WEAVE first light was expected by mid-2020.

Most of the work was dedicated to the draft of the paper for the IGAPS catalogue. Discussions revolved around the contents of the different sections of the paper, as well as the different figures to be included. A preliminary draft existed before the visit, but with a clear lack of content in some of the sections, including abstract, introduction and conclusions, and a clear disproportion of the number of figures in some of the sections. Several telecons were developed during the week with a third collaborator (R.Greimel) who also actively contributed to the content for the paper.

During the discussions and generation of new plots, small issues were identified in a couple of columns of the catalogue that requested an intervention by re-processing few bits and pieces of the catalogue.

Another job done during the visit was to identify the co-authors of the paper. Since the observations for this survey have been developed for up to 15 years, and several quality check tasks have been developed during this time, it was not a straightforward job to identify a list of potential authors.

Tasks related with the SCIP survey within WEAVE were also developed during these two weeks, like the participation in several telecons related with the Survey Working Group and the Quality Assurance Group. They also prepared a detailed plan of the duties to be dealt with during the following few months before first light. That includes the fits catalogue preparation with the input targets list to be potentially observed. Format and columns for this have been agreed with WEAVE central and a clearer timeline for that was reached within SCIP team. BA stars' selection was ready and a full list elaborated, although it might need updating using the final version of the IGAPS catalogue. OB selection is underway, and better communication with the collaborators who are dealing with this task might be required.

Also, organisation related with the Survey Working group itself was discussed, with the identification of a new member of the team that will help with these tasks. Other SCIP topics discussed were: a) contributed software and how to interact with the main pipeline manager to get their own software to compute physical parameters for stars into the main pipeline, b) application for the science verification, and how to distribute the job within SCIP (deadline for proposals submission is December 15), c) Possible meetings to be held during the following year to prepare all the team for survey start.

Main achievements

- ✓ The following article was published after the STSM, and was possible in part thanks to the STSM: <u>https://arxiv.org/abs/2002.05157</u> A&A 638, A18 (2020)
- ✓ The full catalogue with almost 300 million rows and 174 columns now exists and has been made available to a few collaborators willing to play with it. It will be made world available through CDS once the paper is accepted.
- ✓ A clear plan for the following months regarding SCIP tasks was defined, including:
 - Preparation of the codes to create the fits catalogues with the appropriate formats and requested columns.
 - Collection and merging of the different target types among the different members of the survey.
 - Writing the Science Verification proposals.
 - A new Survey Working Group member for SCIP was identified to help with all this tasks.
 - A survey readiness review meeting to be held in Oxford the following January, where J.Drew, and possibly M.Monguio will be assisting.
- ✓ Some other issues and working points were identified and were to be dealt with in the future, such as:
 - Clear plan on how to contact WEAVE physical parameters pipeline manager in order to include SCIP codes in the main pipeline to improve results for their targets.
 - Organisation of future meetings during 2020 to get together the larger SCIP collaboration so everyone is ready for survey start.

Future collaborations planned were related with:

- ✓ Publication of the images related with the IGAPS catalogue.
- ✓ Science exploitation of the IGAPS catalogue.
- ✓ Preparation of the SCIP observations.
- ✓ Data selection from the catalogue for multifiber spectrographs.
- ✓ Comparison of the catalogue with the southern part of the survey.



Improving the analysis of Gaia photometric data for solar system objects

Dr. Alberto Cellino from INAF (Torino) spent a week (17-23/11/2019) at the Helsinki University thanks to a GP1 STSM grant to collaborate with Prof. K. Muinonen and his collaborators on the possibility to improve the performances of some algorithms developed to analyse sparse photometric measurements of asteroids observed by the Gaia space mission of the European Space Agency (ESA). This investigation was timely and important because of three main reasons:

1. A. Cellino had developed for the Gaia Data Processing and Analysis Consortium (DPAC), responsible for the ESA of the preliminary analysis of Gaia data, a genetic algorithm to derive the spin and shape properties of the observed objects, assuming that the shapes of the objects can be suitably represented as triaxial ellipsoids.

2. An analysis of Gaia photometric data for asteroids became possible after the release of a first and limited sample of data in the second Gaia Data Release (GDR2). A. Cellino and collaborators, including K. Muinonen, published a paper on the Astronomy and Astrophysics journal, presenting a first encouraging attempt at deriving reliable spin and shape properties of some asteroids based on Gaia GDR2 photometric data.

3. The Finnish Team led by K. Muinonen obtained some important results concerning specifically the treatment of light scattering by the surfaces of bodies having a triaxial ellipsoid shape, as predicted by a so-called Lommel-Seeliger light scattering model. A paper based on these results was in preparation.

The activities mentioned above in item (3) made possible the implementation of a better determination of the relation between magnitude and phase angle (the latter describing the illumination conditions of the objects at different epochs of observations). In particular, it was then possible to obtain a more accurate value of the slope of the expected linear relation between magnitude and phase angle, for asteroids observed in the range of phase angles covered by Gaia observations. In turn, this opens interesting possibilities to obtain better determinations of the albedo of the observed asteroids, the albedo being a parameter related to surface composition and light scattering properties.

