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The 4MOST Survey of Young Stars (4SYS)

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Most nearby young stars (with ages < 100 Myr) in the Galactic disc no longer reside in their dense, clustered birthplaces; they are found all around us. The 4MOST Survey of Young Stars will identify a representative sample of about 10^5 young, low-mass stars within 500 pc of the Sun and will measure their chemistry, 3D kinematics and ages in order to: trace the spatial and dynamical evolution of star-forming structures; quantify the star formation rate and chemical inhomogeneity in the local disc; vastly expand the number of identified young stars for exoplanetary studies; and provide huge coeval samples to improve young stellar evolutionary models.

Scientific context

The distribution of young stars in space, kinematics, chemistry and age is of key importance in understanding the processes that drive star formation, the origins of the Galactic field population, and the early evolution of stars, their discs and planetary systems. Most stars (including the Sun; Adams, 2010) are born in clusters of various sizes in the Galactic disc, but most of these clusters disperse into the field on timescales of 10–100 Myr (Lada & Lada, 2003; Krumholz, McKee & Bland-Hawthorn, 2019). Most young stars (with ages < 100 Myr) in the Galactic disc, including the nearest ones, are not located in compact clusters and star-forming regions (for example, Zari et al., 2018); they are instead part of the field population. Decades of work have revealed a population of about 1500 young stars within 100 pc of the Sun, a volume that contains no significant clusters (for example, Gagné & Faherty, 2018). Many, but not all, are part of kinematically coherent, roughly coeval 'moving groups' of large spatial extent (for example, Torres et al., 2006). Members of this widespread population trace the recent star formation history in the Milky Way disc on a variety of scales and, because of their proximity, have become exemplars for studying early stellar evolution and planet formation; yet their origins and birth environments remain obscure. While the census of young stars within 100 pc is substantially complete, much less is known about their chemistry or the spatial and kinematic properties of young stars outside this radius, beyond the biased perspective offered by high-density compact clusters and star-forming regions. The Gaia astrometry satellite[1] is revolutionising this field (for example, Kounkel & Covey, 2019; Cantat-Gaudin, 2022; Alfaro et al., 2022; Prisinzano et al., 2022). Precise astrometry and homogeneous photometry can place stars in Hertzsprung–Russell diagrams and provide 2D tangential motions. Early studies are providing tantalising glimpses of rich complexity in the young stellar population — mapping the extended populations of dissolving clusters and associations (Meingast, Alves & Rottensteiner, 2021; Gagné et al., 2021) and finding evidence for kinematically coherent streams arranged in grand filamentary structures on scales > 100 pc (for example, Beccari, Boffin & Jerabkova, 2020).

These studies will continue to be limited in several important ways, however, until they are supplemented by spectroscopy of large and representative samples: (1) samples selected by astrometry and photometry alone are heavily contaminated with older stars; (2) astrometry yields only 2D kinematics, but 3D velocities are important for determining the history and subsequent evolution of star-forming structures; and (3) information about detailed chemistry and chemical (in)homogeneity is absent, but such information is a key diagnostic of the star formation history, of mixing in the interstellar medium and of the co-spatial or coeval nature of star forming events.

