Horizon Europe (HORIZON)
Marie Skłodowska-Curie Actions
Doctoral Networks (MSCA-DN)

ANNEX 1

Description of the action (DoA)

Part B

101072454 – MWGaiaDN
HORIZON – MSCA – 2021 – DN
The Milky Way-Gaia Doctoral Network

List of Changes

Date	Who	Section(s)	Change Description
20220601	AB	3.1.4, Tables 1.1 and 1.3, 3.2.4, Table 3.1d	Second TUD ESR (no 10) description added. ESR10 should be in WP5, this has been made consistent throughout the document. Comments from project officer included. Various minor edits to grammar and spelling. In section 3.2.4 text was added concerning the funding of non-associated third countries. Added the UCAM and UCL ESRs to table 3.1d and 1.3a with a clarification on their funding added as a note to the table.
20220417	NAW	Several	Part B generated from proposal Part B. Removed cover page Deleted the header Replaced the footer with new info Removed list of participants Table 1.1 list of WPs removed Table 1.3.b: updated dates of meetings to reflect the new start date (1 Feb 2023 c.f. 1 Aug 2022 foreseen in the the original proposal). Table 3.1 a Description of WPs removed Table 3.1 b Deliverables List removed Table 3.1 c Milestones List removed Table 3.1e Implementation Risks removed Created section 4 with ethics self-assessment Added table with list of changes Updates related to the ESR feedback: i) Goals related to research on Gaia Frontiers: added text to end of sec's 1.1.2.1 and 1.1.2.2 to note how the mid project deliverables include an assessment of need for future near-IR astrometry. ii) Methodology approach: added text to end of sec 1.2.2 noting that the methodological approach will be reviewed at the network kick-off meeting. iii) Sec 1.4.1 – added some additional comments on the quality of the supervision – all supervisors have significant supervision experience
20220419	NAW	Table 1.3.b	Additional date changes of meetings to reflect the new start date
		Sec 1.3.1.2	Removed ref to Aug 2022 IAU General assembly (now before start of network)
		Sec 2.3.1	Changed IAU GA Busan (2022) to Cape Town (2024)
20220503	NAW	Sec 5.1 (Leiden)	Updated the description of Leiden University to note that the department involved is the Faculty of Science (ensures consistency with the entry in SYGMA). Leiden Observatory is a sub unit of the Faculty of Science.
20220519	NAW	several	Updates to reflect change of status of UK partners from beneficiaries to associate partners, after confirmation from REA that associate partners able to lead non MGT WPs. New coordinator will be Anthony Brown at LEID.
		declarations	Added CNRS/UGA link
		1.1.2, 2.4.1	Updated references to the ESRs, including the UK funded associate partner PhDs in UCAM and UCL
		Table 1.1	Re-assigned WP leads – WP1 now LEID, WP6 now UCAM. Re-assigned the ESRs to WP – ESR1 is now UB (previously UCAM) and ESR10 TUD (previously UCL)

		Sec 3	Updated start date to 1 Feb 2023 (and corresponding changes to dates for student hires)
		Table 3.1d	Updated Deliverables to reflect new numbering for all Fellow ESR descriptions. Replaced ESR1 and ESR10 from the UCAM and UCL descriptions to the new UB and TUD projects.
		3.2.4	Update on UCAM and UCL transferring associate partner status.

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LIST OF PARTICIPATING ORGANISATIONS

Consortium Member	Legal Entity Short Name	Academic (tick)	Non-academic (tick)	Awards Doctoral Degrees (tick)	Country	Dept./ Division / Laboratory	Scientist-in-Charge	Role of associated Partner[1] or link to beneficiary
Beneficiaries								
1: UNIVERSITEIT LEIDEN	**LEID**	✓		✓	NL	Leiden Observatory	Anthony BROWN	
2: INSTITUTO NAZIONALE DI ASTROFISICA	**INAF**	✓		[2]	IT	Padua	Antonella VALLENARI	
3: LUNDS UNIVERSITET	**LUND**	✓		✓	SE	Lund Observatory	David HOBBS	
4: UNIVERSITAT DE BARCELONA	**UB**	✓		✓	ES	Institute of Cosmic Science/ Dpt. Quantum Physics and Astrophysics	Carme JORDI	
5: UNIVERSIDADE DE COIMBRA	**UC**	✓		✓	PT	Departamento de Fisica	Sonia ANTON	
6: TECHNISCHE UNIVERSITAET DRESDEN	**TUD**	✓		✓	DE	Lohrmann Observatory	Sergei KLIONER	
7: UNIVERSITÉ GRENOBLE ALPES	**UGA**	✓		✓	FR	Institut de Planétologie et d'Astrophysique de Grenoble	Carine BABUSIAUX	
8: NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS	**NKUA**	✓		✓	EL	Department of Physics	Despina HATZIDIMITRIOU	
Partner Organisations								
23: UNIVERSITY OF CAMBRIDGE	**UCAM**	✓		✓	UK	Institute of Astronomy	Nicholas WALTON	ESR-HOST/ TRN/ EXCH
22: UNIVERSITY COLLEGE LONDON	**UCL**	✓		✓	UK	Mullard Space Science Laboratory	Daisuke KAWATA	ESR-HOST/ TRN/ EXCH
19: AIRBUS DEFENCE AND SPACE	**ABUSDS**		✓		UK	Future Programmes & Proposals	Paolo D'ARRIGO	ESR-HOST/ TRN/ EXCH
13: DAPCOM DATA SERVICES	**DAPC**		✓		ES		Francesc JULBE	ESR-HOST/ TRN/ EXCH
18: LEONARDO LTD	**LEON**		✓		UK		Keith BARNES	ESR-HOST/ TRN/ EXCH
14: INTERSYSTEMS IBERIA	**INSYS**		✓		ES		Jose Tomas SALVADOR	ESR-HOST/ TRN/ EXCH
17: OHB SYSTEM AG	**OHB**		✓		DE	Scientific Payloads	Maximilian KLEBOR	ESR-HOST/ TRN/ EXCH
15: SPIN.WORKS	**SPINW**		✓		PT		Tiago HORMIGO	ESR-HOST/ TRN/ EXCH
16: SUIL INTERACTIVE LTD	**SUIL**		✓		IE		Owen HARRIS	ESR-HOST/ TRN/ EXCH

[1] For example, delivering specialised training courses, hosting secondments, etc.

[2] The INAF Padua ESR will be enrolled on PhD programs at the University of Padua (**UNIPD**)

21: THALES ALENIA SPACE UK LTD	**TAS**		✓		UK	Advanced concepts	Roger WARD	ESR-HOST/ TRN/ EXCH
20: CNRS	**OBSPM**	✓			FR	GEPI lab, Paris Observatory	Frédéric ARENOU	ESR-HOST/ TRN/ EXCH
12: DIRAC INSTITUTE	**DIRAC**	✓		✓	US		Mario JURIC	ESR-HOST/ TRN/ EXCH
10: NATIONAL ASTRONOMICAL OBSERVATORY OF JAPAN	**NAOJ**	✓		[3]	JP	NAOJ-Jasmine Office	Naoteru GOUDA	ESR-HOST/ TRN/ EXCH
11: NATIONAL RESEARCH FOUNDATION	**SAAO**	✓			ZA	South African Astronomical Observatory & IAU Office of Astronomy for Development	Patricia WHITELOCK	TRN/ COMMS/ EXCH
9: UNIVERSITÀ DEGLI STUDI DI PADOVA	**UNIPD**	✓		✓	IT	Dipartimento di Fisica e Astronomia	Giovanni CARRARO	ESR-HOST/ TRN/ EXCH

Declarations

Name (institution / individual)	Nature of inter-relationship
DAPCOM Data Services (15: DAPC)	DAPCOM Data Services is a spin-off company of the University of Barcelona (UB) and the Politecnic University of Catalunya (UPC). UB is one of the beneficiaries of the MWGaiaDN.
CNRS	The Institut de Planetologie et d'Astrophysique de Grenobe (IPAG), i.e. the department of beneficiary UGA joining the project, is a joint research unit between UGA and CNRS (which is an associated partner).

[3] NAOJ itself does not award degrees. However, NAOJ is a member of the Graduate University for Advanced Studies (SOKENDAI) and awards degrees through this (with some graduate students enrolled at the University of Tokyo).

1. Excellence

MWGaiaDN will deliver **Excellent** science, **Extending** techniques, **Enhancing** people skills, **Effecting** the next revolution in European led astronomy through leadership in astrometric-based science**.**

Gaia, ESA's major space satellite was successfully launched in Dec 2013. It is now on its extended mission to map some two billion stars in our **Milky Way** (hereafter: **MW**). It's first three data releases, of primarily astrometric and photometric data, in 2016, 2018, 2020 have already proved to be a `game changer' for astronomy. The upcoming data releases though present major challenges in terms of complexity and size, bringing in for the first time significant new advanced data products such as the astrophysical properties of the stars, hence preparation to ensure full science exploitation is essential. **MWGaiaDN** will link the key partners responsible for the development and creation of Gaia, forming an effective and unique training network powerfully combining the best research training with a range of academic and industrial placements, specialist research and knowledge transfer workshops. It will develop and train a cohort of young researchers through a set of key science projects pushing the Gaia data to its limits. It will shape the delivery of training in astrometry and the study of the MW across Europe: delivering key insights into the structure and formation of our Galaxy; delivering the roadmap for the next generation of astrometric space telescopes; equipping the DN's recruited Early Stage Researchers (ESRs) with skills to drive the next innovative steps (e.g. the recently identified priority ESA future large MW/near infrared astrometry mission for the mid-30's) in this key area of space discovery, as well as enabling them to contribute to the future, growth and challenges of the big data industry and commerce.

The MWGaiaDN ESRs will generate excellent science in the mid 20's, form a cohort driving future discovery in the mid 30's. With the major new Gaia DR3 release in Q2 2022, our DN is perfectly timed for maximum impact.

1.1 Quality and pertinence of the project's research and innovation objectives

1.1.1 Introduction, objectives and overview of the research programme

Introduction: Astrometry is the technique of measuring the positions of celestial objects over time to high precision. We can determine the parallax, and thus distance, as well as the space motions of the objects. Accurate knowledge of the distances and motions of objects provide fundamental insights into the widest range of astrophysical questions, from the evolution and formation of our Sun and solar system, to that of our MW, and the cosmology of the Universe. Measuring the distance to even the nearest star requires measuring angles on the sky of less than an arcsecond (one 3600th of a degree). Gaia is the ESA cornerstone mission that is revolutionising our understanding of the MW and the Universe. Launched in December 2013, it is now measuring stellar positions to derive the astrometric parameters of some two billion stars between 2nd and 21st magnitudes in brightness to exquisite accuracies: to ~10 micro-arcseconds (μas) for the brightest stars, and to a few tens of μas for 15th magnitude stars (a jump of one to two orders of magnitude in accuracy and four orders of magnitude in number of stars compared to the earlier ESA Hipparcos mission). Gaia Data Release 1 (Sep 2016), saw the publication of the sky positions of 1.1 billion stars, and distances of more than 2 million stars using the Tycho-Gaia Astrometric Solution. Gaia Early Data Release 3 (EDR3: Dec 2020) contained the 3D positions of 1.47 billion stars, making this the largest and most accurate astrometric map ever published[4]. Gaia EDR3 (and the earlier Gaia DR2 April 2018 release) also contained four new data types: broad-band colour information, radial velocities for 7 million stars, stellar characteristics such as the surface temperature and radius of more than 77 million stars, and the positions of more than 14,000 Solar System objects, mainly asteroids. Gaia EDR3/DR2 have enabled the construction of the most accurate three-dimensional map of the positions and motions of stars in our Galaxy. By back-calculating trajectories of all the stars measured by Gaia, we are now directly reconstructing the history of our Galaxy's formation and evolution[5].

Gaia is having a transformational impact in mapping and understanding our MW[6], through advances across all areas of stellar astrophysics, solar system science, extragalactic astrophysics, and fundamental physics[7]. The Gaia data is also identifying new problems and directions that astrophysics will need to take. Gaia is now in its extended mission phase (in flight operations to mid 2025) and with final Gaia data releases in 2030).

The upcoming Q2 2022 full Gaia Data Release 3[8] (DR3) will release an increased range of rich data products, including crucially, the object classifications and astrophysical parameters (e.g. T_{eff}, chemistry) of some billion objects, enabling a multi-dimensional annotated map of the MW to be created. This will usher in the next wave of Gaia powered discovery.

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[4] Gaia Collaboration et al., 2018, Gaia Data Release 2. Summary of the contents and survey properties, A&A 616, A2

[5] Helmi et al., 2018, The merger that led to the formation of the MW's inner stellar halo and thick disk, Nature 563, 7729

[6] Antoja et al., 2018, A dynamically young and perturbed MW disk, Nature 561, 7723

[7] To date (Nov 2021) there have been over 5,700 peer reviewed papers making use of Gaia data, making Gaia ESA's most productive space science mission. The current list of publications can be found linked from https://www.cosmos.esa.int/web/gaia/peer-reviewed-journals

[8] Gaia DR3 content is described at https://www.cosmos.esa.int/web/gaia/dr3 (we understand reviewers will ignore these links, but we provide them for completeness!)

Gaia is establishing the astronomical distance scale for at least the next two decades. Nonetheless, the next European missions to follow Gaia, delivering Gaia-like accuracies in the infrared, are already being envisaged. The white paper 'Space-Time Structure Explorer Sub-μas astrometry for the 2030s'[9] prepared for ESA, outlined a range of potential key science drivers for the 2030s, potential development pathways, and likely technical challenges that would need to be overcome. The recent Voyage2050 white paper `All-Sky Visible and Near Infrared Space Astrometry'[10] did the same for an ambitious near-Infra Red (IR) space astrometry mission (named GaiaNIR). Recently, in June 2021, ESA released the result of its Senior Committee final recommendation for the ESA Voyage 2050 plan. Through this evaluation process ESA has chosen its future science mission themes, defining those which will drive the next three large-class missions, and identify potential themes for future medium-class missions. Importantly a GaiaNIR mission is identified as one of the top priorities for a future large-class mission under the "From temperate exoplanets to the Milky Way" [11] theme (NB: this theme envisages either an exoplanet focused IR spectroscopy mission, or a GaiaNIR global astrometry mission. The ESA senior committee note that the decision on which to focus on will take place in the next few years, with significant concerns raised as to whether a capable exoplanet atmosphere characterisation mission will be possible within a large-class mission budget. At this stage, the GaiaNIR MW focussed mission is more likely to go forward, especially as the recent NASA-NSF astro2020 decadal review[12] is prioritising a very large exoplanet characterisation space telescope, with ESA being seen as leading on the global astrometry mission. Uniquely, in the report, near IR astrometry is also a possible medium-class mission theme, hence there is significant work **now** required to further define GaiaNIR as a large or medium class mission.

Gaia has established European science and industry as leaders in high precision astrometry, and is allowing corresponding scientific leadership in many areas of astrophysics to be established or reinforced. The technical achievements of industry in delivering Gaia are now enabling wider commercial advantages: e.g. silicon carbide structures, large format sensor camera arrays, and cold gas micro propulsion systems developed for Gaia are cutting edge technology, of **significant value for the European space sector**.

In the next few years, further definition of these science priorities and the required technologies will be critical in ensuring that the next steps in understanding the ecosystem of the MW are furthered, through the development of the GaiaNIR ESA large mission. This presents opportunities for the Space Science commercial sector and related industries in responding to the technical challenges inherent in creating the next generation satellites.

DN Objectives: MWGaiaDN **aims** to [**Objective 1 (O1)**] **shape a critical mass of expertise** with the fundamental skills required to power the scientific exploitation of Gaia over the coming decade and to [**O2**] **drive the development of the next major steps in astrometry**. It will achieve this by focusing on [**O3**] **state-of-the-art research projects** linking key centres of expertise in Europe, with each project pushing the boundaries of Gaia science. Each project will deliver insights into the requirements for next generation facilities, and inform the [**O4**] **scientific roadmap towards future space astrometry** missions capable of μas accuracies in the near-IR strengthening the case identified by ESA as a Large Mission theme in the Voyage 2050 programme.

DN Integrated Research Programme: structured around ten individual research projects carried out by the recruited Early Stage Researchers (**ESRs**) located across the ten beneficiaries of the network. The network science themes are organised into three main interlinked science training Work Packages (WP). **WP3** addresses the structure of our Galaxy, **WP4** encompasses projects focussing on the physics of stars themselves. **WP5** covers projects exploring fundamental space and time challenges. Each of the individual ESR projects will deliver key science results through the duration of the network [**O3**], and importantly, will provide insight into where the key science challenges will lie when looking to extend astrometric capabilities into the near-IR. This road mapping exercise (finalised within **WP5**) [**O4**] will provide a key stepping stone in driving future astrometry, with the trained ESRs being optimally placed to lead that process in the decade after Gaia. The relationships between ESR projects is given in 1.1.2 and Tab 3.1d.