Main achievements

During his STSM in Helsinki, A. Cellino and K. Muinonen worked together to improve the algorithm of analysis of Gaia photometric data, taking profit of the previous results described above. They implemented a new version of the numerical code, and carried out some preliminary tests. The results have shown that, with respect to the previous version of the algorithm, the performances in terms of determination of albedo values seems significantly improved. This is based on a comparison with albedo values already published in the literature for a first sample of asteroids published in GDR2.

The obtained results allowed them to be more confident about the possibility to systematically exploiting Gaia photometric data of asteroids to derive from them reliable estimates of the albedo, through further improvement and a better calibration of the

relation between phase-magnitude slope and albedo. This can be done, in particular, by making use of polarimetric data to derive more accurate albedo determinations for a number of asteroids to be used to calibrate the relation between the albedo and the phase-magnitude relation. Asteroid polarimetry is another subject in which both A. Cellino and the Helsinki team are deeply involved, and an analysis of the state of the art in asteroid polarimetry and its possible application to Gaia data was the subject of extensive discussions during the stay in Helsinki of A. Cellino. This might lead therefore to further developments aimed at a better exploitation of Gaia asteroid data.



Synergies between astrometric, radial velocity and future direct imaging measurements of exoplanets

Óscar Carrión González, PhD student at the Technische Universität Berlin spent 13 days (17-29/11/2019) at the Instituto de Astrofísica e Ciências do Espaço (IA), Universidade do Porto, CAUP thanks to a GP1 STSM grant to collaborate with Dr. Nuno C. Santos.

The goal of this Short-Term Scientific Mission (STSM) is to get to collaborate with European groups working on RV and astrometry, in order to build a catalogue of exoplanets observable with future direct imaging missions. Within the proposed 2-week STSM to IA in Porto (Portugal), Óscar Carrion attended the MWGaia WG3 Workshop "Exoplanets in the era of Gaia" (18-20 November, 2019). There, he learned about synergies between Gaia data and other exoplanet-focused missions, and to get familiar to the use of Gaia databases and data analysis techniques. Afterwards, the stay at IA is dedicated to know more about their expertise on radial velocity measurements (e.g. Santos et al. 2016) and stellar physics (e.g. Adibekyan et al. 2018). This would be a great counterpart to the knowledge that the group at TU Berlin and DLR Berlin has on transit observations (e.g. Rauer et al. 2014) and phase curves of exoplanets (e.g. García Muñoz & Cabrera, 2018).

The work during this STSM was divided as follows:

- WP-1: 18-20 November, 2019: Attendance to MW-Gaia WG3 Workshop "Exoplanets in the era of Gaia" (IA, Porto, Portugal). Óscar Carrion learned about how Gaia give a big picture on exoplanet populations, detecting hundreds to thousands of long-orbiting exoplanets. He also was able to discuss with some of the speakers the chances to detect transits of exoplanets in GAIA data.
- WP-2: 21-22 November, 2019: Accessing and handling RV exoplanet databases. (IA, Porto, Portugal). Ó. Carrión got familiar with exoplanet databases and developed code to download the data and process it. The most interesting properties of confirmed exoplanets were selected for further study.
- WP-3: 25-27 November, 2019: Cross-check with direct-imaging requirements. (IA, Porto, Portugal). The observability conditions for a coronagraphic directimaging mission like LUVOIR or WFIRST were established. The work focused on the following limiting factors:
 - Instrument's Inner Working Angle (IWA)
 - Instrument's Outer Working Angle (OWA)
 - Instrument's minimum contrast (Cmin)

An exoplanet will therefore be detectable if it is orbiting at a planet-to-star angular separation (θ) such that it falls within the operating range between the IWA and the OWA. The albedo of the planet will define how many starlight photons are reflected towards the observer, yielding a certain planet/star contrast, C. We could start analysing which of the several limiting factors will play a bigger role.

✓ WP-4: 28-29 November, 2019: Target selection and future work outline. (IA, Porto, Portugal). Selection of interesting targets for in-depth study. Study of which statistical analysis should be applied on the database and which properties to further study over the whole sample of exoplanets (e.g., equilibrium temperature, metallicity of the host star...).

Main achievements

Showed that, since transit detection is a very fruitful method to discover exoplanets, there is an observational bias towards hot, short-period planets. These exoplanets, with greater probability to transit due to the geometry of their orbit, will be too close to their host star and will not be observed by coronagraphs like those on board of WFIRST or LUVOIR.

The Inner Working Angle, therefore, was proved to be a very limiting factor for a direct imaging mission, discarding most of the currently-known confirmed exoplanets. Only planets with a maximum angular separation along the orbit (θ max) bigger than the IWA limit will be observable. Indeed, we computed that this factor alone would leave as observable only 3.2% of the confirmed population of exoplanets for a mission like WFIRST. A mission with improved specifications, as LUVOIR, could detect up to 7% of the known exoplanets if considering only the IWA limitation.



