GaiaNIR: next astrometric mission

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Book of Abstracts

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A new golden age for the proper motion anomaly technique with Gaia-NIR

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In the last couple of years, high contrast imaging observations are changing their focus from broad blind surveys (e.g. SHINE SPHERE-GTO; Desidera et al. 2021) to observations of pre-selected targets exploiting the presence of astrometric signatures such as the Gaia-Hipparcos Proper Motion Anomaly (PMA). This leads to an increase of detection efficiency by about an order of magnitude (Bonavita et al. 2022) and to detection of new benchmarks planetary companions such as AF Lep b (Mesa et al. 2023). Gaia NIR would allow to extend the PMA technique both in time baseline and sensitivity, allowing to greatly expand the completeness of our view of the outer parts of planetary systems.
Synergies with the direct imaging techniques will also be further enhanced by the instrumentation expected to be available at that time.

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The photometric heritage of Gaia missions

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In the light of the experience acquired on photometry and spectrophotometry with the ongoing Gaia mission I try to make some preliminary considerations on the photometry of Gaia-NIR.

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GaiaNIR: a pathway to the dark side of the Milky Way

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We review the current status of young (Classical Cepheids), intermediate-age (Anamalous Cepheids) and old (RR Lyrae, Type II Cepheids) stellar tracers across the Galactic bulge and the thin disk. In particular, we focus our attention on the role that primary distance indicators can play to trace the early formation and evolution of the Galactic bulge. Moreover, we outline the impact that GaiaNIR will have in lifting the veil on the stellar content of the bulge/disk regions located beyond the Galactic center.

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Characterization and occurrence rate of Jupiter and Saturn analogs to assess their impact on the formation of small and terrestrial inner planets. The crucial role of Gaia-NIR

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The large exoplanet population with relatively short orbital periods (P<100 d) around solar-type stars is dominated by small (1⊠Rp⊠4 Re, Earth radii) and low-mass (1⊠Mp⊠20 Me, Earth masses) planets, i.e. super-Earths and sub-Neptunes. These planets are, however, missing in our Solar System, which has only terrestrial planets (Rp ⊠1 Re, Mp ⊠1 Me) in inner orbits, and the reason for that is unknown. Several theoretical works have tried to assess the impact of cold Jupiters (CJs, i.e. Jupiter and Saturn analogs with Mp~0.3-13 MJup and orbital separation a~1-10 au) on the formation and/or migration of small planets (SPs), and predicted either an anti-correlation or a weak or strong correlation between CJs and SPs, thus reaching somehow contradictory results. Here we report on the search, characterization, and occurrence rate of CJs in a sample of Kepler and K2 transiting systems observed with high-precision radial velocities over a decade, finding no evidence of previous claims of an excess of CJs in small-planet systems. We show how improved occurrence rates of CJs and their multiplicity around solar-type stars with Gaia-NIR can provide fundamental clues on both the formation of short-period SPs and their absence in our Solar System.

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Microlensing with exquisite astrometry

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Microlensing is a well-established tool to detect and study the populations of compact objects in our Galaxy, including black holes, low-mass stars, brown dwarfs and extrasolar planets. Gaia has allowed the discovery of hundreds of microlensing events in the Galactic disk adding astrometry to the traditional photometric studies. Gaia-NIR may further increase these discoveries in regions obscured by dust. By astrometry in the central regions of the Galaxy, we may be able to detect and quantify gravitational lensing by Sgr A* and thus characterize the mass distribution in the Galactic center.

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Welcome

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From Gaia to Gaia-NIR: the INAF and Italian technological contribution.

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Starting from the contribution of INAF and Italy to the Gaia mission, we will share some useful lessons learned from Gaia, but not only, and suggestions useful to place the potential contributions of Italy and INAF technological community in context.

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Synergies with LSST

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Over the next decade the Legacy Survey of Space and Time (LSST) at the Vera Rubin Observatory will collect time-series multiband photometry reaching 5 magnitudes fainter than Gaia's limit (G~20.7 mag) in photometry and about 3 mag deeper in astrometry.

The LSST will thus form Gaia's deep complement in the south hemisphere in preparation for Gaia-NIR that is expected to extend the astrometric achievements of Gaia to astronomical sources that are visible in the NIR, allowing to probe deeper through the Galactic dust in the MW disc, the spiral arms and the bulge region, at the same time maintaining the accuracy of the Gaia optical reference frame and improving the stellar parallax and proper motion accuracy by revisiting the astronomical sources about 20 years after Gaia.

I will discuss synergies between Gaia, LSST and Gaia-NIR particularly in the field of stellar variability and pulsating stars as standard candles and stellar population tracers.