The ten research projects are described in Table 3.1d, all supervised by experts in the field, at forefront European research institutes, embedded within a rich collaborative environment established between the network partners. All research projects have clearly defined and measurable objectives, that are realistically achievable within the PhD programme. The ESRs will deliver pertinent publishable science based on the newest Gaia data releases, and also contribute to the science definition studies for the next generation GaiaNIR mission (large or medium class). Upon gaining their degrees, the ESRs will be in a position to drive the future programmes (both scientific and technical) to answer the fundamental questions of the ecosystem that is our MW. The DN ESR cohort will form the nucleus of excellence maintaining the leadership of Europe at the forefront of Galactic astronomy into the 2030's.

[9] http://www.rssd.esa.int/doc_fetch.php?id=3210644

[10] https://ui.adsabs.harvard.edu/abs/2021ExA....51..783H/abstract

[11] See: https://www.esa.int/Science_Exploration/Space_Science/Voyage_2050_sets_sail_ESA_chooses_future_science_mission_themes

[12] (https://www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020)

MWGaiaDN builds on and extends the Gaia Research for European Astronomy Training Network (GREAT)[13] (initiated by the Gaia Science Team (GST) and the Gaia Data Processing and Analysis Consortium (DPAC) Executive in 2009). Notable GREAT results included community input into the shape of the Gaia Archive[14], community building for major ground based wide-field spectroscopic surveys of the MW, support for the formation of follow-up networks of Gaia observations of transient objects and solar system objects, new approaches to realistic chemo-dynamical modelling of the MW, and a range of strategy papers detailing how topic areas could benefit from and should prepare for GaiaNIR. The GREAT-Initial Training Network[15] (2011-2015) successfully trained seventeen ESRs all of whom gained their PhDs and continued their careers in academia or industry. The final conference of the network demonstrated the excellent science carried out in the network[16]. The current MW-Gaia COST Action[10] networks a large scientific Gaia community across Europe. MWGaiaDN will synergistically leverage the MW-Gaia network, with a range of ESR projects aligned with these key science and technological objectives.

MWGaiaDN beneficiaries represent the ESA GST (Cambridge, Barcelona, Dresden) and the Gaia DPAC (Leiden, INAF (Padua), Grenoble, Lund, Athens, UCL). They are active at the forefront of the development and science exploitation of Gaia. They are responsible for designing and developing the sophisticated data analysis systems required to process the complex Gaia data stream. They are running and enhancing the ground data processing system and delivering the Gaia science data products. MWGaiaDN's industrial partners have played key roles in delivering Gaia, ABUSDS was prime contractor for Gaia, INSYS provides the high-performance database system, at the heart of the astrometric processing system for Gaia. DAPC has a key role in the operations of the core processing system for Gaia, and development of the Gaia Archive.

With an effective set of collaborative projects and an integrated training programme, the MWGaiaDN alliance is optimally shaped. This proposal will extend the GREAT training programme into the era of high-precision Gaia data, not only to train a new cohort of young experts in exploiting the exquisite data expected from Gaia, but also to define the scientific roadmap for continued development in the field of space astrometry. **This will ensure the European leadership in this cutting-edge field of science, and will provide a pool of new innovation-orientated expertise with the excellent skill set required to pursue high impact careers in either astronomy or commerce.**

1.1.2 Pertinence and innovative aspects of the research programme

1.1.2.1 WP3: Gaia Frontiers: The MW as a Galaxy

The formation and evolution of galaxies across cosmic time is a central theme in astrophysics. The study of the MW takes a natural place in this work, as it is the one galaxy we can study in exquisite detail – if we have the right observations. The arrival of the Gaia data is currently revolutionizing our picture of the MW. The positions and transverse motions provided through the astrometry done by Gaia must be complemented with ground based spectroscopic follow-up (e.g. Gaia-ESO survey, 4MOST, WEAVE[17]), to derive the full 3D velocities of the stars as well as their elemental abundances. These data will enable us to study the structure and history of the MW centre (**UCL PhD**), disk and halo (**ESR2**), including substructures such as stellar clusters and accretion debris (**ESR5**).

The research includes study of the dynamical structure and history of the Galaxy, also known as Galactic archaeology. We only observe the stars where they are now, but from stellar dynamics and improved knowledge of stellar ages we can use the large ensemble of Gaia and spectroscopic observations to infer the state of the Galaxy at earlier times. This establishes the history of star formation in various Galactic components, which helps understand and compare galaxy formation scenarios, in particular its merger and accretion history that Gaia EDR3 has shown to be a major key to understanding the overall history, current structure and dynamical status of our MW.

In Our Galaxy we see significant substructure in the form of molecular clouds, open clusters, globular clusters, moving groups, stellar streams and accretion debris. How do these structures fit into the overall picture of galaxy formation and evolution? Most stars that populate the Galaxy presumably formed in some kind of cluster/association, rather than in isolation. But are the open clusters we see typical sites, or are they just the long-lived and visible tail of the star formation process? Gaia's accurate astrometry on hundreds of known clusters of a wide range of ages (themselves determined more accurately by Gaia parallaxes and photometry) allows us to determine the cluster membership and disruption, e.g., at what rate do cluster stars or accretion debris populate the Galaxy. Gaia further has enormous discovery potential: using advanced data mining techniques, Gaia's astrometry is being used to identify disrupted clusters and stellar streams: these may be so spread out that they are no longer detectable as a spatial over density, yet remain detectable in velocity space and via a common chemical composition.

[13] http://www.great-esf.eu: ESF research network (2010-2015) and http://www.mw-gaia.org: COST Action CA18104 (2019-2023)

[14] http://great.ast.cam.ac.uk/Greatwiki/GaiaDataAccess/GdaScenariosFeedback

[15] GREAT-ITN: Grant Agreement 264895 - see https://cordis.europa.eu/project/id/264895

[16] http://www.eas-journal.org/articles/eas/abs/2014/03/contents/contents.html

[17] See http://www.gaia-eso.eu, http://www.4most.eu and http://www.ing.iac.es/weave respectively. All of these are massive spectroscopic surveys with key leadership from the DN partners.

With the new Gaia DR3 the increase in precision as well as the amount of complementary information (from Gaia, e.g., spectrophotometry, binarity information and external spectroscopic follow-ups) will enable to make new large steps forwards. The new binarity information over the Gaia DR3 HR-diagram (**ESR8**) will permit to fully revise the initial mass function and the star formation history of the not so local anymore neighbourhood. Gaia DR3 spectrophotometry and spectroscopic follow-up add dimensionality to the clustering approach, enabling to identify new weak structures and their potential disruption within field stars to an unprecedented level. The new data will enable a full characterization of those weak structures, either open clusters or accretion debris, in particular in terms of mass and age, revealing their contribution to the global MW history. We will also experiment with a new way of constraining the MW history by studying the tilting rate of the galactic disk which will be measurable with the increased precision of upcoming data releases and will definitely lead to requirements on future astrometric missions.

During the initial phase of MWGaiaDN, ESRs 2, 5, 8 and UCL PhD will exploit Gaia Data Release 3 as outlined in the project descriptions in Sec 3.1.3. This will inform the requirements for next generation near infra-red astrometry, where the optical Gaia mission will not provide sufficient sensitivity or coverage in addressing follow-on investigations of Milky Way formation (for instance in mapping the detailed disk structure towards the galactic centre).

1.1.2.2 WP4: Gaia Frontiers: Stars and Planets

This theme addresses the main advances expected from Gaia data on the fundamental properties of planets and stars as fossils of the formation and evolution of the MW

The life of Stars. As described in sec. 1.1.3.1 large samples of stars of well-known parameters spanning wide age and metallicity ranges enable the study of the formation and evolution of the MW. However, the determination of stellar parameters often relies critically on the completeness and accuracy of stellar models. In spite of the recent progress in stellar evolution modelling, several open problems remain. In particular the effects of mixing in stellar interiors, stellar rotation, and magnetic fields remain poorly understood. While 3D stellar modelling is still quite challenging, 1D stellar models prescribe or approximate multidimensional phenomena introducing a simple parameterization. Due to their chemical and age homogeneity, open clusters are a key tool for stellar model calibration. MWGaiaDN will exploit Gaia data and supporting ground based spectroscopic surveys to answer a fundamental question *Can we put further constraints on stellar physics to safely use stars as fossils for Galactic formation and evolution?* The immediate goals are: (a) calibrate stellar structure and evolution models; (b) refine our knowledge of the properties of the star clusters for Galactic study; (c) define the properties of stars hosting exoplanets. These key topics of study include:

a) Use open clusters to refine and calibrate stellar models. Do stellar models properly reproduce empirical HR diagrams? Do we really understand the evolution of AGB star? Do we have a good description of the mass-luminosity relation? Do we really understand the evolution of stars at the low mass end? Having well defined ages and distances, star clusters provide an immediate link to stellar properties, such as absolute magnitudes and masses. This allows to calibrate isochrone properties (**ESR9**). Combining this with the analysis of chemical elements, we can get insight into stellar models. In particular, because it only survives in the outer layers of star, Li is a very sensitive tracer of stellar evolution and non-standard mixing, while s-elements in young stars can trace the stellar chromospheric activity and ultimately how magnetic fields influence the formation of lines in stellar spectra (**ESR3**).

b) Refine our knowledge of the properties of the stars and clusters (**ESR1**, **ESR3, ESR9**). Revised stellar models can lead to a more accurate definition of star cluster properties such as stellar content, IMF, ages. The effects of binarity, rotation, and chemical compositions will be thoroughly explored. Ultimately, this will provide an accurate data base of open clusters which will be fundamental to trace the properties of the Galactic disk.

c) Exoplanet host stars (**UCAM PhD**) will be studied to investigate the how the properties of these stars relate to their exoplanet systems. Are solar type stars more likely to host multi-exoplanet systems such as ours, rocky terrestrial planets close in, with more massive gas giants further out? What is the role of stellar multiplicity on exoplanet system architecture? This project will benefit from the long period systems to be published in Gaia DR3 (at the start of the network) and the much fuller list to be release in Gaia DR4 towards the end of the network activity, and the availability of high-resolution spectroscopy from e.g., WEAVE on the 4.2-m William Herschel Telescope.

During the initial phase of MWGaiaDN, ESRs 1, 2, 9 and UCAM PhD will exploit Gaia Data Release 3 as outlined in the project descriptions in Sec 3.1.3. This will inform the requirements for next generation near infra-red astrometry, where the optical Gaia mission will not provide sufficient sensitivity or coverage in addressing follow-on investigations of Milky Way stellar astrophysics (for instance in exploring young stellar clusters in the hitherto optically obscured regions towards the galactic centre).

1.1.2.3 WP5: Gaia Fundamentals: Space and Time

Future Astrometry, probing the Galaxy with Visible-NearIR Astrometry and Gravitational Waves: Gaia was first proposed over 20 years ago and is now delivering its first results with further releases in the coming years. Gaia has unique capabilities, which will keep it at the forefront of astrophysics for the foreseeable future, through to the 2030s. Its scientific results are already raising new questions, and the survey will continue to uncover surprises. To address these we will need the next level of astrometric data, beyond Gaia. The main concepts for this is to shift all-sky Gaia-like absolute astrometry into the Near-InfraRed (NIR). Recently, Hobbs et al. (2021)[18] submitted a white paper to ESA's Voyage2050 call outlining the science case for all-sky NIR astrometry, known as GaiaNIR. This concept requires new technology developments and the development of methodology to extract the science from these challenging missions. To develop an all-sky NIR astrometry mission new efficient detectors in the optical and NIR are required. The conventional CCDs used on Gaia are not sensitive in the NIR. Additionally, to scan the entire sky and make global absolute parallax measurements the spacecraft must have a constant rotation, and this requires the detectors operate in Time Delayed Integration (TDI) mode or similar. A TDI solution would give similar accuracies as Gaia despite doubling the wavelength range. The science return from such a mission is very promising but a solution to the technology problem of implementing a TDI like solution in large format NIR detectors must now be found.

The Voyage2050 white paper (Hobbs et al., 2021) detailed three science cases for a NIR mission:

a. NIR astrometry and simultaneous photometry is crucial for penetrating obscured regions of the MW to obtain a dense sampling of the phase space necessary to study the bulge, bar, bar-disk interface and spiral arms.
b. A new mission could be combined with the older Gaia catalogue (currently ~1.7 billion sources) with a 20-year interval to give a much longer baseline of 25–35 years, with very accurate proper motions (a factor of 14–20 better in the two components) and improved parallaxes needed to measure to larger distances.
c. A new mission would allow the slowly degrading accuracy of the Gaia visible reference frame, which will become the fundamental Celestial Reference Frame and the basis for all modern astronomical measurements, to be re-initialised back to a maximal precision. The mission will also allow the reference frame to be extended into the NIR which will provide a much denser grid suitable for future ground and space-based observatories (many will have IR instruments).

A NIR mission would observe at least 5 times as many stars as Gaia, assuming the same magnitude range, giving a huge increase in the catalogue size. This will present data processing challenges and collaboration with experts (e.g. Vera Rubin Observatory/LSST) will be important as they are pioneering expertise in this field.

A mission with sub-µas accuracies presents a number of significant challenges, e.g.;

- The next level of astrometric accuracy will demand the next level of relativistic modelling of astrometric measurements. This requires research to refine the currently employed models and also, requires a refinement of our knowledge of the solar system and all parameters entering the model (e.g., better planetary ephemerides, asteroid masses, more accurate orbit of the spacecraft).
- Approaching sub-µas levels, simple models of the time dependence of source coordinates may not be sufficient. Research into sources of astrometric jitter (e.g. star spots, faculae, or micro-lensing) and their effect on the interpretation of image locations in the data stream is required.
- Will the Gaia reference stars be sufficiently accurate in 20 years' time for an astrometry mission to achieve sub-µas astrometry?
- How to manage the extreme spacecraft positioning and stability requirements.

Both of the above approaches will require system calibrations that are much better (by an order of magnitude) than the astrometric accuracy aimed for, which will be extremely challenging. This implies that the design of the instruments and mission concept will have to incorporate the data processing demands from the start. The question of how to combine the data from multiple missions with different accuracies and sky coverage at multiple epochs arises and international collaboration is needed to establish a standard framework for this (**ESR4**).

The completeness of detection of the AGN (used to fix the Gaia reference frame and link this to the ICRF) will be investigated, to increase the known catalogue in Gaia and determine how the detectability limits will change with GaiaNIR **(ESR6, ESR10**). The study will look for exotic binary AGN to probe fundamental galaxy growth scenarios.