Semi-transparent dots: confirmed exoplanets for which we know the distance from Earth d and can derive the semi-major axis a. Solid stars: confirmed exoplanetsthat we find Roman-accessible in the optimistic CGI configuration, with Paccess > 25% and orbiting stars brighter than V=7 mag. Colour code indicates the corresponding discovery technique (that by which the planet was first identified), as detailed in the legend. "Others" refers to all other possible discovery techniques considered in the NASA Exoplanet Archive. HD 100546 b appears as the only Romana ccessible discovered in Imaging, although its existence is marked as controversial in the NASA Archive.

The following paper was published as a direct result:

✓ "Catalogue of exoplanets accessible in reflected starlight to the Nancy Grace Roman Space Telescope. A population study and prospects for phase-curve measurements" Ó.Carrión-González, A.García Muñoz, J.Cabrera, S.Csizmadia, N.C. Santos, H. Rauer <u>https://arxiv.org/abs/2104.04296</u> A&A 651, A7 (2021)

The method developed in that paper has been later applied to compute the detectability of certain exoplanets in subsequent publications not directly linked to the STSM:

 ✓ "Doppler wind measurements in Neptune's stratosphere with ALMA" Ó. Carrión-González et al. https://arxiv.org/abs/2305.06787 A&A 674, L3 (2023) ✓ "Large Interferometer For Exoplanets (LIFE). X. Detectability of currently known exoplanets and synergies with future IR/O/UV reflected-starlight imaging missions" Ó. Carrión-González et al. <u>https://arxiv.org/abs/2308.09646</u> A&A accepted (2023)

After the STSM the collaboration with the host continues on the topic initiated there. they developed a statistical methodology to compute the detectability of exoplanets with direct-imaging facilities. They analysed how multi-technique measurements (radial velocity, astrometry, transits) will help in refining the orbital characterization of known exoplanets and thus the detectability prospects in direct imaging. This new methodology was presented in the already mention scientific paper, where they applied it to the Coronagraph Instrument of the Nancy Grace Roman Space Telescope (to be launched in 2026 or 2027). It shows how precise astrometric measurements are a key to accurately determine which exoplanets will be observable in direct imaging and to prioritize the targets. After this, the collaboration with the host in other works not directly linked to the STSM is ongoing.



Finding electromagnetic counterparts to gravitational wave events with Gaia

Dr Zuzanna Kostrzewa-Rutkowska from the Leiden University spent 5 days (25-29/11/2019) at the University of Cambridge thanks to a GP1 STSM grant to collaborate with Dr. Simon Hodgkin.

The main aim of this STSM visit was a study of the ESA-Gaia mission usage to search for electromagnetic counterparts to gravitational wave events. The recent discoveries of gravitational wave events and in one case also its electromagnetic counterpart allow us to study the Universe in a novel way. The increased sensitivity of the LIGO and Virgo detectors has opened new possibilities for serial detections of transient events from stellar remnant mergers. The gravitational wave sources are expected to have sky localisation up to a few hundred square degrees, thus Gaia as an all-sky multi-epoch photometric survey seems to be a perfect tool to search for these events and study them.

From September 2014 onwards new transients from Gaia have been made publicly available after manual vetting of candidate transients detected by the Gaia Science Alerts (GSA) team. To this end, AlertPipe - dedicated software for data processing, transient searching, and candidate filtering was employed. Accurate photometry and low-resolution spectroscopy should allow for a robust classification and reduce the rate of false positives. Hence, we have been planning to implement a new approach to detect candidate transients related to gravitational wave events within the Gaia Alerts stream.

The visit focused on finding the most robust way to discover the electromagnetic counterparts to gravitational wave events with Gaia. Although, the current system has allowed to find many interesting transients the specific of the gravitational wave events (rare events, fast and faint) requires a special approach to increase the sensitivity of the alerting system.

Work carried out during the visit:

- learning the structure of the current transient detection pipelines to discover transients in Gaia – we studied the design of AlertPipe, the order of data processing and filtering, the parameter space;
- discussion on implementation and testing of a new pipeline to detect electromagnetic counterparts in Gaia - using results from already performed tests on the Gaia data we discussed a possible approach to implement a new detection algorithm and possible difficulties (eg. increase in processing time, conflicts with current detection algorithm);
- study of potential false positives coming from the new detector the new alert stream will increase the number of detected candidate transients, however, due to enhanced sensitivity, the number of possible false positives will also increase
 we also considered the ways of filtering the data by fine tuning current filters or designing a standalone approach;
- discussion on features of alerted transient sample (including both electromagnetic counterpart candidates and false positives) the new detections

will leave us with many candidate transients that we would like to study in details - we examined the possible usable features coming from the Gaia data.

Main achievements

The proposed algorithm led to an increase of the number of Gaia-detected electromagnetic counterparts to gravitational wave events. The tests on the new detection algorithm and first attempts to make use of it for previous gravitational wave events were described in a publication:

✓ "Electromagnetic counterparts to gravitational wave events from Gaia" Z. Kostrzewa-Rutkowska, P.G. Jonker, S.T. Hodgkin et al. MNRAS 493, 3264 (2020) https://arxiv.org/abs/2002.04853

They planned the schedule of the new software implementation to be ready it as soon as possible when LIGO and Virgo are operational. It was envisaged that the new alert stream would be available early following year and then the validation process might start. They aimed to use the current system of filtering and eyeballing in order to scrutinise the obtained candidate transient sample. These tests outcomes were the basis of following steps.