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The Gaia legacy: Gravitation and multi-messenger astronomy with Gaia NIR

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The very core of the Gaia data analysis and processing involves General Relativity (GR) to guarantee its scientific products as, at Gaia's precision, Solar System perturbations on stellar light rays cannot be neglected.

Besides, GR models offer the unique possibility of establishing a multi-laboratory for extensively testing gravity theories and gravitational waves (GWs) from Solar System to Milky Way and cosmological scales. As a matter of fact, the large amount of information accumulated over 10+ years by Gaia will be further extended thanks to Gaia NIR to catch possible GW signatures and/or lensing effects on astrometric/photometric raw epoch data and, thus, to further boost synergies with other GW detectors and assist efforts in characterizing GW signal strength and direction, and the astrophysical nature of GW sources.

The Gaia-NIR observations targeting the Galactic bulge and its center will have a huge impact in probing the structure of our whole Galaxy as the product of cosmological evolution shaped by gravity (Local Cosmology), i.e. the relations among baryonic structures (and their evolution) and the dark components of the Universe.

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Unveiling free-floating binary planets with Gaia-NIR astrometry

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Planetary mass objects and brown dwarfs have been shown to exist both associated to stellar objects and as isolated, free-floating objects in the field. While the multiplicity of isolated brown dwarfs was found to be smaller than that of low mass stars, extending the trend of binary fraction with the mass of the primary observed in the stellar regime (Fontanive et al. 2023), a turnover in binary fraction was observed very recently for planetary-mass objects in the Trapezium cluster (Pearson & McCaughrean 2023). This point to a specific mechanism for the formation of binary objects of planetary masses. Theoretical efforts to explain the formation of binary planets both bound to the central star and free-floating are being performed (e.g. Konijin et al. 2023; Portegies Zwart et al. 2023; Lazzoni et al. 2024). The Gaia-NIR space mission may allow a deeper view of the multiplicity of low-mass substellar objects, extending to closer separations the emerging results for visual companions. Objects in different environments, such as nearby young associations and open clusters could be explored, allowing the study of the impact of stellar density.

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Revealing the disc of the Milky Way with Gaia NIR

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Gaia Fireworks: the impact of Gaia on Eruptive Accretion and the crucial role of NIR-Gaia

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The accretion from the circumstellar disk onto the forming star is supposed to be the fundamental process which regulates stellar mass gaining. A way to investigate the accretion process is to study light curves variability, in particular the strong changes in light curves (2-5 mag) that define eruptive young stars as FUors and EXors. These objects experience strong outbursts by which they collect up to 10^4 Msun/year. Unfortunately, only less than 50 Fuors/Exors are known. Recently, thanks to the Gaia Alert Program, further 12 objects have been classified as eruptive stars, and many more are going to be discovered. However, the accretion evolution is very difficult to study because young stars are veiled by the extinction of their dusty envelope and disk. As a consequence, only very bright young stars have been classified as eruptive accreting objects. In this talk I will summarise the outstanding impact of Gaia on eruptive accretion and I will show how NIR-Gaia will help this field of research.

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The young supermassive star clusters: an opportunity to study stars and planets formation in starburst

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With a mass exceeding several 10000 solar masses, the young supermassive star clusters known in the Milky Way today represent the most accessible examples of starburst regions. These regions represent the most extreme star-forming environments, characterized by intense fields of UV and X-ray radiation, and relativistic particles, produced by the compact and rich populations of massive stars in these clusters. Since this energetic radiation impacts every aspect of the star and planet formation process, stars and planets form differently in such massive star-forming environments compared to low-mass ones. Additionally, supermassive star clusters are common in galaxies experiencing intense epochs of star formation, such as interacting galaxies or in the early Universe. Even in the Milky Way, during major merging events, star formation typically occurred in supermassive star-forming environments. For these reasons, despite their low number, large distances from the Sun, and large extinction, the Galactic supermassive star clusters are important targets to understand star and planet formation in the most extreme star-forming conditions. In this presentation, I will discuss recent progress in the analysis of supermassive star clusters and explore the profound improvements that GaiaNIR would bring to this field.

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Discussion: Next steps & Actions

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The GaiaNIR mission: Future Space Astrometry in the Near Infrared

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Our Galaxy contains many different types of stars and planets, interstellar gas and dust, and dark matter. These components are widely distributed in age, reflecting their formation history, and in space, reflecting their birth place and subsequent motion. Objects in the Galaxy move in a variety of orbits that are determined by the gravitational force, and have complex distributions of different stellar types, reflecting star formation and gas-accretion history. Understanding all these aspects in one coherent picture is being partially achieved by Gaia, which surveys around 1% of the Galaxy and is still ongoing today. However much more could be done by using Near InfraRed (NIR) light to peer through the dust and gas to reveal the hidden regions of the Galaxy.