Fundamental Parameters Considering greater accuracy of future astrometry (both from sub-µas astrometry missions and from a combination of Gaia and future µas astrometry from e.g., GaiaNIR) it is very important to ensure meaningful determination of various scientific parameters. This concerns physical or relativistic parameters (**ESR7**) that enter the corresponding astrometric model (e.g., the parameters of the relativistic deflection of light) and astrophysical parameters and, first of all, distances. In the latter case it is crucial to investigate various steps of the cosmic ladder from the very local to the 100 Mpc universe that will greatly benefit from Gaia and from future

[18] Hobbs et al, 2021, Exp Astron, 51, 783: https://link.springer.com/article/10.1007/s10686-021-09705-z

astrometric programmes. The complementary expertise of the various nodes will be integrated in order to provide an accurate calibration of primary and secondary distance indicators and investigate the requirements on observation and source modelling for sub-μas astrometry.
MWGaiaDN is highly original in addressing many key questions exploiting the Gaia and associated data available through the duration of the network (2022-2026). In parallel with these here and now studies, the network will lay the underpinnings for the next steps, where it is already clear that current missions are not sufficient, for example the need to probe more precisely the inner regions of our MW where the bulk of the stars and galaxy mass are. This requires science case and technical assessments to be progressed during the network, to enhance the likelihood of a future mission launching in the mid 2030's. This essential preparatory work now ensures the future. To address these questions, MWGaiaDN includes a work activity (within WP5) that will synthesize the results obtained over the lifetime of the network into a roadmap for achieving the next step in space astrometry. The scientific requirements on the next mission will be refined based on the outcome of the research projects defined in WPs 3, 4 and 5, while the science, technical, and engineering challenges will be more clearly identified from the research carried out in WP5 feeding through to Impact and Engagement in WP6. All the ESRs will be stimulated to provide an outlook on the next level of data required to address the new questions uncovered by their research. The preparation and synthesis of the Roadmap will be carried out in WP5, but with input from the ESRs across the network. This will be complemented by workshops on the art of astrometry and the challenges of future space-based astronomy. The work will culminate with a presentation of the Roadmap at the MWGaiaDN final conference, where initial community feedback will be gathered. The Roadmap document will be valuable to industry, who will have access to this requirements/scoping document, of relevance when participating in future mission proposals

Table 1.1: Work Package (WP) List

WP No.	WP Title	Lead Beneficiary No.	Start Month[19]	End month	Activity Type[20]	Lead Beneficiary Short Name	ESR involvement (by ESR number)
1	Network Management	1	1	48	MGT	ULEI	ALL (partially)
2	Network Training,	4	1	48	TRN	UB	ALL (partially)
3	Gaia Frontiers: The MW as a Galaxy	7	1	48	RTD	UGA	2, 5, 8
4	Gaia Frontiers: Stars and Planets	2	1	48	RTD	INAF	1, 3, 9
5	Gaia Fundamentals: Space and Time	3	1	48	RTD	LUND	4, 6, 7,10
6	Impact, Inclusiveness and Public Engagement	23	1	48	DIS	UCAM	ALL (partially)

1.2 Soundness of the proposed methodology

1.2.1 Overall methodology

MWGaiaDN is built around the four network objectives, the four 'E's, namely: it will generate **Excellent** science exploiting the current state-of-the-art Gaia mission [**O3**]; it will **Extend** the techniques for sub-μas astrometry [**O4**]; it will **Enhance** the skills of the next generation of scientists [**O1**], and it will **Effect** the next revolution in European-led astronomy with leadership in astrometrically grounded science [**O2**].
In order to advance the major science goals of the network, the research programmes are organised into **three research-oriented WPs (WP 3, 4, 5)** that cover the key science frontiers of Gaia. These inform the development of the roadmap (finalised in WP5) defining the future requirements and challenges progressing towards Near InfraRed (NIR) and sub-μarcsec astrometry. The **management of the network (WP1)**, the oversight and coordination of the **ESR training programme (WP2)**, and the organisation of the network's **public engagement, communications, and data management (WP6)**, ensure that the research and training will achieve their maximum impact.

The following sections describe the key scientific challenges for each of the WP themes, noting the science and node-based research programmes for the network ESRs. There will be significant interaction between the ESRs at a range of levels. Within the theme-based WPs, the ESRs will interact through regular science progress teleconferences, meetings, and dedicated instant messaging platforms. Sec. 1.2 describes the network-wide training activities providing the underpinning for training in the techniques (scientific, technical, organisational) needed in addressing the science challenges. This will be organised and overseen by WP2. We highlight the synergies between the academic and industrial partners in Sec. 1.4.3. Deliverables and milestones are listed in Tab. 3.1b and Tab. 3.1c, respectively. The ESRs will all be enrolled in a PhD course leading to the award of a PhD.

[19] Network start month, M1 will be Feb 2021.
[20] MGT: Management, RTD: Research, TRN: Training, DIS: Dissemination and Public Engagement.

1.2.2 Integration of methods and disciplines to pursue the objectives

The research programme is structured around the exploitation of Gaia data to further our understand of the evolution of the Milky Way. A range of techniques will be used: observational, theoretical, statistical, computational, Machine Learning. The DN contains experts in these various disciplines, and the ESR projects are structured to ensure that the research acquires a broad range of multi-disciplinary training through appropriate secondments to other beneficiaries or associate partners, bring in additional competences. Thus, ESR10 developing dynamical MW models will gain expertise in the visit to UGA in stellar populations. Challenges with immersive visualisation will addressed with expert input from our industrial partner (SUIL), who will provide network wide training through input to workshops (e.g., statistics and visualisation) and host an ESR project. The research outputs will be used to inform the next steps towards next generation near-infrared astrometry space missions. This involves assessments of science drivers with technical capability, this work will be undertaken in exchange placements at the DN industrial partners with expertise in space mission design (e.g., TAS, AIRBUS), guidance (SPIN), detectors (LEON).

The methodological approach to be adopted, especially in the areas if stellar evolution, astrostatistics and machine learning, will be reviewed at the kick off meeting of MWGaiaDN. This will allow any required adjustments in approach to be made in the light of insights resulting from the June 2022 release of Gaia data release 3.

1.2.3 Gender dimension and other diversity aspects

The research programme is focused on furthering our understanding of the cosmos, an undertaking that is important to all humankind, irrespective of gender or other diversity considerations. Our DN aims to promote gender equality in carrying out the research and innovation in our network through a range of concrete measures, leveraging the techniques embedded in the partner teams institutionally and through their existing collaborative partnerships. For instance, at the institute level, the IoA, Cambridge has a strong focus on equality & diversity[21], and promotes gender inclusion through initiatives such as 'Celebrating Women in Astronomy'[22], participation in International Women's Day, active mentoring of students, promoting female role models and so forth. Gender equality is embedded in the IoA culture, in training, recruitment, career progression and recognised through the University possessing the Athena Swan and Juno charter marks. Other beneficiary institutes have a similar focus on delivering on gender equality. More widely the Gaia collaboration encourages gender and diversity balance, promoting role models, for instance Gaia Women in Science. In recruiting our DN researchers best practice will be followed, and training will be provided, both institutionally, but also through specific MWGaiaDN events such as during induction and specific diversity training (see Tab 1.3b).

1.2.4 Open science practices

MWGaiaDN will place open science practices at the heart of the DN's research methodology. The data generated in astronomy is published openly and widely. In particular, the success of Gaia is underpinned by the approach of releasing its data to the global community without restriction. Within the DN, its collaborative research will be shared at an early stage. Research outputs will be published as open access articles, with pre-prints made available in advance of publications through the ArXiv preprint server[23]. The DN website will facilitate sharing of research, data will be linked via DOI's, articles will be published through mechanisms such as Zenodo to ensure that material of a more technical nature, of contributions to workshops, are shared. Code generated through the network will be shared through a common code repository. The impact of the DN outputs will be increased though sharing more widely, e.g channelling through our associate partner SAAO's IAU Office of Astronomy for Development[24].

1.2.5 Research data management and management of other research outputs

The Data Management Plan (**D6.1**) is an early deliverable. This plan will define how all data generated during network activities will be accessed, mined, exploited, reproduced and disseminated, making the data findable, accessible, interoperable and reusable. Within MWGaiaDN a range of research outputs will be generated, including new survey data outputs, images and catalogues, simulations and software algorithms. The data volumes are significant (100's GB for WEAVE survey data for instance – ESR1) but disk and processing resources are readily available to the beneficiary partner group teams. Data outputs will be made available through Virtual Observatory (IVOA)[25] protocols, e.g. WEAVE data will be available at the WEAVE Archive, and catalogues associated with publications will be made available via the CDS VizieR data repository[26]. Software will be published on the

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[21] IoA, Cambridge equality and diversity pages at https://www.ast.cam.ac.uk/about/equality.diversity.inclusion

[22] https://www.ast.cam.ac.uk/about/equality.diversity/celebrating.women.astronomy

[23] Open source: http://www.zenodo.com, https://arxiv.org/archive/astro-ph, https://github.com/

[24] The Office for Development: https://www.astro4dev.org/

[25] International Virtual Observatory Alliance: https://www.ivoa.net – generate data access protocols, implemented widely.

[26] https://vizier.cds.unistra.fr/viz-bin/VizieR

MWGaiaDN github repository[27]. All data generated will be published conforming to FAIR principles, with standard metadata being provided to ensure that the data is described. The beneficiaries are all at the front of ensuring open access to data, and Gaia has been at the forefront of this open revolution. MWGaiaDN will continue this tradition.

1.3 Quality and credibility of the training programme

1.3.1 Overview and content structure of the doctoral training programme

Table 1.3 a Recruitment Deliverables per Beneficiary

Researcher No.	Recruiting Participant (short name)	PhD awarding entities	Planned Start Month 0-45	Duration (months) 3-36
1.	UB	University of Barcelona	8	36
2.	LEID	Leiden University	8	36
3.	INAF (Padova)	University of Padova	8	36
4.	LUND	Lund University	8	36
5.	UB	University of Barcelona	8	36
6.	UC	University of Coimbra	8	36
7.	TUD	Technical University Dresden	8	36
8.	UGA	Universite Grenoble Alpes	8	36
9.	NKUA	National and Kapodistrian University of Athens	8	36
10.	TUD	Technical University Dresden	8	36
Total				360
11*	UCAM	University of Cambridge	9	36
12*	UCL	University College London	8	36

* Researchers 11 and 12 are recruited by UK-based associated partners, they are not supported by EU funds, and will be supported by UK funds.

The training programmes seek to **develop the expertise of ESRs** across the key science topics where Gaia will have a major impact. These topics, taken as a whole, will lead to fundamental breakthroughs in our understanding of the properties of the MW and its constituents. Each research topic, working at the limits of the possibilities offered by the Gaia data will act to inform the requirements on future programmes aimed at delivering NIR astrometry.
The training programmes offered at each of the nodes are tailored to the specific needs of that particular science question. The ESRs will be working with leading experts in those fields. The ESR training will be matched to their individual career development plans (Sec. **3.1.10**). The benefit of the network is fully realised with the **integration of the science themes**, coupled with the application of cross theme technique developments. In order to progress beyond each of the science themes, new techniques will need to be developed and utilised to address a range of technological challenges. The network wide training will emphasise expert training in these techniques and technologies. Science theme training will be delivered through interactions within the WPs and through a PhD study programme for each of the ESRs.
The training is structured to provide **cross science theme technology and complementary skills training**, organised primarily on the network wide basis. Here the involvement and the expertise from the industrial partners in the MWGaiaDN are of paramount importance. This training, coupled with the WP/node-based science thematic training, ensures that each ESR receives the best possible blend of training delivered by the experts in the network. The training exposes the ESRs not only to the non-academic sector, through visits and workshops involving all the industrial partners, but also provides opportunities to attend workshops and secondments across Europe, with involvement of experts in a range of disciplines (e.g., astronomers, engineers, computer experts).
The training at the **non-academic partners will extend the core academic training**. At ABUSDS and SPINW, the ESRs will learn how scientific priorities are implemented in the industrial and commercial settings in the context of both large and SME organisations, and how the trade-off process is managed. At INSYS, the ESR will learn how advanced IT systems can be commercialised, e.g., the economics of software as a service, and cloud-based computing charging structures. Training at DIRAC will show how the largest ground-based telescope project (LSST/VRO) in the USA is being developed, and how the significant data handling issues will be addressed. Training at DAPC will focus on the integration of ESR developed algorithms to directly access the Gaia data in a production environment.
MWGaiaDN training involves **core science and transferable skills schools**, together with WP specific workshops, in addition to student (and indeed expert researcher) exchanges. The training events all involve expert organisation, the full organising committee for each event would have ESR involvement (with appropriate gender balance). It is valuable to have ESR involvement in the training organisation; this benefits the ESRs and brings the student voice to the forefront of the network. All meetings will involve presentations from network experts complemented by external experts.

[27] See https://github.com/agabrown/PyGaia for an example of Gaia related software published via GitHub

For most workshops and schools, we would seek to co-organise (and co-fund) through the wider GREAT/MW-Gaia network (see Sec. **1.1.1**) or other related networks, as this allows for greater interaction (and hence impact) with partners and students outside of MWGaiaDN. This interaction worked extremely well with the GREAT ESF RNP and EC FP7 GREAT-ITN networks.
Workshops and schools will publish on-line the talks and presentation materials. The final conference will be published as a proceeding via an open access journal.

The training programme will result in a group of motivated and skilled young researchers.

Table 1.3 b Main Network-Wide Training Events, Conferences and Contribution of Beneficiaries

	Main Training Events & Conferences	**ECTS[28] *(if any)***	**Lead Institution**	**Action Month *(estimated)***
1	WP1: MWGaiaDN Kick-Off: full network meeting (FM1) [Cambridge]	-	LEID/ UCAM	2
2	WP2: The MWGaiaDN Training programme: Kick-Off Workshop [Barcelona]	-	UB	6
3	WP2: ESR Induction School: Introduction to the Science and Data of Gaia [Leiden]	1	LEID	9
4	WP3: Thematic Workshop: Galaxy Modelling [London]	0.5	UCL	10
5	WP4: Thematic Workshop: The frontiers of stellar physics: comparing theory with observations [Padova]	0.5	INAF (Padova)	11
6	WP2: ESR School: Introduction to Astro-statistics and data visualisation [Coimbra]	1	UC	12
7	WP1: MWGaiaDN mid-term review and full network meeting (FM2) [Leiden]	-	LEID	13
8	WP5: Thematic Workshop: The Art of Astrometry and computation [Lund]	0.5	LUND	15
9	WP2: ESR Transferable Skills School: Managing Complex Systems & Enterprise [Barcelona]	1	UB/ DAPC	16
11	WP6: OUTREACH Event: Gaia Map@ IAU GA [Cape Town/ Athens/ Cambridge]	0.5	SAAO/ NKUA	19
11	WP2: ESR School: Astro Big Data [Seattle]	1	DIRAC	20
12	WP2: Diversity, Public Engagement and Communication training [Leiden]	0.5	LEID	21
13	WP5: Roadmap: Technical Challenges workshop [Cambridge]	0.5	LUND	26
14	WP3: Thematic Workshop: The Galactic Centre [Grenoble]	0.5	UGA	29
15	WP5: Thematic Workshop: Gravitation and Astrometry [Dresden]	0.5	TUD	30
16	WP1: Year 4 and final full network meeting (FM3) [Padova]	0.5	INAF (Padova)	42
17	WP6: At the Frontiers of Gaia: pushing boundaries, exploring NIR astrometry and breaking the microarcsec barrier. An international conference [Athens]	1	NKUA	47

1.3.1.1 Core Training Schools

These core training schools will constitute keystones of the training programme for each ESR. The main cross network training events will occur in the second and third years of the network, to ensure that all ESRs will be able to benefit, recognising that all ESRs will be in place by the end of the first year. All core schools will take place after the Gaia DR3 release[29], hence the ESRs will benefit from access to high quality Gaia data. The envisaged core schools are:

a) Induction school [5days] for all new ESRs (Lorentz Centre, Leiden, NL) to introduce all to Gaia and its science potential. Each science theme will be addressed via expert invited talks. Each ESR science project will be introduced. Specific sessions devoted to working with the rich data from Gaia, e.g., new spectrophotometric data forming a key component of Gaia DR3, to ground all ESRs in the use of techniques for exploiting Gaia data. Sessions on improving ESR scientific presentation skills (where feedback on the ESR presentations will be given by professional trainers), project management (for international collaborations) and grant proposal writing.
b) Astro-statistics school and data visualisation [5days] (University of Coimbra, PT): providing an intense hands-on course covering practical approaches to the statistical analysis and interpretation of astronomical data. This will be organised by UC, DIRAC and SUIL, taking advantage of their expertise in developing machine learning and data mining for astronomy[30] and immersive visualisation[31].

[28] Indicated ECTS credits are the approximate credit equivalent of the training. Computed using the NL level of 1 ECTS = 28 hours of training and preparation time. NB; not all countries in the network have implemented the ECTS system (e.g. not used at the University of Cambridge).
[29] Gaia data release schedule at http://www.cosmos.esa.int/web/gaia/release. Gaia DR3 is due Q2 2022 and will be available for the ESR projects, with the Gaia DR4 likely 2025, hence available for the final year of a typical researcher 4 year PhD project.
[30] See e.g. the AstroML site at http://www.astroml.org/ (developed by the Washington, DIRAC partners).
[31] See Suil's immersive visualisation in the context of annotated cellular analysis. This will be transferred to the case of annotated stellar data from Gaia. https://cancergrandchallenges.org/news/why-virtual-reality-future

c) Astro-Big data school [4 days] (DIRAC, University of Washington, Seattle, USA): providing a focused course covering approaches to the handling and interpretation of large (big) data, and in particular complex Gaia data. Co-organised by the DIRAC and UCL and follows the earlier astro-statistics course.

1.3.1.2 Core Project Management, Entrepreneurship and Public Engagement Training

These core schools will provide key additional training in addition to that normally found within the academic PhD programmes. These skills will provide the ESRs with a powerful set of techniques, essential if they decide to transfer their academic knowledge to the commercial setting.

a) Managing complex systems, enterprise and entrepreneurial skills: (Barcelona) [5-day] Topics: introduction to formal project management techniques such as Agile programming, waterfall methods, the Unified Process. Human resource management, project planning, financial control, risk management, scientific project control. IPR, and how patents, licensing rights are managed. The ESRs will receive specific enterprise training. One day will be devoted to team-work skills.

b) Diversity and Public Engagement Training (Leiden, NL) [5-day] Topics: 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.

c) Public Engagement events. The main outputs of the network will be presented at the summer 2024 IAU GA with an event that will demonstrate the wonder of the **Gaia Map** of the Cosmos. This event will link schools in Europe to those in Southern Africa, to provide a unique link up between Gaia, Europe and Africa. Organised by NKUA, UCAM and SAAO/ IAU Office for Astronomy Development.