The publication strategy for the new alert stream was also agreed.

The proposed algorithm to detect GW counterparts in the Gaia Alerts stream was implemented and tested in real time as can be seen in this Gaia image of the week: https://www.cosmos.esa.int/web/gaia/iow 20210825



The all-sky distribution of candidate transients detected during the year 2018 using the GaiaX algorithm (Kostrzewa-Rutkowska et al. 2020). The map resolution is HEALPix of nside 32. The plot is in Galactic coordinates.

Another paper from the collaboration has been recently accepted:

✓ "Preparing for Gaia Searches for Optical Counterparts of Gravitational Wave Events during O4" S. Biswas, Z. Kostrzewa-Rutkowska et al. MNRAS accepted (2023) <u>https://arxiv.org/abs/2307.05212</u> The LIGO-Virgo-Kagra gravitational wave detectors started to observe in May 2023 and Gaia Alerts are planning to provide EM counterpart candidates during these observations.

On-going collaboration on implementation and testing of the new algorithms for searching for electromagnetic counterparts to gravitational wave events in the Gaia transient stream.



CNO abundances of open clusters studied with Gaia and high resolution spectroscopy

Juan Carbajo Hijarrubia, PhD student at the Universitat de Barcelona enjoyed a two weeks stay (12-25/01/2020) at the Vilnius University thanks to a GP1 STSM grant to collaborate with Prof. Grazina Tautvaisiene.

Juan Carbajo thesis "Chemical evolution of the Galactic disk from star clusters" developed in the framework of the Open Clusters Chemical Abundances from Spanish Observatories survey (OCCASO). The aim of the Ph.D. thesis is to study the dynamics and abundances of Open Clusters (OCs) in order to investigate the formation and evolution of the Galactic disc.

This research project is carried out in the Gaia team at Barcelona University. The team is involved in the Gaia space mission of the European Space Agency since 1998. Gaia is a unique instrument that takes a giant step in the precision of measurements and in the understanding of the formation and evolutionary history of our Galaxy, as demonstrated by the data published up to now. Most of the stars are born in OCs and, therefore, their study is a fundamental piece to understand the evolution of the Galaxy.

Although Gaia provides very precise distances and movements of the stars, its capabilities to determine radial velocities and precise chemical compositions are limited. The Barcelona Gaia team participates in spectroscopic projects to obtain complementary information from the ground such as Gaia-ESO Survey, OCCASO, and the future WEAVE and 4MOST.

The OCCASO project (Casamiquela et al. 2016) is framed in this context, and its main objective is to derive detailed chemical abundances for OCs in the Northern hemisphere. Large ground-based spectroscopic surveys are mainly sampling the Southern hemisphere OCs (Gaia-ESO survey, GALAH), or do not have a specific program for homogeneously sample OCs (APOGEE). OCCASO aims to complement these surveys. For each of the studied clusters at least 6 Red Clump stars have been observed with a signal-to-noise ratio (SNR) ~70. The spectrographs used in the survey are CAFE@CAHA, FIES@NOT and HERMES@Mercator, all of them with resolutions R > 65,000. This resolution combined with the high signal-to-noise ratio of the observations allows the determination of detailed abundances. The team had already performed an abundance analysis of 10 species (Fe, Ni, Cr, V, Sc, Si, Ca, Ti, Mg, O) for red giant stars in 18 OCCASO clusters. (Casamiquela et al. 2019) and had completed data for 37 OCs thanks to the discoveries based on Gaia DR2 (new members of known OCs and new OCs detected). This conforms a homogeneous sample regarding the instrument features, method, line list and solar abundances from confirmed member stars.

One of the goals of the PhD thesis is to determine the CNO abundances in the OCCASO sample. Since the group led by Gražina Tautvaisiene at the Vilnius University holds the needed expertise for the determination of such elements, this visit has played a crucial role in the development of the PhD. The STSM allowed establishing a collaboration between the two groups (Barcelona & Vilnius) on this and other projects related to the characterization of OCs in the Gaia era.

The stay has allowed Juan Carbajo to learn more about the physics of the atmospheres of red giants, mainly those effects concerning CNO lines like the molecular equilibrium, and also about how these physical processes affect the stellar spectra in the case of the molecular bands used for CNO abundance determination.

The OCCASO spectra has been reviewed to confirm that their characteristics are adequate to perform the analysis, in terms of covered spectral range, signal to noise ratio (SNR), and spectrum normalization. OCCASO spectra cover well the regions usually measured by the Vilnius team. The spectrum SNR is sufficient to perform these studies. Regarding normalization, it is necessary to perform a local renormalization in the C₂ region Swan band at 5135 Å.

One of the most important parts of the stay has been acquiring knowledge about the methodology used by the Vilnius team to determine abundances of CNO elements. They have used the differential synthetic spectrum method for that. The abundance of carbon has been derived using the C_2 Swan band heads (0,1) at 5135 and 5635.5 Å. The nitrogen abundances and carbon isotope ratios have been determined studying wavelength range 7940-8130 Å. Oxygen abundances have been determined from line [O I] to 6300 Å (Tautvaišienė et al. 2015). They have also used the region around of 8004 Å to determine the carbon 12C/13C ratio. The relative abundance between these two carbon isotopes depends on the evolutionary state of the star. The different dragged-off processes that occur in stars causing element mixing of their different shells are not fully understood yet. Therefore, the analysis of carbon isotopes in the high-quality OCCASO survey sample can provide new information about these processes.