A new all-sky NIR astrometric mission will expand and improve on the science of Gaia using basic astrometry. NIR astrometry is crucial for penetrating obscured regions and for observing intrinsically red objects. The new mission is aimed at surveying around 12 billion stars in the Galaxy, revealing important new regions obscured by interstellar gas and dust while also improving on the accuracy of the previous results from Gaia. The mission will explore the Galaxy, particularly the very important hidden regions, to reveal nature's true complexity and beauty in action.

In 2019 ESA announced the next planning cycle for their long term Science Programme, called Voyage 2050. The program called for White Papers outlining new ideas for future space mission themes. In June 2021 Voyage 2050 finally set sail, with ESA having chosen its future science mission themes. Our proposal on All-Sky Visible and Near Infrared Space Astrometry has been selected as one of two possible themes for a future Large category mission for ESA or as a Medium class mission with international partners. This talk will give an update on the science goals, the mission design and its current status.

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The RR Lyrae in the disc as an interesting GAIA NIR scientific case.

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In this talk, I will present an interesting scientific case for GAIA NIR regarding the characterization of metal-rich RR Lyrae stars in the stellar disc. While RR Lyrae stars have traditionally been considered old and metal-poor population II stars, it is well known that metal-rich (up to solar values) RR Lyrae stars exist in the solar vicinity. Leveraging GAIA's capabilities (Gaia DR2 and Gaia DR3), we have discovered that these metal-rich RR Lyrae stars are distributed throughout the Galactic disk, extending beyond the Solar neighborhood.
The kinematics of these stars align with a young (less than 5 Gyr) thin-disc population, challenging conventional RR Lyrae formation scenarios. Our research suggests that significant mass-loss events in binary systems could produce a population of metal-rich RR Lyrae stars with ages consistent with the thin-disc populations. However, identifying RR Lyrae stars in binary systems remains a challenge.
In this context, GAIA NIR may be the perfect instrument to increase the number of observed RR Lyrae in the high-extinct regions of the Galactic disc. The combination of photometry and astrometry will fundamental to characterize such objects and confirm or not the proposed binary formation channel.

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Towards the innermost boundaries of the Galactic disc

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Open clusters have been known for decades as excellent tracers of Galactic disc chemistry (and kinematics). Gaia has made possible the discovery of thousands of new clusters, particularly in the Solar neighbourhood, which was thought to be already complete for cluster searches. The innermost regions of the Galactic disc, at the edge of the Galactic bulge, remain less explored. The VVV infrared survey is contributing to the detection of new clusters in the inner disc, but an instrument like Gaia-NIR will revolutionise the field, contributing to our understanding of, for example, the rate of cluster formation and destruction in crowded fields, the shape of the metallicity gradient in the inner part of the Galaxy and the bimodality of disc and bulge clusters.

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Cepheids and RR Lyrae in the Gaia-NIR perspective

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Cepheids and RR Lyrae in the Gaia-NIR perspective

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The Gaia mission has so far revolutionised our knowledge of Galactic Cepheids and RR Lyrae distance scales and still more accurate results are expected from the next data releases. In this contribution, the main results obtained for Cepheid and RR Lyrae pulsation properties from Gaia data and the predictions of nonlinear convective pulsation models will be shown and their implications for stellar population studies will be discussed.
The advantages of studying Cepheids and RR Lyrae in the NIR filters, in particular for what concerns the reduced dependence on reddening corrections, the reduced number of epochs needed to characterise the light curves and evaluate mean magnitudes and colours, as well as the reduced effect of the finite width of the instability strip on the intrinsic dispersion of Period-Luminosity relations, will be finally emphasised in the perspective of future Gaia-NIR observations.

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Euclid Early Release Observations - first results on Milky Way globular clusters

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On July 1st 2023, the Euclid mission has officially started its operation with a succesful launch, and a few months ago its optical VIS and near-IR NISP intruments have taken the first astonishing images on the sky.
The main objective of the Euclid mission is to explore the distant universe to solve the most pressing cosmological open questions, but the unprecedented combination of high-resolution, wide field and depth makes it a fantastic instrument to study resolved stellar populations as well.
As part of its very first observations, under the Early Release Observations (ERO) programme, Euclid observed two Milky Way Globular Clusters. The main scientific objective of these observations is to investigate the globular cluster morphology in search for tidal features in their outermost regions. In this talk, I will present the first results obtained from this effort, that showcase the potential that Euclid has for advancing the study of star clusters in our Galaxy well beyond the current limit.