1.3.1.3 WP Thematic Workshops and Conferences

Workshops will address key WP specific issues, with ESRs from the WP attending. All will involve detail in-depth discussions on the topics, and include invited external expertise.

a) **WP3**: Galaxy Modelling (London, UK): workshop topics: mass modelling, kinematic modelling, dynamical modelling, stellar population modelling and dust extinction modelling. Challenges in applying modelling techniques to reconstruct the structure of the Galaxy from a large volume of the complex observational data that Gaia will produce. Hands-on session for ESRs to apply some of the modelling techniques to the available Gaia real and model data.

b) **WP3**: The Galactic Centre (Grenoble, FR): workshop topics: dynamical structure of the Galactic nucleus, search for observational relics of a sequential merger of multiple black holes to form the supermassive black hole at the centre, formation of open clusters at the Central Molecular Zone, the origin of X-ray point sources around the centre (e.g. symbiotic X-ray binaries), dust distribution. The challenges of near infrared astrometry in the crowded galactic centre will be addressed

c) **WP4**: The frontiers of stellar physics: comparing theory with observations (INAF/Padua, IT). The workshop will address next decade challenges on stellar evolution and pulsation, through synergies between new observation technologies, advances in theory, and multi-dimensional modelling. The challenges and the opportunities posed by the on-going and near future spectroscopic, photometric and astrometric and asteroseismic surveys (Gaia next data releases, WEAVE, 4MOST, LSST, TESS, PLATO...) will be discussed

d) **WP5**: The Art of Astrometry and Computation (Lund, SE): Building astrometric modelling and first global solutions of the Gaia mission, this workshop will give ESRs a deep insight into the astrometric and computational challenges of this and future missions with tutorials and hands-on simulations.

e) **WP5**: Gravitation and Astrometry (Dresden, DE): The problem of relativistic modelling in astrometry both at the level of Gaia and beyond will be overviewed. Open problems will be formulated, and the prospects assessed. Applications of astrometry to test fundamental physical theories will be reviewed.

f) **WP5**: Technical challenges of space-based astronomy (Cambridge, UK). Organised by UCAM/LUND/TUD, with involvement of ABUSDS, LEON, OHB, SPINW, TAS. Part of the NIR and sub-μas road-mapping exercise, will consider the complexities of constructing, and using space-based telescopes. Cover successes and challenges in the delivery of the Gaia mission, and note issues in moving to a successor mission.

g) **WP6**: Final Conference. ‘At the Frontiers of Gaia: pushing boundaries, exploring NIR astrometry and breaking the μas barrier’. This major conference (Athens, GR) will present all research carried out in MWGaiaDN, and keynote invited talks. Some sessions will be organised by the ESRs. The conference will present the WP5 Roadmap for next steps in astrometry.

1.3.1.4 Training at the host and partner institutes

Each ESR will benefit from the professional development and training courses available at their host institutes, all of which have a strong record of excellence in research and training. Each institute offers a comprehensive range of

training in complementary skills[32]. All will be encouraged to take appropriate courses, for instance in language skills, academic writing, effective research management, communication and presentation skills. Local training will also be delivered in topics such as grant preparation, appropriate at the national level. The DTC will monitor the level of local complementary training undertaken by each ESR, to ensure that minimum levels are reached.
ESRs on secondment to industrial or astronomical facility partners will receive local training in areas such as project management, finance control, use of IT in a commercial setting, and so forth.

1.3.1.5 Opportunities through the wider GREAT/MWGaia network

The network's ESRs will be encouraged to participate in relevant activities organised through the wider GREAT/MW-Gaia programme. Additional science workshops and exchanges will be funded through our MW-Gaia COST supported action.

1.3.2 Role of non-academic sector in the training programme

The industrial partners (both large and SME) bring considerable expertise and experience in a range of key areas: development of advanced space systems (ABUSDS, OHB, SPINW, TAS), advanced database technologies (INSYS), managing Big-Data (DAPC), developing high performance virtual reality environments (SUIL). They have a fundamental role in delivering the required complementary training to the network ESRs and play a significant role in the organisation of the network wide training aspects of MWGaiaDN. Their membership of the Consortium Supervisory Board (CSB) and the Doctoral Training Committee (DTC), ensures that they strongly influence the strategic development of the network to ensure that the training offered through the network is not only appropriate scientifically, but also has more general relevance in training future expertise able to contribute to industry. The focus here would be ensuring relevant technical skills to enable an ESR to enter into the knowledge economy, essential for ensuring European economic success. The industrial partners represent significant leaders in technologies of immediate use to the science of Gaia. All of the partners have existing links to one or more of the full beneficiary nodes of the network, and are working with ESA and the DPAC in the design and implementation of the processing and analysis system for Gaia. These links to the industrial partners will make their integration into the network that much quicker.

1.4 Quality of the supervision

1.4.1 Qualifications and supervision experience of supervisors

Each ESR will be enrolled in a postgraduate programme at their host node (ESR project descriptions can be found in **Table 3.1.d**), leading to the award of a postgraduate degree at the PhD level. All of the MWGaiaDN nodes are world-class research institutions, with established excellence in academic training. Each ESR will benefit from state-of-the-art research training delivered by working in their host institute, coupled to a rich network-wide training programme. Qualified expert academics, all with significant experience in supervision of PhD's, all leading research teams, and all leaders in the development and science of Gaia will supervise the ESRs.
Importantly each ESR will gain further benefit from the close and dynamic research networking offered through the MWGaiaDN, particularly through the science interactions within the WPs. All hosts offer a full range of complementary training in related skills, such as transferable skills, scientific writing and presentation skills, language and programming skills, etc. In addition, where a particular host institute may not have the complete range of in-house complementary skills training, the ESRs will be able to benefit from 'top-up' training offered via training from other nodes in the network. A number of the core and associate nodes offer specialised training programmes, through the DN these will be made available to all network ESRs. All ESRs will additionally be encouraged to participate in relevant nationally organised training events, e.g. the STFC PhD summer school in the UK.
The DTC will be responsible for network wide oversight of the training programme, and will review progress of each student against his or her personal career development plans. The supervision offered at all beneficiaries follows the MSCA guidelines on supervision[33].

Note: Information concerning the role and profile of beneficiary node staff can be found in the Participating Organisations tables. The lead supervisors at each beneficiary node have significant experience in student supervision, all having supervised multiple PhD and MSc level students at their host institutions. For instance, the MWGaiaDN coordinator (Walton) was previously coordinator of the FP7 GREAT Initial Training Network (grant 264895) and his PhD student from that project has recently been awarded a new ERC Starting Grant in the latest Horizon Europe ERC 2021 round.

[32] E.g. transferable skills courses at LEID: https://www.lumc.nl/res/att/14050700035257/Transferable-skills-courses or the training courses offered at UCAM: http://www.training.cam.ac.uk/ & researcher specific at http://www.training.cam.ac.uk/theme?providerId=36644

[33] MSCA guidelines on supervision: https://op.europa.eu/en/publication-detail/-/publication/bb02d56e-9b3c-11eb-b85c-01aa75ed71a1/language-en

1.4.2 Quality of the joint supervision arrangements

All ESRs will be enrolled in a PhD programme at their host institute. To support the training of the ESR, each will have a Supervisory Committee (**SC**) which will contain the primary host institute supervisor, one supervisor from the ESRs academic secondment host institute, and one from the industrial or technical facility secondment partner. The role of the SC will be to establish the ESR's Personal Career Development Plan (PCDP) and then review the ESR's training and development progress. The SC will meet with the ESR on a quarterly basis (or at the request of the ESR if needed more frequently), with the first meeting being shortly after the ESR joins (so before M10). Day to day supervision will rest with the primary supervisor together with the ESRs secondary supervisor when on secondment. All PCDPs will be held by the Doctoral Training committee (DTC), and each ESR SC will report to the DTC on a 6 monthly basis to enable overall monitoring of the Doctoral Training. Further details of progress monitoring and evaluation of the ESRs is described in **Sec. 3.2.5**.

2 Impact

2.1 Contribution to structuring doctoral training at the European level and to strengthening European innovation capacity

MWGaiaDN will enhance the innovation capacity across Europe, with our network and training supporting:

1. Open innovation, open science and open to the world EU research and innovation goals[34].
2. Research related to the ICT and Space sectors, identified by the EU[35] as key areas of industrial competences enhancing Europe's global competitiveness.

MWGaiaDN will contribute to the realization of an integrated European Research Area. It will:

a) Structure European expertise in Galactic astronomy and the efficient handling of the associated huge data sets required to support key science programmes. The research programme will provide open access to its outputs, supporting open science, open to the world.
b) Facilitate and provide a framework for the interaction between scientists and experts from the industrial sector and academia. Foreground generated in the network will support open innovation.
c) Reinforce the existing European competitiveness in the exploitation of the Gaia data, and the continuation and enhancement of this competitiveness in the young generation of scientists.
d) Prepare the participating institutes for future collaborative projects in this and related areas.
e) Link the wider community with the team generating the Gaia data products: the GREAT/MW-Gaia network generally and MWGaiaDN specifically, provides the essential venue in which the community of researchers and engineers directly involved in the construction and operations of the Gaia data analysis system can interact with the wider European and World community of astronomers who will be involved in the scientific exploitation of Gaia.
f) Foster collaboration between partners: a legacy of MWGaiaDN will be the enduring research collaborations and industry links developed by the partners as a result of this network. Looking ahead to future ESA European space missions[36] collaborations developed here (e.g., with NAOJ, TAS, OHB, LEON, ABUSDS) may be further developed in the development of major new ESA space missions.
g) Train the ESRs with transferable skills. Leverage our industrial and specialist partners training expertise in areas such as research commercialisation, training in entrepreneurship, training in research facility operations, to increase the innovation potential of the network and its ESRs.
h) Balance the needs of mobility and research interaction with the needs of the climate. We will optimise the training programme to reduce travel where possible (e.g., co-organisation of some network meetings, enabling remote participation via video link). Where travel is required, participants will be encouraged to use 'low carbon footprint' options, e.g., train instead of plane.

This DN programme will stimulate a vibrant European astronomy research community, at the forefront of the analysis and interpretation of the Gaia data. This will **make Europe attractive to scientists from abroad**, including US astronomers who have no comparable space astrometry project planned, as confirmed in their recent US decadal survey.

Our network builds upon our active MW-Gaia COST action, through the training of a new cohort of ESRs, in specific research topics focussed on maximising the scientific exploitation of Gaia, and building the scientific (and to a lesser extent, the technical case) for the next generation European astrometry mission. The COST Action, by its nature, does not finance people, rather it supports the organisation of training events and short-term exchange visits. Thus, there are strong synergies between COST and the DN, and indeed the impact and reach of MWGaiaDN will be

[34] see https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy_en

[35] see https://ec.europa.eu/programmes/horizon2020/en/h2020-section/leadership-enabling-and-industrial-technologies

[36] see https://www.cosmos.esa.int/web/voyage-2050 for planning for ESAs space programme from the mid 2030's

increased through the alignment of the two programmes (to the benefit of the ESRs, and the wider community engaged in the COST Action).

Gaia is a flagship European mission through the current decade and its data is unique in size and accuracy, the data is publicly available world-wide as soon as they are released. The GREAT/MW-Gaia network has a key role in ensuring European leadership of the scientific exploitation of the Gaia data. **The collaborative projects envisaged in MWGaiaDN will ensure maintenance of this leadership and drive our understanding of the cosmos.**

2.1.1 contribution of the non-academic sector to the doctoral training

MWGaiaDN links key partners in the Space and Information Technology sectors. These linkages provide a strong two-way exchange of expert knowledge:

a) The ESRs benefit from gaining a meaningful degree of exposure to industry and commerce. All ESRs will have training secondments to the leading industrial partners (or in some cases major technical facilities), offering them insight into the application of their research in generating products and services.

b) The industrial partners benefit by their close interaction with the world's leading scientific groups of the DN. Their exposure to the scientific use cases will be invaluable to the industrial partners in furthering the development of their technologies.

The ESRs will have access to training across a range of topics that will improve their data science skills. They will also gain an understanding of the role of research outside of the academic setting.

Training examples that will be carried out at the non-academic partners include:

i. With ABUSDS, OHB, LEON, TAS to define scientific drivers for the next generation of space astrometry.
ii. With INSYS, DAPC, where use of advanced database systems will be stretched when using them to support large scale analysis of multi-million object sub samples.

Most ESRs will have a secondment visit of between 2 to 4 months to an industrial partner where they will receive technical training related to their specific research project. These are outlined in the ESR project specifications in Tab. **3.1.d**. The industrial partners bring expertise topics ranging from the development of immersion VR applied to data exploration (SUIL), to optical design considerations for future astrometry missions (ABUSDS, OHB, TAS), to detector choices for future near-IR astrometry missions (LEON), to advanced high performance database systems (INSYS), to asteroid-relative optical navigation (SPINW), to data and complex data processing pipelines design (DAPC). The ESRs will experience the working environment in industry, and have the chance to contrast the difference between work processes in academia and commerce. ESRs will be seconded to our Astronomical Facility partners (NAOJ, SAAO, DIRAC), gaining training in design of space systems (NAOJ), observational programmes (SAAO) and data analysis techniques (DIRAC).

Many aspects of the industrial and network wide training will support enhancing the ESRs technical skills in the data science arena. These are highly transferable skills relevant for future careers outside of astronomy or indeed cross domain research, e.g., astronomical image analysis expertise is being used in a high impact cancer research programme investigating breast cancer treatment pathways[37].

The non-academic partners bring essential training to the development of the ESRs, their participation increasing the level of inter-sectoral collaboration across the network. The active participation of the industrial partners in the development of the ESR research programme (e.g., through their involvement in the ESR's Supervisory Committee (SC) and input the PCDP for each ESR - see Sec. **1.3.2**) will help shape the nature of the ESR's research, which will be a good means to enhance knowledge transfer within an ESR project and across ESR projects. Coupled with the mobility aspects of the training, this will enhance the ESR skills relevant to careers outside of the academic sector.

The unique combination of skills and partners in this network, blending the very best science groups in Europe, the leading science development and support teams in Gaia/DPAC, together with leading IT and Space sector industrial partners, will ensure enduring partnership, delivering better science for Europe and the World.

2.1.2 Developing sustainable elements of doctoral programmes

The MWGaiaDN training programme strongly aligns with the **seven principles for innovative doctoral training**[38]. The research topic for each ESR will be of the highest scientific quality, carried out at research intensive institutes. Each host institute will offer an excellent working environment. The training offered will have interdisciplinary options, both through options offered by the host institute training programmes, and through exposure to the network secondments within the network. Each ESR will have meaningful exposure to industry, and other employment opportunities, through secondments to the network's industrial and astronomical observatory partners. There will be opportunities for international networking, through secondments, participation at network workshops and training events, and attendance at scientific conferences, across Europe and further afield (e.g., USA, South Africa). The **ESR training is quality assured**, through network and host institute processes (see Sec **1.3.2**).

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[37] Walton leads the image analysis group of the Cancer Research UK's Grand Challenge project: Imaging and Molecular Annotation of Xenografts and Tumours (IMAXT) - see https://www.cruk.cam.ac.uk/research-groups/imaxt-laboratory

[38] See the Salzburg II Recommendations & Principles for Innovative Doctoral Training

MWGaiaDN will have impact in furthering the development and spreading of best practice in wider European collaborative research training programmes. Through links with our related MW-Gaia COST Action, it will be possible to **align best practice** in the delivery of the MW-Gaia COST Action exchange visits, e.g., MWGaiaDN training events will be co-organised with participation of the COST Action (i.e., the Public Engagement and Communication event). At the national level, best practices will be used by our participants in designing their personal, departmental or institutional training programmes. MWGaiaDN will leave a long-term imprint on the participating organizations through the establishment of joint courses and curricula that will continue to be very useful long after the end of this project. Lecture notes and other training material will be made openly available so that departments throughout Europe can benefit from them in their education.