From the point of view of the determination of chemical gradients in the Milky Way, it is especially interested to know the evolutionary state of the stars under study. It is necessary to be able to separate variations in abundance due to the evolutionary state, from those due to the position occupied by the cluster in the Galaxy and the age at which it formed. The CNO elemental determination and carbon isotope ratio provide complementary information to the Gaia photometry in the evolutionary state determination.

We have started the development of a new code designed to fit interactively the OCCASO spectra with synthetic spectra. The program is a new implementation of the methodology developed by Vilnius team in a new environment. The program uses iSpec, a Python tool for the treatment and analysis of stellar spectra. The goal of the program is to apply the iSpec multiple capabilities to the analysis of CNO elements. The radiative transfer code used to generate the synthetic spectra is Turbospectrum and the line list used is VALT.

Main achievements

During the stay, one of the main results have been the development of the first version of the python code described in previous section. This new implementation of CNO analysis take all the advantages of iSpec tools. It is a program capable of doing the most essential tasks, such as spectrum normalization, as well as the more advanced tools dedicated to spectral synthesis. The development started during the stay aims to become an automatic pipeline dedicated to the CNO analysis that can be a useful tool for both teams.

This first analysis has allowed the collaboration to evaluate the possibilities that OCCASO data has for CNO analysis regarding the data quality. How to perform the analysis so that work can be continued in both universities has been established.

This short visit has allowed the start of the collaboration and to take the first steps towards our final goal, which is the determination of CNO abundances and carbon isotope ratio for the complete OCCASO sample: 245 stars have been observed in the OCCASO survey belonging to 37 open clusters.

This visit has also allowed each team to know better the other's scientific goals and to be able to prepare new projects based on our common interests. One of the future collaborations, that we have started to prepare, is to observe some open clusters of common interest using the telescope and instrumentation available in Moletai observatory (Lithuania).

As a result of the STSM with the Institute of Theoretical Physics and Astronomy in Lithuania, a collaboration on the study of the Galactic radial gradients and age variation of 21 chemical elements measured in open clusters is underway. This work is under referee review. In addition, the publication of the chemical abundances of CNO elements in these same objects is in preparation.

MW-Gaia STSM Simulation Stellar Clusters



Dr Tristan Cantat-Gaudin from the Institut of Cosmos Science of the University of Barcelona spent a week (19-25/01/2020) at the Leiden University thanks to a GP1 STSM grant to collaborate with Prof. Simon Portegies Zwart and Dr. Anthony Brown.

Tristan Cantat-Gaudin research focuses on stellar clusters in the disc of the Milky Way. Thanks to the data provided by the ESA Gaia mission, many nearby clusters have resolved internal kinematics, which means that we can follow the individual motions of stars within clusters, and characterise their dynamical state. In particular, a complex spatial distribution of young stars was recently identified in the nearby Vela region. The purpose of this visit was to begin an investigation of the dynamical state and establish a possible formation scenario for this region, combining observations and numerical simulations.

Visiting the Leiden Observatory allowed the direct collaboration with A. Brown, who has expertise in the characterisation of young stellar aggregates and is the world expert on the advanced use of Gaia astrometric data, and with S. Portegies Zwart, professor of computational astrophysics and developer of the software environment AMUSE. The aim was to be able to perform simple simulations, taking into account the following physical processes: gravitational interactions of stars within a cluster, influence of the Galactic tidal field, and stellar evolution.

The main activity during the exchange was the technical implementation of the tools needed in order to simulate the structure and evolution of the Vela region. The software suite AMUSE is a modular environment that allows to simulate various astrophysical processes. A simulation reproducing the gravitational interaction between stars within a cluster was initially set up. Then the influence of a simple Galactic potential on the dynamical evolution of the cluster was added. Later a more complex Galactic potential was added by interfacing AMUSE with Galpy, a powerful and widely-used Galactic dynamics Python package. The third physical process relevant to this simulation is stellar evolution, which AMUSE allows taking into account. By assigning masses to the stars in the simulations and running a stellar evolution code, the fact that over several millions of years the most massive stars explode as supernovae and their mass no longer contributes to gravitational interactions within the cluster could be reproduced. Finally, simulations were run where several stellar clusters of different ages interact with each other, which is necessary in order to reproduce the overlap of populations of different ages in the Vela region.

Main achievements

The main objective of this visit, which was to set up a numerical simulation including at the same time the effect of 1) gravitational interactions between stars, 2) the influence of the Galactic tidal field, and 3) the effect of stellar evolution including subgroups of different ages, was achieved.

Using the stellar evolution codes included in AMUSE, it was possible to estimate that, given the number of young stars currently observed in Vela, a large number of supernova explosions (possibly up to 100) took place in the past 50 Myr. It is therefore possible that the formation of several of the observed clusters was triggered by supernovae.