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The structure and dynamics of ISM: spiral arms, molecular clouds and the earliest formation of stellar clusters.

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The possibility that Gaia-NIR offers to extend the determination of distances and proper motions of stellar sources over a large fraction of the Galaxy and in dense star forming regions unlocks unprecedented potential to investigate the 3D structure and dynamics in the assembly process of star forming regions, once coupled to ancillary datasets provided by large-scale HI and CO Galactic surveys. Furthermore, the possibility to put together the proper motion information from relatively evolved YSOs, with the radial velocity of the early-stage millimeter cores from ALMA, will allow to trace the complete dynamical scenario in the formation and evolution of the youngest stellar clusters in the Galaxy, for which new detailed numerical simulations are being developed.

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Synergies with space-based transit surveys

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Several space missions dedicated to transit surveys (TESS, PLATO) or, more in general, dealing with transit-based exoplanetary science (CHEOPS, JWST, Ariel) are currently flying or being developed. While their timelines are not going to overlap with GaiaNIR, it is worth exploring what are the scientific synergies in this field, in both ways.

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Characterizing of long-period exoplanets with radial velocities and present and future high-precision astrometry

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The study of complex systems with long-period companions is currently at the forefront of the observational efforts in the study of extrasolar planets. Both radial velocities (RV) and astrometry can provide valuable information on such systems, but they both suffer from inherent limitations. We present several recent results that prove how the combination of these two techniques can overcome these limitations, both in the context of recent and upcoming Gaia data releases, and of future high-precision astrometric missions such as GaiaNIR.
We present the combination of RV measurements from HARPS-N and Gaia astrometry, to study in great details the long-period companions orbiting a sample of stars with known RV detected systems. We show how the combination of RV information with proper-motion anomalies from GaiaDR3 and Hipparcos can measure the inclination and real masses of several long-period companions in our sample. We also present a set of realistic simulations of Gaia and GaiaNIR astrometric time series, to quantify the great boost in precision that the combination of these well-spaced datasets will bring to the study of long-period exoplanetary companions.

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Low-mass young stellar populations in the Milky Way: the next frontier with Gaia NIR

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Star formation occurs in high density environments or embedded clusters, but very young stars are also found in low density environments or stellar associations.
These regions are key tracers of the large-scale Galactic structure,
as well as pivotal astrophysical laboratories for understanding the complex physical phenomena involved in the star and planet formation process. They include large populations of embedded young stellar objects (YSO) that, depending on their evolutionary phase, can show an excess from the near-IR to the sub-mm, due to the presence of circumstellar material. In addition, they are mainly found in regions with high extinction, being enshrouded in the remnants of the molecular clouds from which they formed.
I will discuss the great impact in the comprehension of these structures over the past decades and how a forthcoming mission like GaiaNIR could represent a revolutionary step, akin to Gaia, by revealing hidden young populations. This would allow us to study
the star formation history, understand the mechanisms that trigger star and planet formation in different environments, and provide better tracing of the yet unknown spiral arms of the Milky Way.

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Unveiling the initial stages of star formation with Gaia-NIR

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Investigating the physical mechanisms leading to the formation of stars is fundamental for understanding the evolution of galaxies and the origin of the solar system. The Gaia Space mission with the support of ground-based spectroscopic surveys started a revolution in this field thanks to the discovery of sparse young stellar populations and because allowed us to investigate the structure and kinematics of young star clusters.
However, such studies focus on stars that are visible in the optical band and, therefore, have already completed the initial stages of the star formation process when they are embedded in molecular clouds.
Gaia-NIR will allow us to investigate the dynamics of young stellar systems in these very early stages, probing the initial conditions of star formation. In this talk I will outline the open issues that can be addressed with Gaia-NIR in this field and discuss the scientific motivation for equipping the satellite with a Radial Velocity Spectrometer and/or developing new graund-based instruments for ground based follow up.

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Exoplanet Demographics

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We call exoplanet demographics the body of studies of the distribution functions of planetary parameters and occurrence rates, expressed as a function of as many of the physical parameters that may influence planet formation and evolution as possible, over as broad of a range of these parameters as possible. The development of exoplanet demographics has leveraged the thousands of exoplanets detected and characterized over the last three decades. Thousands more are expected to be found and delivered by the two final Gaia data releases, DR4 and DR5. I will provide a brief summary of the major breakthroughs in exoplanet demographics obtained to-date, and discuss the broad perspective for development of the field over the next 25 years, placing the potential contributions of GaiaNIR in context.

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Goal of the meeting

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Discussion: Next steps & Actions-Part II

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Gaia-NIR: next astrometric mission

We present the Gaia-NIR mission, as proposed to ESA Voyage 2050. We will update on the status of the project