The extreme breadth of Gaia's scientific scope has a **lasting beneficial effect** on the participating institutes, which the DN will help to bring about through its involvement of researchers from many different sub-disciplines of astronomy. For example, cosmologists are brought together with stellar dynamicists, with astronomers working on stellar abundances and astronomers searching for exoplanets. In contrast to other astronomical observing facilities with a broad range of astronomical applications (e.g., HST, VLT), where the different fields of research independently collect and analyze their specific data, all fields of research on Gaia will use the very same observed data set. This unique characteristic of Gaia will greatly reinforce the mutual understanding of the different sub-disciplines.

MWGaiaDN is an initiative of our long running Gaia GREAT/MW-Gaia network, which been active in supporting the development of expertise related to the Gaia mission, since 2009. Our currently running MW-Gaia COST action will overlap with the first year of MWGaiaDN. We anticipate that this **training, networking, and collaboration will continue** on after MWGaiaDN ends, where we will propose a follow-on COST Action from November 2024. The impact of MWGaiaDN will be ensured through continued networking, recognising that Gaia and the astrophysical research that it enables continues through to the end of this decade, and that there will need to be the strong community links to support the development of missions post Gaia in the 2030's.

2.2 Credibility of the measures to enhance the career perspectives and employability of researchers and contribution to their skills development

The network will deliver a cohort of excellent new researchers, who will be well placed to either form a future generation of scientific leaders in astronomy, or in applying their innovative skills in industry, commerce, the public sector, etc. The training programme strongly aligns with the priorities set out in the Europe 2020 Flagship Initiative – Agenda for new skills and jobs[39], providing the ESRs with the mix of skills and competencies needed to compete in Europe's job market.

MWGaiaDN will deliver the highest quality **research training** in this key area of astrophysics, utilising the state-of-the-art Gaia data, delivered by the key experts in the field. The network will take place during the period when the most complex and scientifically rich Gaia data will be published. The network timing is ideal for the recruited researchers to continue their careers within the large and expanding scientific community exploiting the Gaia mission data. The ESRs will gain unique expertise, in key astrophysics topic areas, with skills in cutting edge data science technologies, not readily available elsewhere, that will be much in demand in the coming decade. The projects undertaken by the ESRs will generate significant science returns in the form of high impact publications, of benefit to their future academic careers.

MWGaiaDN **transferable skills** training in project management, efficient team work, distributed computing, handling 'big data' and advanced data analysis techniques will make these young researchers attractive to the industry sector as well, should they choose to continue their careers outside of academia. The ESRs will be especially well equipped for areas requiring analytic and data science expertise, such as finance, IT, aerospace, defence, or in data analysis in for instance the life sciences sector. **Employment opportunities** may open for the ESRs at one of the network partners.

Many of the science programmes exploiting Gaia data require multi-institute collaborations; the ESRs will gain experience in these, the ability to work in distributed teams, being a valuable skill in many work situations. The ESRs will gain significant **networking skills** through their interactions across the network, through the secondments and exposure to a range of organisations, through participation in network workshops and other training events. These will be useful networking opportunities, helping each ESR build up their network of contacts, valuable in the next steps of their career. The ESRs will also have gained the ability to work in differing environments (sectorial, geographically, etc) which will also enhance their entrepreneurial opportunities. The ESRs will participate in a range of **public engagement training and activities** which will ensure that they are equipped with the communication skills required to succeed in their future careers. Their exposure to the transnational **mobility** aspects of the network,

[39] see https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0682:FIN:en:PDF

including secondments and attendance at training events will ensure that they benefit from exposure to the range of cultures (working, organisational, social) across Europe[40].
MWGaiaDN will not only have a positive impact for its ESRs but also for a significant number of PhD students at the network institutes, and wider. We envisage many of the Doctoral Training events to have the capacity to involve external PhD students, and with the material from each event made available, it will be possible to re-use in many cases. This will be especially important in supporting continuing training more widely across Europe, and further afield, e.g. USA, South Africa and Japan. The training will impact the training experience of astronomy PhD students across Europe and wider.

2.3 Suitability and quality of the measures to maximise expected outcomes and impacts, as set out in the dissemination and exploitation plan, including communication activities

2.3.1 Plan for the dissemination and exploitation activities, including communication activities

MWGaiaDN will generate a wide range of outputs, of value scientifically, technically, managerially. It will be of interest to a wide range of audiences, from specialist science groups, more generally across research boundaries, to industry, to the wider public. All materials will be published through the appropriate channels: peer review journals, technical journals. Software will be made available through the MWGaiaDN website and we will participate in the EU Open Data pilot initiative. Blogs and Twitter feeds will disseminate new results.
Research papers will be published by the ESRs through high impact journals, primarily, Nature, Nature Astronomy, and Astronomy & Astrophysics. Technical papers will be presented at relevant conferences such as the SPIE Astronomical Telescopes track and proceedings. Our research papers will always be published as open access papers. Development of the technical Astrometry roadmap exercise will continue within the ESA Voyage 2050 programme. It is expected that each ESR will have 3 to 5 peer reviewed papers published or in review at the point of gaining their PhD. The PCDP for each ESR will give a target figure for these publications, together with estimated conference/ meetings to be attended. This will be reviewed each year by the Training Committee.
The ESRs will attend all network wide schools and conferences (e.g., those organised within WP2 and WP6). They will also attend workshops organised within their WPs (e.g., WP3). The network will ensure ESR participation in the organisation of these events, with participation from the ESR cohort on the final network conference. ESRs will be encouraged to attend relevant externally organised workshops and conferences to enable them to present their research to the wider community.
MWGaiaDN will participate in the Horizon Europe Open Data Pilot, the concept of open access science is well established in the astrophysics research community, openness encourages discovery.
The networks Public Engagement and Impact Committee (PEIC, see Sec **3.2.1**) will be responsible for developing measures to maximise the innovation potential of MWGaiaDN. It will define a set of quantifiable targets for measuring the effectiveness of dissemination, exploitation, communication and public engagement activities (e.g., monitoring number of website visits, twitter feed followers, citations of network publications, etc), and track these through the life of the network. Statistics as to network meeting attendance will be gathered. Evaluation surveys will be carried out after each event, with feedback from these helping improve future events. Impact of events will be monitored, e.g., tracking publications resulting from ideas or partnerships initiated at network meetings.
MWGaiaDN will implement a high-profile effective communication strategy, the plan being published as part of the Network Plan (within **D1.1**). The ESRs will be involved in communication and public engagement at all levels, from planning, to delivery, to reporting and evaluation of the effectiveness of the actions. WP6 is constituted to organise and deliver the DN's Communications. Evaluation of the public engagement programme will be the responsibility of the PEIC (see Sec **3.1.5** below).
Scientific outreach will be facilitated via MWGaiaDN participation at major astronomical society meetings. There will be a presence at each of the annual meetings of the European Astronomical Society. These week-long meetings are usually held end June of each year at a major astronomical centre. The GREAT network has participated at each EAS Annual meeting since 2012, organising meetings and science symposia. The DN's ESRs will thus be able to present, to a large European science audience, their current research results.
The International Astronomical Union's General Assembly (IAU GA) is held every three years and is the premier astronomy science meeting, typically with several thousand attendees. The DN will host an outreach exhibition stand at the IAU GA (**D6.2**), which is to be held in Cape Town, August 2024, updating on MWGaiaDN activities.
In order to demonstrate the wonder of Gaia and its mission to Map the MW, the DN will organise a live '**Gaia Map**' link up with schools in Europe and Africa. This will be modelled on the successful 'Gaia Live in Schools' event that

[40] The transnational training delivered by MWGaiaDN in key areas of data science, highly relevant both to academia and important segments of European industry and commerce, strongly supports the Europe 2020 Flagship Initiative – Youth on the Move (see http://europa.eu/youthonthemove/docs/communication/youth-on-the-move_EN.pdf)

took place soon after the launch of Gaia[41]. The event (**D6.3**) will be held after the release of the major Gaia DR3 astrometric catalogues (which provide detailed distances to a billion stars in our MW – and hence the 3-D map of the Galaxy). At each school participating (target age of pupils being 12 yrs, thus starting secondary school children), an ESR (with additional PhD students from the DN's research teams) will provide demonstrations of science around Gaia in a practical and hands on manner. The session will include a live slot linking all schools to the Gaia team at ESA, where the school pupils get the opportunity to ask questions to the scientists 'running' this space satellite. Schools in southern Africa will also be involved, with the participation and organisation of our SAAO partner organisation (through the IAU Office of Astronomy Development). This event will be unique, inspiring and provide a lasting legacy of reusable materials.

During the network, News items will be published of the main network outputs and activities, with items specifically generated for varying end users (e.g., industry, policy makers, public engagement). The network will organise some specific workshops of relevance to industry. Policy makers will be invited to the network wide conferences. The DN will participate in relevant EU organised events. All presentations will acknowledge funding from the EU through the Horizon Europe MCSA programme.

The DN's website and associated social media feeds will play an important role in facilitating internal project networking and collaboration. It will consist of static pages to publish final reports, and also contain a wiki to allow for group interactions. Collaborative document creation (e.g., Dropbox, used for the creation of this proposal!) will also be used. MWGaiaDN will be present on social networking sites such as Twitter for the purposes of wider outreach. The ESRs will be tasked with ensuring that the project twitter feed is active, and that network meetings are adequately 'tweeted' out to the community.

Each network beneficiary and partner will also communicate and publicize the network's activities within their organisations, and at national levels. This will increase the visibility of the network.

2.3.2 Strategy for the management of intellectual property, foreseen protection measures

MWGaiaDN will produce new scientific advances in understanding in Astronomy and Astrophysics. These will be published as peer reviewed papers (**D3.3, D4.3, D5.4**) made accessible through open access repositories and journals. The network is focused on cutting edge astrophysical research increasing our understanding of the MW, and this supports the development of the case for next generation astrometry. Technical development is not envisaged, and hence directly patentable outputs are unlikely to result. However, it is anticipated that some techniques developed; especially in computational and analysis techniques may have wider applicability. For instance, techniques in the analysis of astronomical images can be applied to other domain data (e.g., remote sensing data, medical image data). ESRs that develop new techniques which may be exploited will be trained with the tools required to, for instance, patent the technique. Dissemination of results will consider implications for protecting the intellectual property[42]. In the case that patents will be filed, detailed and extensive peer review publication will occur later. The Collaboration Agreement will govern the use of Foreground IP by the network partners and cover the ownership and exploitation of such IP. The publication policy (within **D1.1**) will provide information on the routes for publication, which include publication via patent.

The key 'Toward near NIR-band sub-μas astrometry' roadmap white paper, developed through the network, and finalised as deliverable **D5.3**, will be published as an open source document. It will be valuable to the community, decision makers and industry, providing input into science priority definition for future space astrometry (and related) missions, and the technical issues to be addressed.

The **CA** (Sec **3.1.5**) will govern the relationship and responsibilities of the partners of the network. Importantly this agreement will also define the intellectual property rights (IPR) and ownership of results pertaining to network activities. The guiding principle for the network is that all 'foreground' generated as a result of activity of the network will be released through open source channels such as GitHub and the EOSC portal[43] (for software) and Zenodo (for documents). Additionally, it is expected that all partners will provide access to their 'background' necessary to support the training activities of the network. The case of jointly owned results is explicitly defined in the **CA**. All node leaders have experience in management and policies concerning IPR and can draw on institutional IPR expertise in their Technology Transfer Offices, e.g., Cambridge Enterprise.

2.4 The magnitude and importance of the project's contribution to the expected scientific, societal and economic impacts (project's pathways towards impact)

2.4.1 Expected scientific impact(s)

MWGaiaDN will push the analysis of Gaia data to the limits, leading to feedback to DPAC on areas of improvement for DR4/DR5 and providing better quantified requirements on future space astrometry missions and future

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[41] See http://blogs.esa.int/gaia/2014/04/04/gaia-live-in-school-inspiring-the-next-generation-of-european-space-scientists/ - this event linked over 2000 pupils in 34 schools across 10 European countries with Gaia scientists.

[42] Advice will be sought from e.g. Cambridge Enterprise see https://www.enterprise.cam.ac.uk/

[43] See https://eosc-portal.eu/

complementary photometric/spectroscopic surveys. The Milky Way will be understood at a deeper level, directly measuring galaxy hierarchical formation models through measuring changes in the MW disk orientation (**ESR2**), and how our MW formed through discovery of MW substructures as evidence of accreted galaxies (**ESR5**). The link from structure to stars will have a step change improvement, with the impact of binarity in determinations of the star formation rate being assessed (**ESR8**). Confrontation of stellar evolutionary models with Gaia observational data will provide ideas for and insights into improvements needed, such as in the role of magnetic fields on evolution (**ESR3**) or late-stage stellar modelling of AGB stars (**ESR9**) or reveals stars most likely to host solar type planet system architectures (**UCAM PhD**). A range of new analysis techniques for big data will emerge, for instance in optimised techniques to visualise the large Gaia datasets (**ESR1**). Relativistic astrometry modelling (**ESR7**) will reach new levels of accuracy, informs future developments needed for nano-arcsec missions. The celestial coordinate system will be established, with improvements to the lists of AGN anchoring that system (**ESR6, ESR10**), Study of galactic central regions will inform the plans for the JASMINE mission (**UCL PhD**). Finally, the DN will deliver a key study (**ESR4**) of how Gaia and a future GaiaNIR mission will finally reveal all components at play in the MW ecosystem, to allow the link between Galaxy dynamics and the link to star formation to be deciphered. This is truly a key question in our understanding of the cosmos, at large scales, and in our search for life in nearby stars.
MWGaiaDN will then make a significant and direct contribution to our study of the MW as an ecosystem, already identified as a key priority for future missions (e.g., the ESA Voyage 2050 assessment). The unique combination of expertise in galactic structure, stellar astrophysics, fundamental astrophysics, computational and advanced machine learning techniques, ensures a unified picture will emerge of the MW at all scales. The ESR cohort will be a vital core of human potential to drive forward the emerging plans to drive astrometry powered science into the next decade.
MWGaiaDN: Truly impactful

2.4.2 Expected economic/technological impact(s)

MWGaiaDN will position European industry for the next step in a large European led space astrometry mission. It will equip a new generation of young researchers with the skills needed by increasingly complex challenges to industry (technological, data analysis, etc). It will provide inspiration for a younger generation through exposure to Gaia and its science. The high impact network will deliver a cohort of adaptable researchers, highly employable, who will be well placed to contribute to both the academic and knowledge-based economy in Europe.

2.4.3 Expected societal impact(s)

MWGaiaDN will impact on society through its outreach activities, inspiring students in the study of space science, not only in Europe, but also in the developing world. Our research will be made accessible for use in Schools (e.g., Cambridge's AstroEast project working with schools in the local region. In the longer term, in humankind's ambition to send probes and people to explore the cosmos, MWGaiaDN will provide a better understanding of how to map the route to nearby worlds with its celestial reference frame, and study of stellar systems of interest for habitation!

3. Quality and Efficiency of the Implementation

MWGaiaDN will create **Excellent** science exploiting the current state of the art Gaia mission (through WP3, WP4, WP5); it will **Extend** the techniques for NIR and sub-μas astrometry (through WP5); it will **Enhance** the skills of the next generation of scientists (through WP2, WP6) and it will **Effect** the next revolution in European led astronomy through leadership in astrometric-based science (through WP5).
The network will commence 1 February 2023 and run for 48 months. All 10 ESRs will be recruited over spring/summer 2023 and commence their 36 months of ESR training from ~Sep/Oct 2023. All will complete their PhD projects within four years[44], with the first thesis by ~Oct 2026.

3.1 Quality and effectiveness of the work plan, assessment of risks and appropriateness of the effort assigned to work packages

3.1.4 Fellow's individual projects, including secondment plan

The ESR projects are linked in addressing the ecosystem of the MW, from stars to structure to the definition of the celestial reference frame and the MW's place within it. Together the MWGaiaDN delivers a highly focused research programme with all projects linked through the common Gaia linked thread.
Table 3.1 d also contains the descriptions of the PhD projects to be carried out by research fellows at UCAM and UCL. These two fellows will be funded from the UK and will not be MSCA fellows and will not be funded through MWGaiaDN. Otherwise, the UCAM and UCL fellows will participate normally in the network activities and thereby enhance the science output from the network as a whole.

Table 3.1 d Individual Research Projects

[44] Length of PhD programme depends on the local institute doctoral programme. Typically 3.5 to 4 years duration with the additional months institute funded

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR1	**UB**	**(Y: UB)**	**Month 8**	**36 months**	**D4.1, 4.2, 4.3, 4.4, 5.3**

Project Title: WP4: The joint star-formation, migration, and habitability history of the Galactic disc

Objectives: The PhD candidate will develop a framework that allows better determination of the Galactic star-formation history and the stellar mixing rate as a function of time and position in the Galactic disc from basic observations of stellar age, metallicity, and kinematics, accounting also for non-diffusive stellar mixing. We can take advantage of two things: larger samples because of Gaia and the ongoing/future spectroscopic surveys (like WEAVE and 4MOST), and novel determination of ages accounting for possible unresolved binaries (also a task for the ESR; benchmarked by asteroseismic observations from Kepler, CoRoT, K2, TESS, and eventually PLATO). The influence of stellar migration on the Galactic Habitable Zone is a completely unexplored and exciting terrain connecting Galactic Astrophysics to exoplanet research. This project has strong links to WP3.