This visit was a part of an ongoing collaboration. Two possible angles for further studies of this complex region were identified:

The first goal was to look for evidence of the processes that drove star formation and left their imprint in the observed spatial and kinematic structure of the stellar population. The plausibility of the supernova scenario can be further explored by looking for high-velocity stars in and around Vela (ejected by the supernova explosion of their companion, if they were part of a binary system). Evidence for such an intense supernova activity might also be found in the expansion of the large gas shell surrounding the entire region.

The second aim was to rely on numerical simulations to understand on which time scale the Vela stars will disperse into the Milky Way field population, and whether some of the denser stellar aggregates can remain gravitationally bound clusters. This requires not only that the simulation reproduces the observed characteristics of Vela, but also that it includes the low-mass stars for which observations are missing. Further work to investigate how different prescriptions on how to include these unobserved stars in the simulation affect the predictions of the modelled Vela will be developed.

The collaboration is still ongoing to build on what was done during the visit to set up a numerical simulation of the entire Vela-Puppis complex and determine if some of the dense clumps are going to remain gravitationally bound and form star clusters. The first challenge for this is methodological: it is necessary to account for the stars that Gaia does not see, and for those that can be seen but whose motions cannot be measured. The second challenge is technical: the volume of space represented by this simulation is large, and in order to explore several possible outcomes for the dynamical evolution of the stellar structures, the project may require significant computing resources.



Binaries in open clusters, matching Gaia observations to N-body simulations

Dr. Zephyr Penoyre from University of Cambridge spent two weeks (27/06-08/07/2022) at the University of Barcelona thanks to a GP2 STSM grant to collaborate with Dr. Mark Gieles.

The collaboration largest ambition was to identify in the Hyades open cluster a possible central black hole (BH), which models from Mark Gieles and students suggest would likely have a luminous (and thus detectable by Gaia) Main Sequence star (MS) as a companion. The collaboration started by selecting members of the Hyades cluster, from all Gaia sources in the vicinity on sky, based on proper motion, parallax and position. For each of these the existing astrometric RUWE values were combined with derived spectroscopic RUWEs (from estimates of Gaia's measurement errors). From this, inferred periods, mass ratios and companion masses were derived for all stars in RVS, along with some speculative values for stars expected to have radial velocity measurements but which were missing. There are some potential candidates for an intermediate mass BH in the speculative candidates, along with many MS or WD companions among the RVS sample.

Dr. Penoyre was also able to present work at the ICCUB Weekly Gaia meeting and give the Wednesday Seminar on Astrometric Binaries in Gaia. As well he attended the European Astronomical Society annual meeting to present related work and meet in person (most for the first time) various members of DPAC which lead to fruitful discussions and hopefully future collaborations.

Main achievements

Estimated periods and mass ratios for 39 binary systems in the Hyades were defined, with another 11 speculative candidates (out of 242 members of the cluster). A follow up of these, firstly with a literature search by then ground based measurements if any systems seem promising as being binaries compatible with a BH companion.

Furthermore, the estimated binary population will allow better calculations of the velocity dispersion of the cluster. In the first instance the plan is to remove these systems which will have an extra apparent velocity caused by the binary motion. A step further will be to estimate the extra binary motion and recalibrate these systems (also including the extra mass of the second star) and then re-include them in the velocity dispersion estimate.

The period sensitivity of Gaia astrometry and spectroscopy can only rule out companions in a certain range of periods - so our possible non-detection (if our speculative candidates do not prove fruitful) does not exclude the possibility of a massive BH but does constrain its properties.



Hyades candidates colored by astrometric (top) and spectroscopic (bottom) renormalized-unit-weight-error (RUWE). Values significantly above 1 suggest that the system has an extra source of noise, most ubiquitously a binary companion. Many sources don't have radial velocity measurements in the Gaia source catalog, and these are denoted with empty grey circles in the bottom plot.

A successful collaboration that resulted in co-authorship of the published paper:

 ✓ "Stellar-mass black holes in the Hyades star cluster?" S. Tornamenti, M. Gieles, Z. Penoyre et al. MNRAS 524, 1965 (2023) https://arxiv.org/abs/2303.10188

and established a good relationship with the host.



Physical characterization of Small Solar System Bodies using Gaia DR3 data complemented by data from other sources

Dr. Alberto Cellino from Osservatorio Astrofísico di Torino spent two weeks (28/08-09/09/2019) at the Observatoire of the Côte d'Azur (Nice) thanks to a GP3 STSM grant to collaborate with Prof. Paolo Tanga.

The goal of this STSM was to improve and optimize the scientific output of the asteroid data obtained by the Gaia space mission of the European Space Agency (ESA). This data was published on June 2022 in the third Gaia Data Release (GDR3). The activities carried out during this STSM took also profit of the presence in Nice in the same days of Prof. Karri Muinonen, from Helsinki University. As in the case of Cellino and Tanga, Prof. Muinonen is also deeply involved in the activities of the international Data Processing and Analysis Consortium (DPAC), which is responsible of the processing and interpretation of Gaia data.