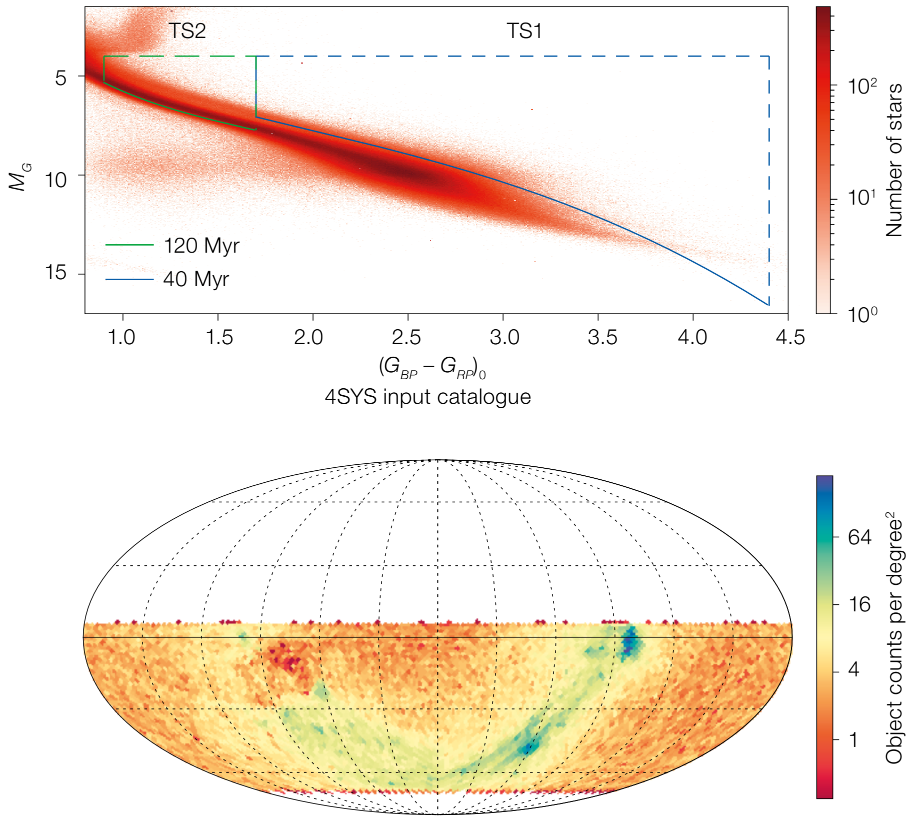

Figure 1. Top panel: two-dimensional histogram representing the absolute *G* magnitude M_G vs. dereddened $(Bp–Rp)_0$ colour of all the stars in the Gaia DR3 catalogue with parallax > 2 milliarcseconds, –70 < Declination < 5 deg, which meet the standard quality criteria for photometry discussed in Riello et al. (2021). The blue and green continuous lines represent the empirical isochrones used to identify stars younger than 40 and 120 Myr, respectively. The areas included within the isochrones and the dashed blue and green lines are used to select stars for the target sample 1 and to pre-select stars for the target sample 2, respectively. Bottom panel: sky distribution of the targets in the 4SYS input catalogue.

Specific scientific goals

Age, chemistry and kinematics are stellar properties that cannot easily be determined. Spectroscopy is essential to identify young stars, eliminate contamination, improve age estimates, and obtain precise chemical abundances and radial velocities (RVs). The 4MOST Survey of Young Stars (4SYS) is aimed at observing a representative sample of ~ 100 000 candidate young low-mass stars within 500 pc of the Sun, increasing the volume probed and numbers of identified young field stars by two orders of magnitude. 4SYS will cover the spatial scales of grand structures recently found in the disc (Zari et al., 2018), and closely match the sensitivity of the TESS satellites and the eROSITA instrument on board the SRG satellite (Ricker et al., 2015; Predehl et al., 2021). The 4SYS targets are split between two samples. The first, mostly observed at low resolution, is selected from absolute colour–magnitude diagrams based on Gaia data[2] and targets pre-main-sequence stars cooler than spectral type K7 with ages < 40 Myr, with a focus on accurate demographics and kinematics, and using stars at the peak of the stellar initial mass function (0.2–0.5 $M_\odot$). The second, observed at high resolution with a focus on precise kinematics and chemistry, selects brighter G7–K7 stars on or above the zero-age main sequence (ZAMS), and filters them using TESS rotation periods and X-ray activity from eROSITA, in order to remove binaries and giants and to include stars younger than 100 Myr. The overarching objective of 4SYS is to construct a catalogue of 3D positions (to 1 pc precision), 3D space motions (to < 1 km s^{-1} precision), stellar parameters (effective temperature, surface gravity and global metallicity), stellar properties (mass and age), diagnostics of magnetic activity and accretion from the disc for the majority of objects, detailed chemistry and projected rotation rates for the high-resolution sample. These will be combined with data from TESS, eROSITA and the WISE satellite. Uniquely, 4SYS is not biased towards dense, clustered young populations; instead, it will capture the dominant dispersed young population that can be used to address key science areas: (1) to understand the origins of the young field population and initial conditions for star formation by mapping the spatial and kinematic evolution of star-forming structures on scales of 1–500 pc over the last 100 Myr and determining the extent of chemical homogeneity in the local young population; (2) to expand the number, and determine the properties and origins, of nearby young stars, which serve as the prime targets for studies of protoplanetary discs and young exoplanetary systems with current and next generation facilities (for example JWST and ESO's Extremely Large Telescope);

and (3) to identify the missing ingredients in current models of early stellar evolution, provide the large samples necessary to improve the next generation of evolutionary models, and empirically determine how stars and their discs, accretion, rotation and magnetic activity, change during the epoch of planet formation.