Expected Results: Using the more precise migration models obtained in the first part of the project, the PhD candidate will characterise the time evolution of the habitable-planet hosting star population around and beyond the solar vicinity. This type of study will also benefit from sophisticated comparisons to state-of-the-art cosmological Milky Way models, especially for modeling the statistical influence of cosmic radiation on potential planet host stars and for determining the occurence rate of accreted exoplanets.

Planned secondment(s): UGA: (M25-26: Babusiaux) Star Formation analysis. **LEID:** (M29-30: Brown) Stellar binarity analysis. **UCAM**: (M33-24: Walton) Exoplanet host variations

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR2	**LEID**	**(Y: LEID)**	**Month 8**	**36 months**	**D3.1, 3.2, 3.3, 5.4**

Project Title: WP3: The tilting rate of the MW disk

Objectives: Hierarchical structure formation models for the MW predict that the dark matter halo tumbles at a typical rate of a few tens of μas/yr, which suggests that the MW disk orientation may also vary in time. Modelling by Earp et al. (2019) showed that the tilting rate of the disc is well correlated with the gas inflow rate, and that the warp provides a good indication of the direction of the tilt. Interactions with satellite galaxies such as the LMC may lead to a rotation of the angular momentum vector of the disk population. It has been estimated (Perryman et al 2014) that the time varying MW disk orientation should be measurable in the Gaia data, provided the reference frame defined through quasars observed by Gaia is inertial to sufficient accuracy. This ESR project is aimed at researching how to make this measurement in practice from the Gaia data. A successful measurement of the time variation of the MW disk angular momentum vector would provide insights into the accretion history and dynamical state of the MW as well as the ongoing interactions with massive satellite galaxies such as the LMC and the Sagittarius dwarf galaxy. It is not guaranteed that the time variation of the MW disk orientation can be measured, one of the problems being that it may not be possible to define 'the disk' uniquely in terms of a fundamental plane. However, even an estimate of the upper limit on the orientation variation would lead to insights into the questions above and in addition provide valuable information on how the measurement is affected by systematic errors in the Gaia astrometry and reference frame. This in turn would provide guidance on the future requirements on high accuracy astrometry and reference frames.

Expected Results: Methods for determining the time variation of the angular momentum vector of the MW disk; new insights into the definition of the disk, new knowledge on the MW accretion history and on the interactions with satellite galaxies; insights into Gaia astrometry and reference frame systematic errors; accuracy requirements on future astrometric surveys.

Planned secondment(s): TUD (Klioner, M15-16): Training on astrometric reference frames, precision / accuracy Gaia reference frame. **UB** (Romero-Gómez, M20-23): MW & satellite galaxy modelling in cosmological context. **INSYS** (M32-33 Salvador) IRIS data platform **{Industrial secondments are noted in bold/underline}**

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR3	**INAF (Padova)**	**(Y: UNIPD)**	**Month 8**	**36 months**	**D4.1, 4.2, 4.3, 5.4**

Project Title: WP4: [Young clusters: kinematics, stellar evolution & modelling]

Objectives: Gaia's precise parallaxes, proper motions, and photometry, combined with the ground-based spectroscopic programs (e.g. (such as APOGEE, Gaia-ESO Survey, WEAVE) and deep photometric surveys (PAN-STARRS, LSST) that have been or will be set-up to complement the Gaia data will provide datasets that will lead to a better understanding of stellar models. The ESR will use the kinematics of nearby clusters in the range than 100–7000 Myr and large star-forming complexes in order to select members. In young objects this will allow to define the interplay between internal kinematics and stellar evolution in the early stages of cluster life. Chemical abundances of s-process elements (Ba, Y, La) and Li in clusters from 150 Mys to 7 Gyr will be used to set constraints on stellar models. Namely, absorption lines of s-process elements are extremely sensitive to the stellar chromospheric activity, therefore monitoring the abundance variation of these elements as a function of activity indexes will provide key information on how magnetic fields influence the formation of lines in stellar spectra. Furthermore, Li abundances in giants and subgiants and when possible, in main sequence and pre-main sequence stars are sensitive to mixing processes. The ESR will study the variation of these elements with cluster ages and compare the results with stellar models. The work will be done first with Gaia DR3 and already available spectroscopic surveys. At later times, WEAVE radial velocities and chemical abundances will provide a homogenous data base of about 300 clusters. The ESR will develop machine learning and/or clustering algorithms to analyze fully automatically the big data samples represented by the stellar spectra. The collaboration with DAPCOM will train the ESR to enter the realm of big data, learning the necessary skills to perform this task.

As contribution to WP5 activity, the ESR will explore the future astrometric and photometric requirements for studying young clusters under different physical conditions (gas density, metallicity…), either in the external regions of the disk and/or in external galaxies such as the Magellanic Clouds and local group galaxies. LSST data reaching g=24 mag already in single exposures will further enlarge the horizon where the analysis will be possible down to the low mass stellar regime. The use of near-infrared LSST bands will make it possible to observe objects in moderate to high extinction regions inaccessible to Gaia.

Expected results: The project will allow us to improve our knowledge of stellar models, in particular concerning mixing processes in stellar interiors and magnetic fields. The analysis of clusters in different evolutionary phases will result in a better definition of the stellar content down to the low mass and M dwarf regime for nearby clusters (1–2 kpc using Gaia data and possibly up to the outer disk with LSST). In turn, this will lead to isochrone improvement. Ultimately this will result in better determination of star cluster age and properties. Astrometric requirements to extend the science case to Local Group Galaxies will be derived.

Planned secondment(s): DAPC, Julbe, M09-10, clustering algorithm, big data training. **UGA**, Babusiaux, M12: interstellar extinction maps. **LEID**, Brown M15-16, internal kinematics of young star forming regions.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR4	LUND	(Y: LUND)	Month 8	36 months	D5.1, 5.2, 5.3, 5.4

Project Title: WP5: Probing the Galaxy with Visible-NIR Astrometry and Gravitational Waves

Objectives: The era of multi-messenger astronomy has arrived and is crucial to fully understand the Galaxy's formation and evolution. Gaia has just entered its extended mission period while a deeper survey, LSST, is close to first light and future astrometry missions such as small-JASMINE and GaiaNIR will extend the wavelength range to the NIR giving distances and dynamical information in important obscured regions, such as the Galactic centre and spiral arms. The LISA mission will add another spectrum to this puzzle and the gravitational wave radiation from double white dwarf binaries will overlap with the visible and NIR astrometric detections of the same objects but will also extend the positional measurements throughout the Galaxy giving a more complete picture. Now is a good time to take stock of what these enormous projects will provide and how they overlap to improve our understanding of the Galaxy as a whole.
This project will have two connected aims. The first aim is to assess the impact on our understanding of the Galaxy by adding future Visible-NIR astrometric observations to the existing Gaia catalogue. LSST observations will go deeper than Gaia and many of the stars observed by small-JASMINE and GaiaNIR will be new NIR objects while in the case of objects already measured by Gaia the astrometric accuracy will be improved, especially the proper motions. The Galaxia code (Sharma, et al. 2011) will be used to generate, using an N-body sampling scheme, synthetic surveys of the MW with and without the new observations - this was recently used to provide a mock stellar catalogue for Gaia-DR2 (Rybizki, et al. 2018) and to provide number counts for the GaiaNIR Voyage2050 proposal (Hobbs, et al. 2019). The resulting synthetic catalogues can be used to understand how to identify structures in the Galaxy, how to determine the all-sky distribution of different stellar families and how to identify substructure in the Halo. Importantly this will show the advantages of combining the data from different missions and will feed directly into the science proposal for the upcoming GaiaNIR mission. The second aim is to investigate the sources of gravitational waves that will be observed by astrometry missions (Gaia, LSST, small-JASMINE and GaiaNIR) and by the upcoming LISA mission which is a very different kind of instrument. This will be used to construct a comprehensive source list with associate errors (basically a Galactic map) of potential electromagnetic sources which can also be observed by LISA in the next decade (see Korol, et al. 2017 for early work). This study should be done both with the real Gaia data to develop a realistic all-sky map of gravitational wave sources for LISA and with synthetic data from Galaxia to make predictions when including future astrometry missions in the coming decades.

Expected Results: An assessment of the benefits of including data from the different astrometric missions considering their respective accuracies. Detailed predictions of the science return achieved by shifting astrometry into the NIR. A realistic all-sky catalogue of Gaia and LSST electromagnetic sources of gravitational waves for LISA. A prediction of future LISA observations beyond those of the realistic all-sky catalogue. Demonstration of synergies between Gaia, LSST, small-JASMINE, GaiaNIR, and LISA.

Planned secondment(s): DIRAC, Connolly, M12-13 about big data and ground-based astrometry. **NAOJ**, N. Gouda, M14-15 small-JASMINE and relative astrometry. **TAS,** Herbert-Guest, M24-25, investigate performance implications of Gaia NIR design.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR5	UB	(Y: UB)	Month 8	36 months	D3.1, 3.2, 3.3, 5.4

Project Title: WP3: Revealing weak substructures in the MW

Objectives: Precise astrometry of Gaia DR2/EDR3 has allowed the detection of many structures in the MW from clusters and star forming regions to moving groups and stellar streams, some of them know and many previously unnoticed. The data has also permitted to rule out some of the groups previously claimed. In parallel, the kinematic studies carried out so far have revealed the rich complexities of the thin and thick disks as well as the halo, due to non-equilibrium states motivated by mergers. Additional information, especially ages and chemical composition, will act as a valuable signature to understand the nature of the groups detected and put them in the context of the MW formation and evolution. The ESR will extend existing all-sky data mining clustering methodologies to the third Gaia Data Release by including its new data products (information from low and high-resolution spectra like extinction and chemical composition) and complementary measurements based on ground surveys (WEAVE, OCCASO, APOGEE, LAMOST, MIRADAS, Pan-STARRS, JPLUS/JPAS, LSST, among others). The increase of the dimensionality of the clustering approach and the globally improved precision of Gaia DR3 will allow to identify tiny/weak structures unnoticed so far because of the domination of the field population. This will be applied to study the completeness of the current open clusters and ultra-faint dwarf galaxies samples, the process of clusters disruption by the identification of their tidal tails and extended coronas, the identification of hidden subpopulations of specific types of stars like white dwarfs (to identify the very cold ones constraining the age of the populations they belong to) or RR-Lyrae (tracing substructures in distant halo streams, ultra-faint dwarf galaxies, the Galactic bar).The UB group is deeply involved in the development of such algorithms as done for Gaia DR2/EDR3 and in some ground based spectroscopic surveys like OCCASO, WEAVE and MIRADAS. The UB group also has well established collaborations with the JPLUS/JPAS and APOGEE teams and the future 4MOST project.

Expected Results: Multi-dimensional methods to identify groups of stars in areas where the stellar field population dominates. Application of these methods to analyze the full sky with Gaia EDR3, DR3 and complementary data. The successful applications and the limitations of the methods and data will be identified and will constitute inputs for the WP5 roadmap. Analysis of the detected structures in the context of the MW formation and evolution. Methods and results will be disseminated through peer reviewed papers.

Planned secondment(s): UGA, Carine Babusiaux, M15-M17: interstellar extinction and its inclusion in the clustering algorithm; **LUND**, Hobbs, M22-24: systematics, statistical treatment of Gaia data. **INSYS** (M32-33 Salvador) IRIS data platform / Cache DB

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR6	UC	(Y: UC)	Month 8	36 months	D5.1, 5.2, 5.3, 5.4

Project Title: WP5: AGN and the ICRF with Gaia

Objectives: The main goal of Gaia mission is to obtain the best ever multi-parameter map of the MW, in order to make progress in our knowledge of the Galaxy and also of its evolution. Besides the detection of galactic bodies, Gaia has also the capability of detecting point-like or even limited extended extragalactic sources. Among the latter are Active Galactic Nuclei (AGNs; a class that includes the QSO, Quasar, BL Lacs, Seyferts, etc), extremely bright and commonly variable cosmological objects that harbour in their centre super massive black holes (SMBH). Even though Gaia is a relatively shallow mission it has nevertheless been very successful in detecting this class of objects, with more than 1 600 000 AGNs having been reported so far. Why is the investigation in AGNs important?
(a) *Per se*, as they are among the most extreme emitters in the Universe, being multi-wavelength and multi-messenger objects, so a relevant laboratory to investigate matter at extreme conditions. (b) But also, as a tool to understand the formation and evolution of the AGN host galaxies. Different studies have shown that there is a strong correlation between SMBH and host galaxy properties, suggesting a common formation and evolution process. Even if several models predict that merging is a fundamental process, there are still many unknowns, that can only be partially solved by analysing many systems at different stages of the merging process. Gaia astrometry is key in the identification of putative close binary systems. (c) These are the cosmic sources that define the International Celestial Reference Frame (ICRF) in the optical and the best candidates for the alignment between the optical and radio realizations of the ICRF should be identified.

Expected Results: The research project proposed here aims at exploring Gaia data with the following main objectives: (1) To identify new AGNs via a multi-parameter space analysis; (2) To characterise (variability, SED, luminosity functions, etc) in a statistical way the population of Gaia AGNs, taking advantage of the fact that Gaia is an all-sky mission, and so provides a (mostly unbiased) flux limit sample. We will be in the best position to select the best Gaia AGNs for reference frame alignment; (3) Identify binary systems. These systems have been reported in Gaia data, but no systematic follow up has been performed. Confirmed binary systems can have an impact on constraining models that predict merging as a fundamental process of SMBH growth, and so the ESR project will partially develop theoretical modelling, to improve estimates on quantities like time scales of merger processes.

Planned secondment(s): UB, Luri, M14-15, supervised and unsupervised techniques for source classification; **LEID**, Brown, M21-23, sources of reference frame systematics & catalogue mining; **SPINW**, Hormigo M26-27, ICRF & space navigation reqs.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR7	TUD	(Y: TUD)	Month 8	36 months	D5.1, 5.2, 5.3, 5.4

Project Title: WP5: Relativistic challenges of sub-µas astrometry

Objectives: Astrometric observations of µas and sub-µas accuracies require very careful modelling in the framework of general relativity. A relativistic astrometric model can be formulated efficiently and with a high accuracy only for some simplified models of gravitating matter. In practice it is virtually impossible to consider all relativistic effects of a realistic Solar System exceeding some level in magnitude below about 1 µas. This is related both to some unsolved theoretical problems and to the practical impossibility of accounting for all minor bodies that could potentially produce sufficiently large astrometric signatures. Small relativistic effects coming from non-sphericity of the gravitational fields of Solar System's bodies as well as from their translational and rotational motions are also very difficult and computationally expensive to compute. Gravitational fields generated outside Solar system – gravitational waves from unknown sources and unmodeled microlensing effects – can also create systematic effects in the observational data. Another aspect is avoidable systematic errors in the data and parameters used in the model: e.g., errors in the Solar System and spacecraft ephemerides, limited accuracy of the masses of gravitating bodies, etc. For all these reasons, in the case of future sub-µas astrometric projects the feasibility and usefulness of the usual approach that the relativistic model should be about an order of magnitude more accurate than the final accuracy is no longer obvious. It is now important to investigate the size and character of systematic errors in the solutions when certain relativistic effects are missing in the model. This will first be investigated for the Gaia accuracies. The deficiencies of the model will be introduced and special Gaia-like astrometric solutions will be simulated. A detailed analysis of the errors of the resulting solutions, both at the level of global-scale statistics and at the level of individual, most affected objects, will demonstrate the real consequences of the model deficiencies. Secondly, an analogous study will be performed for a hypothetical astrometric mission with an accuracy of 10 nano-as (this level of accuracy can be expected from a combination of Gaia and GaiaNIR data). Several scenarios will be pursued: a global Gaia-like astrometric mission with higher accuracy, combination of Gaia and GaiaNIR as well as small-field astrometry. Detailed simulations of astrometric solutions will be performed using Gaia DPAC software AGISLab. Using the results from these numerical experiments, quantitative models for the influence of unaccounted effects will be formulated, to show which relativistic effects must be modelled to achieve sensible astrometric solution, and which effects, can be tolerated as acceptable additional noise.