The activities carried out in this STSM included the following:

Dr. Cellino is one of major world experts in the field of asteroid polarimetry. He is co-PI of the Calern Asteroid Polarimetric Survey (CAPS), a research project in collaboration between the Astrophysical Observatory of Torino (Italy) and the Observatoire of the Côte d'Azur (OCA). During his staying at OCA, Dr. Cellino gave a seminar about CAPS and its role in modern asteroid polarimetry, with the presence of many colleagues and students. In particular, he pointed out the role played by polarimetric data in determining some properties of the layer or surface regolith on asteroid surfaces that are difficult to obtain by means of other techniques. He stressed also the possibility provided by polarimetric data to identify special classes of objects, including very primitive asteroids and candidates to be extinct comets. CAPS has already obtained a relevant part of all the available database of asteroid polarimetric measurements, which make it possible to derive reliable phase - polarisation curve for about 200 asteroids. One important goal of this STSM was to discuss the possibility to carry out a new and updated calibration of the existing relations between different polarimetric parameters and the geometric albedo, in order to update and improve the most recent work in this field, published by Dr. Cellino and colleagues in 2015. A very important agreement was established with the OCA colleagues (Dr. Benoit Carry and co-workers), who are developing a massive effort to derive from the whole data-set of currently existing asteroid data the most reliable values of some physical parameters, including the size obtained from star occultation data, the absolute magnitude, the spectral reflectance properties, for thousands of asteroids. According to their agreement, Dr. Carry was to provide in mid-October the most reliable parameter determinations for a large number of objects, including many present in the CAPS database. In this way, a new calibration of the relations between the albedo and different polarimetric parameters would be produced based on CAPS polarimetric data. The following step would be to use the set of physical properties derived by polarimetric data as a constraint in the analysis of spectroscopic and photometric Gaia DR3 data.

- During this STSM, most time was devoted to the preliminary results of photometric inversion of Gaia photometric data, making use of the genetic algorithm developed by Dr. Cellino. This algorithm is devoted to deriving, from Gaia sparse photometric data obtained at different epochs, the most reliable estimates of the spin properties (rotation period, orientation of the rotation axis), of the overall shapes and of some properties of the surface regolith. The analysis of the results obtained for a large set of about 25000 objects observed by Gaia led to the discovery of an important consequence of the properties of the Gaia sky scanning law, namely an effect producing in a non-negligible number of cases some spurious results of photometric inversion. These effects tend to produce particular values of the resulting rotation period and of the error bars affecting these determinations. This is an important result, because it allowed us to design and implement some changes in the algorithm of photometric inversion, and set up some rejection filters aimed at minimizing the number of unreliable results.
- The analysis of the spin properties obtained from GDR3, after the elimination of suspect photometric inversion solutions as explained in previous item, made it possible to build a first list of spin properties for asteroids present in the GDR3 database. It is important that this database includes the first determination of spin properties for tens of thousands asteroids, mostly small and faint ones, never observed before. Comparisons of the results obtained in GDR3 with those obtained in the past by means of ground-based observations for a much smaller subset of objects listed in GDR3 made it possible to estimate the most likely uncertainties of the photometric inversion solutions. The role played by the still incomplete sampling of viewing conditions for asteroids listed in the GDR3 database could be better evaluated. This is also useful to predict the improvement of the quality of the expected results from the photometric inversion of following Gaia data releases, including a much larger number of observations and a much better sampling of the space of possible viewing conditions.
- The general activities described in previous item also include some studies of particularly interesting cases. Among them, worth mention the cases of asteroids apparently displaying very long spin periods, to be interpreted in terms of collisional histories (including the possible formation of binary objects), thermal radiation effects, and the possible effects of a tumbling rotation state. Moreover, a very preliminary analysis of the properties of the phase mag curves obtained from Gaia GDR3 photometry suggested some procedures to implement the possibility to use photometric data also for the purposes of a preliminary estimate of the albedo of different taxonomic classes, derived from Gaia spectroscopic data. The general lines of this work was only sketched due to the short available time, but the developments will certainly take profit of the activities and results of this STSM.

Summarizing, the results obtained during this STSM are important, and indicate both specific and more general directions for future developments in the scientific exploitation of Gaia asteroid data.

Main achievements

There are a couple of papers produced using input obtained during A. Cellino STSM in Nice on September 2022:

- ✓ "Gaia Data Release 3. The Solar System Survey." Tanga, P. et al., A&A 674, A12, 2023
- ✓ "Gaia Data Release 3. Reflectance spectra of Solar System small bodies." Gaia Collaboration, A&A 674, A35, 2023
- "Asteroid spin and shape properties from Gaia DR3 photometry." Cellino et al. A&A submitted 2023



This plot shows the rotation frequency distribution for the sample of 8670 asteroids having at least 25 recorded transits in the Gaia FOV at the epoch of the 3rd release of Gaia data (GDR3), after removing low-quality data.



This plot shows a sin(orbital inclination) vs. semimajor axis for Main Belt asteroids, in which objects found to have prograde rotation are plotted in blue, and asteroids having retrograde rotation are shown in red. The clusters of objects correspond to asteroid dynamical families. The sense of rotation data has been computed based on analysis of GDR3 photometric data, after filtering out low-quality data.