Target selection and survey area

4SYS aims to select a large sample of young stars, with excellent astrometry and photometry, that has a well understood selection function and which is as complete as possible, but with low contamination by older objects. We include stars with ages from 1 to 100 Myr, covering the main epochs over which star-forming clusters evolve dynamically and disperse, planetary systems form, discs disperse, and PMS stars with $0.5 < M/M_{\odot} < 1.0$ reach the ZAMS. To obtain the necessary resolution in time and space, the volume needs to be sampled by many stars. We therefore choose low-mass targets with spectral types G7–M6 that are at or near the peak of the initial mass function. These targets have the added benefit that their youth can initially be guessed from their position in absolute colour-magnitude diagrams (CMDs) and then unambiguously confirmed with spectroscopy using the lithium absorption feature at 670.8 nm and/or gravity- and activity-sensitive diagnostics. We started from a parent catalogue including all the stars in the Gaia DR3 catalogue (Gaia Collaboration, 2022) with parallax > 2 milliarcseconds (d < 500 pc) and –70 < Declination < 5 deg, which meet standard quality criteria for photometry discussed in Riello et al. (2021). Stars later than K7 and younger than 40 Myr are well separated from the main sequence, in particular they are high enough above the ZAMS to avoid heavy contamination by unresolved binaries. Older/hotter stars are closer to the ZAMS and we cannot rely on CMDs alone to select these targets. We therefore defined two main samples.

Target sample 1 comprises stars in the magnitude range $10 < G < 18.5$ mag that lie in two CMDs (M_G vs. $(G–Rp)_0$ and M_G vs. $(Bp–Rp)_0$) above a 40 Myr isochrone, derived empirically using data from star clusters, with absolute G magnitude $M_G > 4$, and in a colour range that corresponds to the spectral types K7–M6 (see blue dashed lines in the upper panel of Figure 1). It includes a total of about 100 000 stars. Closer stars in the magnitude range $10 < G < 15.5$ will be observed at high resolution, while fainter stars with $15.5 < G < 18.5$ will observed with the low-resolution mode. Contaminants will include some unresolved binaries/triples with high mass ratios, subgiants, and unusually reddened old field stars. 4MOST spectroscopic measurements of gravity, Li and chromospheric activity are needed to exclude these.

Target sample 2 comprises stars in the magnitude range $10 < G < 15.5$ mag, that in the same CMDs used for target sample 1 lie above the 120 Myr isochrone (and are hence likely to be aged 100 Myr or younger), with absolute G magnitude $M_G > 4$ (to exclude turn-off stars and subgiants) and within a colour range that corresponds to spectral types G7–K7 (see green box in the upper panel of Figure 1). Since young stars are fast rotators and strong X-ray emitters, we are using rotation periods derived from the TESS light curves and X-ray fluxes from eROSITA to complement the CMD-based selection, which otherwise will be affected by severe contamination. To home in on young stars, we select those stars that have either rotation periods smaller than the upper envelope of the rotation-colour relation defined by members of the 120 Myr Pleiades cluster and/or a ratio between the flux in X-rays and in the G band higher than a threshold defined using stars in young clusters that have been detected with eROSITA. In total, target sample 2 is composed of about 40 000 stars that will be observed at high resolution.

The bottom panel of Figure 1 shows the distribution on the sky of the stars in the input catalogue of 4SYS. As expected, the stars are located mostly in the galactic disc with lower densities in the area of high extinction. The areas with the highest densities correspond to well-known star-forming complexes or young associations like Orion (RA = 83.8 deg, Dec. = –5.44 deg) and Vela OB2 (RA = 122.4 deg, Dec. = –47.34 deg). When the survey is completed, more than 66% of the input catalogue will have been observed. The level of completeness will be approximately homogeneous across the observed area and as a function of the stellar distance.

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Links

[1] Gaia mission website: https://www.cosmos.esa.int/web/gaia
[2] Gaia data archive: https://gea.esac.esa.int/archive/