Expected Results: (1) Understanding of the content of a reasonable relativistic model for astrometry at the 10 nano-as level. (2) Characterization of the influence of unaccounted relativistic effects in the high-accuracy astrometric solutions. Both results will pave the way for relativistic data modelling for the future astrometric projects like GaiaNIR but will also be useful for the interpretation of the final Gaia results.

Planned secondment(s): LUND, Hobbs, M20-21: learn additional details of the AGISLab software, GaiaNIR project and its combination with Gaia. **UC**, Anton, M30-31: learn about statistical properties of the QSO's. **ABUSDS,** D'Arrigo, M40-41: learn about self-calibration methods of space-based astrometric instruments.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR8	UGA	(Y: UGA)	Month 8	36 months	D3.1, 3.2, 3.3, 5.4

Project Title: WP3: Deriving the MW IMF and SFR from high-accuracy astrometry

Objectives: The accuracy of the Gaia DR2 and EDR3 HR-diagrams and associated kinematics led to a number of studies on the local properties of the Star Formation History (SFR) and of the Initial Mass Function (IMF), both galactic properties being highly degenerate. Gaia DR3, by providing diverse information about stellar multiplicity will allow to fully revisit our understanding of the Gaia HR-diagram. However, the properties and limitations of the astrometric, photometric, and spectroscopic observations and data reduction will have to be considered to recover the de-biased multiplicity frequency. Separating the statistically different galactic populations through their kinematics, we aim to study the variation of the binarity fraction and of the IMF with galactic population, age, and formation history.

Expected Results: bias-corrected multiplicity information over the Gaia HR-diagram for different galactic populations. Enhancement of existing simulation and statistical analysis tools to consider potential differences in the multiplicity and the IMF of different galactic populations. Constraints and discussion on the global IMF and SFR of the MW. Expected improvements for the low mass part of the IMF from GaiaNIR.

Planned secondment(s): LEID, Brown, M10-12: learn how to reconstruct the selection functions affecting the astrometric, photometric and spectroscopic data. **OBSPM,** Arenou, M14-16: learn the stellar multiplicity processing and validation selections that affected the DR3 content and the way forward to reconstruct the multiplicity frequency. **NAOJ,** Gouda M22-23, small JASMINE astrometry implications for near-IR populations in and towards the galactic centre.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR9	**NKUA**	**(Y: NKUA)**	**Month 8**	**36 months**	**D4.1, 4.2, 4.3, 5.4**

Project Title: WP4: Testing the model predictions for the Asymptotic Giant Branch phase (specifically for carbon stars) using star clusters in the Milky Way and the Magellanic Clouds

Objectives: Precise astrometry from Gaia DR2/EDR3 has resulted in the detection of several new star clusters in the MW Galaxy. For many clusters HR diagrams and membership probabilities have been published from DR2 and EDR3 data. In this ESR project we aim to analyze the Gaia DR3 data of all intermediate age and old (open) star clusters (previously known or newly discovered), that can potentially host carbon stars. HR diagrams will be constructed for the cluster members using Gaia DR3 magnitudes and colours, and ages derived based on state-of-the-art stellar isochrones. The second step is to associate Carbon Stars (CS) to star clusters. For this purpose, we will utilize all available bibliographic sources and multiwavelength data archives, as well as Gaia-ESO-Survey results on carbon-rich stars, in conjunction with parallaxes and proper motions provide by Gaia DR3. We will also search (using Gaia DR3 data) for Mira variables associated with the clusters. Mira variables are AGB stars that can be used as distance indicators. Inter-calibrations with other distance indicators associated with the clusters will be explored.
Comparison of the ages and metallicities of the clusters (when metallicities are not known, follow-up spectroscopy will be attempted) that host carbon stars to model predictions, will help constrain the window of masses and metal abundances where the CS phenomenon occurs. Comparison with current stellar model predictions is expected to lead to their refinement and a better understanding of the third dredge up in stellar interiors. As a secondary objective, stellar multiplicity will also be searched for among the cluster members, and its effect on the AGB evolution explored. The project will be extended to lower metallicities to cover the full parameter space using star clusters in the Magellanic Clouds. The methodology followed in that case will leverage on Gaia data, as well as on other surveys (including VMC, 2MASS etc).

Expected Results: The main result is a significant improvement of our understanding of the AGB evolutionary stage, and especially of the third dredge-up. As a by-product, we will provide a full analysis of intermediate age and old star clusters in the MW, and any Mira variables that they may contain. Mira variables can constitute a viable alternative to other distance indicators.

Planned secondment(s): DAPC, Julbe, M14-15, big data and data integration training; **INAF**: M 17-19 - stellar evolution modelling/star clusters, supervisor Vallenari (Padova)

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
ESR10	**TUD**	**(Y: TUD)**	**Month 8**	**36 months**	**D3.1, 3.2, 3.3, 5.4**

Project Title: WP5: Astrometric characterization of QSOs and the stability of the Gaia-CRF

Objectives: Quasi-stellar objects (QSO) play several important roles in Gaia. Besides allowing for certain scientific results (e.g., the measurement of the acceleration of the Solar system), QSOs are used to fix the orientation and the rotational state of motion (the "spin") of the resulting Gaia catalogue. On the other hand, the true parallaxes, and proper motions of the QSOs are statistically zero (apparent proper motions due to time-dependent sources structure could exist for some sources) and can be used to trace systematic errors of Gaia astrometry all over the sky. All these tasks require a possibly cleanest and possibly largest sample. The challenge is to identify genuine QSOs in the Gaia data. The approach developed for Gaia Celestial Reference Frame 3 (Gaia-CRF3) uses crossmatches with external QSO/AGN catalogues and subsequent two-stage astrometric filtering. This resulted in about 1.6 million QSOs in Gaia EDR3. Gaia DR3 contains the first results from the various pipelines for astrophysical source classification in Gaia. Those results were also used in a similar astrometric filtering and additional 300000 QSOs were identified. Given the development of both astronomical instrumentation and machine-learning methods of source classifications one should expect a great number of new QSO catalogues in the coming years. Also, Gaia will substantially improve its own astrophysical classification. A total of 3-4 million quasars is suspected in the final Gaia data. The cross-matches and the astrometric filtering should be further refined. One important topic here is to introduce source structure index characterizing the astrometric quality of the QSOs, so that subsets of Gaia-CRF with better quality and stability can be identified. This should be attempted based on the already available parameters of the Gaia astrometric solutions. Another aspect is to identify and characterize all expected sources of systematic proper motions in the Gaia astrometric data for the QSOs. Those systematic proper motions, when uncorrected or corrected only with a certain accuracy, disturb the Gaia positions of the QSOs at a future epoch. Those effects must be carefully considered e.g., when combining Gaia and Gaia-NIR results.

Expected Results: (1) A source structure index for Gaia QSOs defined from Gaia own astrometry and allowing one to select more stable subsamples of the Gaia-CRF. (2) Characterization of the systematic proper motions of QSOs in the Gaia astrometry. An optimal way to combine the Gaia-CRF astrometry with the future Gaia-NIR results for the QSOs.

Planned secondment(s): LEID, Brown, M20-21: learn about the characterisation of the QSOs in the crowded areas. **UC**, Anton, M27-28: exchange about the methods to study the Gaia data for QSO candidates and the statistical analysis of those data. **LUND**, Hobbs, M34-35: learn additional details of the GaiaNIR project and its expected combination with Gaia.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
UCAM PhD*	**UCAM**	**(Y: UCAM)**	**Month 9**	**36 months**	**D4.1, 4.2, 4.3, 4.4, 5.3**

Project Title: WP4: Exoplanet Host Star Characterisation with Gaia and Spectroscopy

Objectives: In preparation for PLATO, WEAVE and Gaia have an important role in building up a detailed knowledge of the bright star sample that will be targeted by ESA's PLATO. Detailed chemical analysis studies of exoplanet host stars have been used to infer that low metallicity stars that host exoplanets have an overabundance of alpha-elements. Precise chemical determinations of the host stars of exoplanets can potentially be used to statistically infer the makeup of their orbiting planets (terrestrial-like, gas-dwarf planets or gas giant planets). However, recent studies are revealing a range of subtle and sometimes conflicting results and trends (e.g. lack of clear correlations between stellar metallicity and planetary residual metallicity that would be predicted from Giant planet formation models). Currently a comprehensive study in twilight time survey of bright exoplanet host stars using the WEAVE multi-object spectrograph (science observations commence 2022) is being defined. These observations will provide detailed, high precision, chemical (covering a range of elements sampling the main nucleosynthesis pathways) characterization of the stars to be observed with PLATO. Gaia data will be used to establish the host star within their local (10pc) environment, to additionally study the correlations between host stars and their nearby neighbour star chemo-dynamical properties with their exoplanet systems. Pilot studies will be carried out initially against known star/exoplanet systems being discovered by TESS. The high precision abundances (to better than 0.1 dex) obtained will be important in understanding star-planet environmental effects. The ESR project will involve definition and implementation of the WEAVE twilight survey, investigation of contaminating sources (involving assessment of the Gaia release investigating close pairs, separations < 1 arcsec), comparison of exoplanet host star properties (chemo-dynamic) to their local neighbourhood.

Expected Results: Implementation of the WEAVE twilight survey. Catalogue of exoplanet host star high precision abundances. New insights into the relationship between host star chemistry and their exoplanet properties. New method for use of VR analysis environment and use in exploration of high dimensional data. Implications for bright star observations in the IR.

Planned secondment(s): SUIL (M15-16: Harris)) **{Industrial secondments are noted in bold/underline}**: advanced virtual reality visualisation environments to explore multivariate data. **UNIPD:** (M25-26: Vallenari) use of Gaia for PLATO input catalogue selection and contaminant analysis. Identify nearby(10pc) stars to each exoplanet host star from Gaia parallax/ proper motion data. **OHB** (M30-31: Klebor) technical considerations for sub-μas astrometry around bright stars.

Fellow	Host institution	PhD enrolment	Start date	Duration	Deliverables
UCL PhD*	**UCL**	**(Y: UCL)**	**Month 8**	**36 months**	**D3.1, 3.2, 3.3, 3.4, 5.3**

Project Title: WP 3: Revealing the dynamical structure of the Galactic centre

Objectives: The Galactic centre (R<~1 kpc) where is heavily obscured is a prime target for the future NIR astrometry missions, including JASMINE and GaiaNIR, based on the heritages of the current success of Gaia. The ESR will develop a Bayesian Made-to-Measure (M2M) tool (Hunt & Kawata 2014, MNRAS, 443, 2112; Bovy, Kawata, Hunt 2018, MNRAS, 473, 2288) to fit the Vista Variable in the Via Lactea (VVV) NIR photometry data, VVV astrometry data (VIRAC, Smith et al. 2018, MNRAS, 474, 1826), NIR spectroscopic data from SDSS/APOGEE and upcoming SDSS-V and VLT/MOONS data with a dynamical model with multiple stellar population. This will tell us the age distribution of stars in the nuclear stellar disk, which is a promising indicator for the formation time of the Galactic bar (Baba & Kawata 2020, MNRAS, 492, 4500), and will identify or reject the existence of the Ultra Light Dark Matter (ULDM, 10^{-23}–10^{-18} eV) soliton core from the stellar dynamics constraints (Toguz, Kawata et al. arXiv:2106.02526). This work will be supported also by Ralph Schönrich (MSSL, UCL) and Jason Sanders (Physics & Astronomy, UCL), who are the world expert of dynamical model and the Galactic centre observational data. In addition, the ESR will develop the multidisciplinary skills by being involved in verification work of the TDI performance of Leonardo's APDs NIR detector within a wide collaboration of GaiaNIR:UK consortium, whose initial phase of study has been funded by UK Space Agency. We will verify the NIR TDI performance required for GaiaNIR precision astrometry for the Galactic centre crowded region with MSSL built "TDI simulator" with a cooled vacuum chamber and moving light sources.

Expected Results: Identifying the formation epoch of the Galactic bar. Identifying or rejecting the existence of ULDM. Development of Bayesian M2M modelling technique for the future NIR astrometry data. Future NIR TDI detector verification.

Planned secondment(s): UGA Babusiaux**,** M10-M12 : Stellar population modelling; **UB,** Romero-Gómez, M25-M27, Inner Galaxy modelling; **LEON**, Barnes, M32-M35, NIR detector study.

* The UCAM and UCL PHDs are recruited by UK-based associated partners, they are not supported by EU funds, and will be supported by UK funds

3.1.5 Network organisation

The Consortium Supervisory Board (**CSB**) has overall responsibility for the delivery of the DN goals. The CSB will define the skills requirements for the ESRs such that the needs of both the academic and industrial partners are considered. It will ensure that scientific and technological training through the node based ESR research projects is supplemented with relevant complementary skills training, appropriate to the needs of each ESR. It will establish a set of best practice guidelines for the DN to ensure a uniformity of opportunity across the network in terms of training opportunities for each ESR, and monitoring and mentoring systems to measure ESR progress.

The budgeting process is strongly coupled to the activities of the ESRs with the budget being determined, in the main, according to a rigid formula. The CSB is responsible for the distribution of funds and **financial management** of the network. The individual host institutes[45] are responsible for their devolved budgets. The associate nodes will invoice the relevant full node for costs incurred in hosting an ESR on secondment. Associate node costs for network wide events will be invoiced against the coordinating node. All financial transactions will be subject to audit, according to the local audit practices of the full partners, and by the EC. Full documentation &receipts will be available to support claims. The CSB will ensure the **scientific and research integrity** of the network. The European Code of Conduct

[45] Fundació Bosch i Gimpera (FBG) manages the funds at UB: it is a third party of Universitat de Barcelona (UB). FBG was created and is controlled by UB, and has an authorisation to administer International funds on behalf of UB. According to the "Annotated General Grant Agreement", FBG falls under the specific case "Foundations, spin-off companies, etc., created in order to handle the administrative/financial tasks of the beneficiary", and it's in charge of the administrative and financial management of European projects at the UB. FBG does not perform scientific/technical work in the project.

for Research Integrity[46] will be followed. The CSB will set procedures for dealing with cases of scientific misconduct. When a case of misconduct is raised, the Research Coordination Committee will convene an ad-hoc panel to investigate the allegations and recommend action in a report to the CSB. The panel will be composed of senior network representatives (from institutes un-associated to any participants involved in the misconduct allegations). Based on network institution procedures handling misconduct[47].

The **Project Coordinator (PC)** will be the point of contact between the network and the European Commission (EC). The PC will manage the network budget, according to the principles laid down by the GSB and guidelines issued by the EC. The PC will be the main point of contact with external bodies. The PC will have overall executive responsibility for the project and will provide leadership, supported by the RCC (see below) for the scientific aspects of the project, and the **Project Office** in UCAM (with science/admin support staff[48]) for the financial and legal areas of the project. The full role and tasks of the PC will be detailed in the Consortium Agreement.

The **Doctoral Training Committee (DTC)** will manage network training. The DTC, chaired by the lead of WP2, will consist of the DN WP Leaders, two Industrial partner representatives, one from the academic partner nodes and the PC. With full WP representation, the DTC will be able to align the network wide training with the individual WP science-based training. The DTC will have responsibility to ensure that there is equivalence of training opportunity for all ESRs irrespective of host location. The DTC will ensure that full risk monitoring and health and safety procedures are in place when EU project teams travel to non-EU based partners. The DTC will meet by telecon bi-monthly and face-to-face at least once per year at the annual network meetings. The **Research Coordination Committee (RCC)** will be chaired by the **PC** with membership from the **WP Leaders** (**WPL**). It will have responsibility in managing the science and training interactions between the research nodes. The RCC will encourage and monitor the networking between the ESRs, and the quality of the science generated across the network. The RCC will be responsible for managing the investigation process into allegations of scientific misconduct. The **Public Engagement and Impact Committee (PEIC)**, chaired by the lead of WP6, will coordinate the engagement and communication activities of the network. It will monitor the effectiveness of these engagement activities. It will evaluate the networks impact and ensure that the innovation potential of the network is fully realised. The **Recruitment and Equal Opportunities Committee** (**REOC**) will coordinate the recruitment process and monitor and evaluate the DN's equal opportunities practices across the network. The **supervisor** and **SC** of each ESR will be responsible for the academic and pastoral care of their ESRs.

External expert advice will be taken from the consortium's **Science, Training & Innovation Advisory Panel (STIAP)**, to help ensure that the network's scientific, innovation and training goals are met. The STIAP will be composed of independent experts with a background in astronomy, innovation and training policy. It will also provide general advice on possible ethics and 'duty of care to the ESRs' issues.