The collaborations with the host continue regularly, in spite of the fact that A. Cellino is currently retired. He is still very active in the investigations carried out in the framework of the COST STSM.



The bar pattern speed of the Large Magellanic Cloud - Three-months stay at the Observatory of Lund

Óscar Jimenez Arranz, PhD student at the Universitat de Barcelona enjoyed a three months stay (May to July 2023) at the Observatory of Lund thanks to a GP4 STSM grant to collaborate with Dr. Santi Roca-Fàbrega and Dr. Paul McMillan. During these three months, he worked on the production and analysis of N-body simulations to understand the formation and evolution of the Magellanic Clouds at the light of the new observations by the Gaia satellite.

In parallel, they also worked in a project on the determination of the bar pattern speed of the Large Magellanic Cloud.

Óscar participated in most activities in the Lund Observatory, including both academic and outreach, and also presented his work in formal and informal seminars. His research at the Lund Observatory during those months allowed him to attend to the COST Action WG4 meeting "<u>Science and technology roadmap for µas studies of the Milky Way</u>" that took place on Lund 18-20 July 2023.

Main achievements

The STSM achieved the expected and planned goals, being the products of this research visit a paper "The bar pattern speed of the Large Magellanic Cloud" submitted to a fully refereed journal, and a second paper that will be submitted shortly afterwards. Those results were presented in the COST workshop "The Milky Way Revealed by Gaia: The Next Frontier" that was held in Barcelona in September 2023.

The amount of data that the N-body simulations represent suppose an almost endless source of analysis and studies that will continue in the future within the collaboration with Dr. Santi Roca-Fàbrega and Dr. Paul McMillan.

Images:

https://en.wikipedia.org/wiki/Lund_Observatory#/media/File:Lundsobserv.jpg

Related links

https://www.cosmos.esa.int/web/gaia/edr3-structure-magellanic-clouds https://www.cosmos.esa.int/web/gaia/iow_20230131



Massive classification of new hot subdwarf binary systems with Gaia DR3

Carlos Viscasillas Vázquez, PhD student at the Vilnius University spent a week (29/05-02/06/2023) at the Universidad de Vigo thanks to a GP4 STSM grant to collaborate with Dr. Ana Ulla.

An analysis of the sample hot subdwarfs (hot sds) of Solano et al. (2022) has been carried out, which includes a comparison with the new Gaia DR3 available data, as well as the normalization and subsequent treatment of the BP/RP spectra for their posterior analysis with artificial intelligence (AI) techniques. Several AI techniques are to be applied, including SOM (Self Organised Maps) and using software available in the collaboration group. This collaboration is inserted within the GGG, Galician Group for the Gaia satellite, integrated by researchers from the universities of A Coruña (UDC) and Vigo (UVIGO), and linked to the DPAC (https://www.cosmos.esa.int/web/gaia/dpac/consortium) consortium.

So far, a new classification method for hot subdwarfs in binary systems based on supervised ML techniques has been explored, performing the subsequent calculation of binary probabilities distribution. Training samples from Solano et al. (2022) and from Drilling et al. (2013) were selected and applied the technique to a larger sample, of about 39.000 blue candidates, in Geier et al. (2019). The results are to be compared with the outcome from SOM techniques, to be conducted by UDC colleagues, and that from Virtual Observatory (VO) techniques, as those explored in Solano et al. (2022).

Although only very preliminary conclusions can be handled after this 5-day in person working meeting, it has been positive, useful and fruitful in setting a sound base for the application of AI techniques to this massive discovery and classification line of research, to build up on the VO approach already proposed and exploited. In fact, an interesting outcome from the continuation of the present collaboration in the near future is foreseen.

Main achievements

The scientific visit was very positive and the treatment of the Gaia DR3 BP/RP spectra obtained for the sample in Solano et al. (2022) was possible, and have it ready and in optimal conditions for its next treatment with an adaptive visualization tool for unsupervised classification of astronomical objects in a Big Data context. All the parameters of the aforementioned sample have been updated with the new data of Gaia DR3. New techniques of supervised learning methods used for classification based on Support vector machines (SVMs) have been successfully tested. And they have been applied to the sample of binaries by Solano et al. (2022) obtaining preliminary but promising results. In particular, only a probabilistic colour-magnitude approach on Geier et al (2019) catalogue is already revealing in terms of its discovery potential

During the visit Carlos Viscasillas was able to interact with other members of the GGG at UDC, as well as with Enrique Solano from the Spanish Virtual Observatory. The following steps include further treatment of the spectra and the data, as well as the use of the Gaia Utility for the Analysis of self-organizing maps (GUASOM) analysis tool. Intercomparability of various ML techniques on the collaboration data sets will also be performed. So, the scientific visit was crucial to start a formal collaboration and to continue a promising project.

In the short term, the collaboration presented the preliminary results in a talk at the European Astronomical Annual meeting (https://eas.unige.ch/EAS2023/), held in Krakow from July 10 to 14, and in a poster to the Final Conference "The Milky Way Revealed by Gaia: The Next Frontier" that took place in Barcelona from 5 to 7 September 2023. And, by the end on 2023, a draft paper on the topic is expected. For sure, this collaboration will continue in the future.