3.1.6 Joint governing structure: the MWGaiaDN Consortium Agreement

In order to formalise the internal workings of the DN, a Consortium Agreement (**CA**) will be drawn up and agreed at the start of the programme[49]. It will define the roles and responsibilities of the beneficiaries and partners of the network, the employment status of the recruited researchers, and the supervision arrangements, including qualifications of supervisors. It will also lay out the management of Intellectual Property Rights within the consortium. The **CA** will be essential in underpinning the structure of the DN, supplementing the formal contract with the European Commission. The **CA** will set out the decision-making powers of the network and will detail how potential conflicts and disputes will be resolved. In general disputes will be resolved at the lowest possible level. Initially issues will be handled within the node, or within the WP. Escalation will be to the Supervisory Board. Failing that, recourse to the legal provisions in the CA will occur.

3.1.7 Joint admission, selection, supervision, monitoring and assessment procedures: [not applicable]

3.1.8 Supervisory board

The **CSB** is the top-level board governing the overall management of the DN programme. The Project Coordinator (PC) will chair the CSB. Each beneficiary partner and associate partner will have one representative on the CSB, with **two ESR CSB members** (one male, one female for gender balance) to represent the ***student voice***. Full meetings of the CSB will occur once per year at the annual full project meeting. Additional full meetings will be held as required, face-to-face or by tele/videocon.

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[46] See https://ec.europa.eu/research/participants/data/ref/h2020/other/hi/h2020-ethics_code-of-conduct_en.pdf

[47] e.g. the University of Cambridge's policy of misconduct at https://www.research-integrity.admin.cam.ac.uk/research-misconduct

[48] A project administrative assistant will be employed to assist the PC concerning administrative and legal tasks related to the operation of the network. All beneficiaries will contribute a share (40%) of their management and indirect costs budget to UCAM, jointly sharing the funding of this position and cost of the management of the project as a whole. This will be formalized in the consortium agreement.

[49] The CA will be modelled on the DESCA Horizon 2020 Model Consortium Agreement (http://www.DESCA-2020.eu)

3.1.9 Recruitment strategy

The recruitment and selection policy for the DN will conform to the principles of the European Code of Conduct for the Recruitment of Researchers. There will be a centralised recruitment exercise for the network. The recruitment procedure will place an emphasis on individual excellence. However, the principles of ***equal opportunity*** and ***gender balance*** will be stressed. Selection of the ESRs at the full nodes will be carried out conforming to local procedures, but with a member of the DTC on each selection panel to ensure an equivalence in selection procedures, and aid in bringing a balance in terms of network hires. Members of the selection panels will have training according to their local institute norms. Recruitment will begin when the network has been approved and the Grant Agreement implemented. All posts will be advertised at once, through a range of media, including the EU Euraxess site and national and international[50] job sites. Whilst applicants will apply to a specific host beneficiary, suitable candidates will be made aware of opportunities across the network. With a Aug 2022 network start, ESRs will be typically interviewed from then until December 2022, with all starting Sep-Dec 2022 depending on host institute.

3.1.10 Progress monitoring and evaluation of individual projects

Each ESR will have a personal career development plan (PCDP) against which they will be able to track their progress. Their host node will provide the primary supervisor for that ESR, whilst a secondary mentor will be allocated based at a partner node. The ESR supervisor will work with the ESR in drawing up their PCDP and provide regular monitoring and guidance to their ESR. The PCDPs will be reviewed annually to allow for regular formal monitoring of the progress of the ESRs. This will ensure that the ESR is able to progress; any issues or problems can be identified and corrected at an early stage. Each ESR will be able to make full use of the career development support offered through their host institutions and they will be able to call for support through the DN. Career development information will be collated in WP2 and best practice for use by all ESRs across the network; this resource will be of value to the host nodes. All ESRs will be enrolled in PhD programmes at the host institutes. Some PhDs will complete in the 36-month period of the ESR. However, for those institutes with PhD's running for longer than 36 months (e.g., Netherlands), local arrangements will be put into place to ensure that the ESR continues to be registered and supported for the 4th year of the PhD.

3.1.11 Quality and Risk management

The risk register will be maintained by the Project Coordinator and reviewed by the DTC and reported upon to the annual meeting of the CSB. Table 3.2a presents the implementation risks. This will be updated at the first meeting of the DTC. A yearly checkpoint will allow for alterations of the programme to reflect possible alterations required, tailored to the progress of each individual ESR.

Before any MWGaiaDN researcher visit or secondment to one of our non-EU partner organisations, a risk assessment will be carried out conforming to the norms of the ESR's beneficiary host institute. This would include arranging for suitable insurance cover, health and safety information, and contact points for emergencies.

The MWGaiaDN'S STIAP (see Sec. 3.1.5) will have a remit to provide general advice on any specific 'Care of Duty' or ethical issues that may arise during the network.

3.1.12 Gender aspects

The recruitment procedure will prioritise the excellence of the individual. However, the principles of ***equal opportunity*** and ***gender balance*** will be stressed. Recruitment of the ESR positions will include advertising to reach under-represented groups, for instance via the IAU working group 'Women in Astronomy'. The ESR training programme will include a specific training element on gender issues during the Transferable Skills school. Decision-making within the network will take account of gender, will seek to increase diversity and in particular gender diversity, throughout the network activities. For instance, seven of the fifteen (47%) of the DN's primary ESR supervisors are women, and the network will aim to achieve at least 40% female membership of the DTC and other committees of the network. The research programmes will consider the needs of women (and men).

3.1.13 Environmental aspects in light of the MSCA Green Charter

MWGaiaDN will adhere to the MSCA Green Charter where consistent with the network's science driven excellence. Measure to reduce the environmental impact of the research programme will be implemented. At the researcher-level, network meetings will be organised such that participants will be able to attend in person or remotely using videoconferencing tools[51]. This will help minimise unnecessary travel. Where travel is essential, low carbon forms of transport will be used, for instance the train rather than the plane, public transport rather than car. Institutionally all ESRs will be given guidance in minimising the environmental impact of their research activities. MWGaiaDN will aim to reduce the environmental impact of its research at every opportunity.

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[50] e.g. http://www.ast.cam.ac.uk/admissions/phd and https://jobregister.aas.org/

[51] As a result of the Covid-19 pandemic all MWGaiaDN partners have made additional investments in their video conferencing capabilities to support remote participation in meetings.

3.2 Quality, capacity and role of each participant, including hosting arrangements and extent to which the consortium as a whole brings together the necessary

3.2.1 Appropriateness of the infrastructure and capacity of each participating organisation

Each beneficiary and partner have the appropriate research and training infrastructure in place to carry out the tasks assigned to them in the network. The beneficiary nodes are all world-class research institutions[52] with the required research infrastructure (research and administrative) to support the activities of the ESR projects and the training. The network beneficiaries will provide an excellent environment for the ESRs. Relocation advice will be offered through the local institute offices, and EURAXESS Services for relocation. Many of our research institutes have the 'HR Excellence in Research' accreditation. UCAM has the Athena SWAN Silver mark. UCAM has significant experience in leading DNs. The key expertise and facilities at each beneficiary node are listed in Sec. 5.

3.2.2 Consortium composition and exploitation of participating organisations' complementarities

All MWGaiaDN beneficiaries and partner organisations are fully committed to the research and training programme, with the contributions of all partners given in terms of their organisation and participation of workshops and training events (see **Sec. 1.2.1**), hosting ESRs during their individual projects (see **Sec. 3.1.4**) and as described in the partner organisation letters of commitment (see **Sec. 5**). We note that the network is reasonably large with some 23 organisations participating. The management structure (Sec 3.2.1) is configured to ensure that the network interactions proceed in an effective manner. In particular the network subcommittees and the supervisory board will review progress on a regular basis. Our DN network leadership are experienced in managing large networks. Walton (UCAM) has coordinated a previous ITN, and currently chairs the MW-Gaia COST Action. Brown (LEID) is Chair of the Gaia Data Processing and Analysis Consortium, whilst Vallenari (INAF-Padova) is its deputy chair. Jordi is grant holder for the MW-Gaia COST Action. The network participants have had a range of earlier partnerships and interactions. Together this expert experience will ensure effective interactions across the network, and delivery of the ESR projects.

The network brings together experts in Gaia and related astronomy, together with partners with expertise in related industry. There are strong synergies between the partners, and through the network significant research and training will be delivered which would not be possible at a national level. All ESR research projects involve secondments and exchanges with multiple partners, academic and industry or technical facilities, across the network, which provides access to the relevant world leading expertise. The network will both create new links between the participating groups and strengthen existing links.

Close interactions between the network participants will be established and maintained through: active involvement in the various schools/conferences of the DN; the Gaia data processing and analysis activities involved in many of the ESR projects; direct collaboration between the different DN project teams via telecons, document exchange (common papers), and ESR and partner exchange visits.

Jointly authored papers involving several ESRs and participants will result from many of the ESR projects. Each ESR will have a secondary thesis mentor, located in a collaborating network institute.

The network will deliver added value, in linking partners with complementary skills. The majority of the network beneficiary groups are already involved in the delivery of Gaia data to the community through the DPAC[53]. All beneficiary groups are active in the MW-Gaia COST Action. MWGaiaDN WP leads also have leadership roles in the matching COST Action working group structure. The industrial partners have either been involved in research or technical partnerships with individual or groups of academic groups. INSYS were a partner in the earlier GREAT-ITN. ABUSDS were the prime contractor of Gaia. SUIL works closely with the UCAM group in a medical project (see Sec **2.1.1**). The academic partner organisations have and do work in partnership with the academic beneficiary nodes. All are involved in the MW-Gaia COST Action. The beneficiaries and partners bring the range of skills and expertise required to deliver a high impact DN, with a cohort of excellently trained ESRs resulting.

The network links partners with a range of complementary skills, with the individual ESR projects fully exploiting these synergies. The UCAM ESR1 will exploit the new virtual reality environments developed by SUIL, to enable improved visualisation and analysis of the complex multivariate chemical and dynamical information on exoplanet host stars. ESR2 at LEID will benefit from local expertise in Gaia data, and will learn from the visit to UB how to compare observational data with the latest high-resolution theoretical Galactic structure models. ESR4 at LUND will benefit from local expertise in precision astrometry from Gaia. The visit to ABUSDS will provide additional insights into the implications in possible spacecraft instrumentation designs if extending observations into the infrared. The industrial partners will participate in all workshops at some level, taking a key role in the WP2 big data and WP5 technical challenges workshop. This will expose all the ESRs to valuable knowledge in transferring their science knowledge to the commercial sector. Participation of the industrial partners in the WP5 science road-mapping

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[52] Several of the network institutes are 'world top 100' universities QS World University Rankings 2020: UCAM (7th), LUND (92nd)

[53] see DPAC at https://www.cosmos.esa.int/web/gaia/dpac/consortium

exercise, will demonstrate how the assessment of science priorities can scope and define future technical directions, which in turn will be implemented in the industrial sector.
Partners such as LUND, TUD, NAOJ bring leading experts in astrometry (e.g., Hobbs, Lindegren, Klioner, Gouda). UCAM, LEID, DIRAC, UB bring experts in data and statistics (e.g., Brown, Jordi, Ivezic, Walton), whilst others such as CU, NKUA bring experts in astrophysical objects (e.g., Anton, Hatzidimitriou). Together with the experts from industry, both large space (e.g., TAS, OHB, ABUSDS) and IT (e.g., INSYS) and other more specialised SMEs (e.g., DAPC, SPINW, SUIL), the ESRs will be able to work on projects furthering our understanding of the MW (exploiting the exquisite data from Gaia). Crucially they will be able to drive the definition of the roadmap essential for the development of the next generation of space astrometry missions, leading to innovation possibilities for both science and industry in Europe.
The beneficiaries/partners, located across all parts of Europe represent key groups who will push the boundaries of exploiting Gaia. The ESRs will gain vital cross science, cross domain experience required to play a leading part in moving this area of astrometry to the next level in the coming decades.

3.2.3 Commitment of beneficiaries and associated partners to the programme

All ESRs will carry out secondments at other network institutes during the course of their individual research projects, with each visiting an industrial or major technical/facility partner. Full details of secondments (host, duration and timing) are given in **Tab. 3.1.d** with a summary in **Tab. 1.2.a**. Many will have one of their secondments at an institute outside of Europe. The secondments will provide exposure to a variety of research, technical and industrial facility. Thus, some will be to smaller research university groups, others will be to larger research organisations, to national research facilities (e.g. NAOJ), or to industry, large (e.g. ABUSDS, OHB) and small (SUIL). This breadth of exposure will provide the ESRs with experience with learning and growing in a wide range of international, interdisciplinary and intersectoral research environments. In addition, this will provide valuable exposure to potential future employers of the ESRs.
All beneficiaries are fully committed to the network, and each has already agreed a distribution of their institution funds to support the DN network project office. Each of the partner organisations, both academic and industrial, provide a full letter of commitment, which are attached in Sec. 5. These highlight the wide range of interactions, which will occur, and how each of the partner organisations will add significant value to the network. Each beneficiary and partner will sign the Collaboration Agreement. All partners will host ESR secondments (see **Tab 1.2a** and ESR project descriptions in **Tab 3.1.d**), offer training, participate in the research projects and network training events.
MWGaiaDN brings together a unique and world-class combination of research groups across Europe linked with key global partners: coupled to strongly complementary industrial groups participating at the highest level. This will ensure world class training to deliver a new cohort of ESRs able to exploit the opportunities from Gaia, drive innovation in the 2020's, and ensure continued leadership of European science and industry in this fundamentally important area of space science.

Specialism	Tasks	Organisations (Industry, Facility, Academic)
Space satellite design	WP5: technical challenges	ABUSDS, OHB, SPINW, TAS , NAOJ
Near infrared detector design	WP5: technical challenges	LEON
Commercialisation	WP5: knowledge transfer	UCAM (Cambridge Enterprise)
Big-Data databases	WP3: massive data database use WP5: technical challenges	DIRAC, INSYS
Big-Data applications	WP3, WP4: application integration	DAPC, DIRAC, INSYS
Ground based imaging expertise	WP3: Data mining, astro-statistics	DAPC, DIRAC, INSYS
Ground based spectroscopy	WP4: integrated spectroscopy observations	SAAO
Simulations	WP3: Galaxy modelling WP5 stellar models	UB, UCL
Public Engagement and Communications	WP6: Outreach, links with schools	SAAO, NKUA, UB, LEID
Visualisation and VR	WP3, WP4: data visualisation	SUIL
Project Management	WP2: ESR transferable skills training	ABUSDS, OHB, TAS

3.2.4 Funding of non-associated third countries

As at the time of Grant Agreement Preparation, following communication 25/04/2022 from the REA, the United Kingdom's association to Horizon Europe is not expected to apply at the time of planned signature of the grant agreement for your proposal. Legal entities established in the United Kingdom in the proposal are therefore not eligible for funding and cannot be beneficiaries. UCAM and UCL transferred from beneficiary partners to associate partners. They will participate in MWGaiaDN with finance provided through full matching UK support[54] [55] with

[54] https://www.gov.uk/government/publications/horizon-europe-guarantee-open-letter-to-the-uk-research-and-development-sector
[55] https://www.ukri.org/wp-content/uploads/2021/12/UKRI-Horizon-Europe-Guarantee-Guidance-May22-update.pdf

both UCAM and UCL contributing a UK funded PhD research fellow to the doctoral network, and delivering the WP6 lead (UCAM) and other non-management deliverables and tasks as noted in this Description of the action.

The UCAM and UCL doctoral fellows will carry out the individual projects foreseen in the original proposal. The UCAM PhD project being in WP4 titled: "Exoplanet Host Star Characterisation with Gaia and Spectroscopy" (with secondments foreseen to SUIL, UNIPD and OHB). The UCL PhD project being in WP3 titled: "Revealing the dynamical structure of the Galactic centre" (with secondments foreseen to UGA, UB and LEON). In addition, UCAM and UCL will fulfil their role in acting as secondment hosts to the EU funded beneficiary fellows as noted in section 3.1.4.

4. Ethics

The project involves associate partners located in United Kingdom (UCAM, UCL, AIRBUS, TAS), United States (DIRAC), South Africa (SAAO) and Japan (NAOJ). The beneficiary research fellows will undertake exchange visits to the partners as specified in Section 3.1.4. Furthermore, risk assessments for travel from EU to non-EU countries will be made, with network polices set by the supervisory board (CSB) and monitored by the doctoral training committee (DTC - see Section 3.1.11).

No activity to be undertaken in these countries raises potential ethical issues, plans to use local resources, plans to import any material (other than data) from non-EU countries into the EU or from a non-EU country to another non-EU country, involves low and/or lower middle-income countries or puts the individuals taking part in it at risk