Isochrone fitting in the Gaia era. III. Distances, ages and masses from UniDAM using Gaia eDR3 data.

A. Mints

Leibniz-Institut für Astrophysik Potsdam (AIP), Potsdam, Germany

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Abstract

We present estimates of distances, ages and masses for over million stars. These estimates are derived from the combination of spectrophotometric data and Gaia eDR3 parallaxes. For that, we used the previously published Unified tool to estimate Distances, Ages, and Masses (UniDAM).

1 Introduction

In (Mints & Hekker 2017) we presented the Unified tool to estimate Distances, Ages, and Masses (UniDAM). UniDAM uses Bayesian scheme to derive distances, ages and masses for stars from spectrophotometric data. This tool was further updated (see (Mints & Hekker 2018)), to allow for the use of parallax data in isochrone fitting. Once Gaia DR2 was released (Gaia Collaboration et al. 2016, 2018) we produced a new catalogue of distance, ages and masses for over 3.5 million stars (Mints & Alexey 2018). The recently released version 2.3 of UniDAM also allows the use of asteroseismic data.

Several spectroscopic surveys have made new releases recently: RAVE (final DR6 Steinmetz et al. 2020), LAMOST DR6 (Luo et al. 2015, also containing the first data from medium-resolution survey), GALAH+ DR3 (Buder et al. 2020) and APOGEE DR16 (Ahumada et al. 2020).

When supplemented by other surveys already processed in (Mints & Alexey 2018), this gives almost 8 millions of measurements for almost 6 million sources. They are distributed over almost entire sky (see Figure 1), with some gaps in southern Galactic disc and around northern equatorial pole. An overdensity at about $l = 75^\circ$ and $b = +13^\circ$ corresponds to the Kepler field of view, that was extensively studied by APOGEE and LAMOST (see, for example Ren et al. 2016; Pinsonneault et al. 2019).

All surveys used in the current work are listed in Table 1.

2 Gaia eDR3 data

Gaia early data release 3 (Gaia eDR3, Gaia Collaboration et al. 2020) was released on December 3rd 2020. It contains among other data parallaxes and proper motions for around 1.468 billion sources. As compared to the previous Gaia DR2, precision and accuracy of astrometry was substantially improved as additional 12 month more of observations were used and as calibration was largely improved. We have crossmatched all sources in our catalogues listed in Table 1 with Gaia eDR3 data using Vizier XMatch tool.

As stated in Gaia Collaboration et al. (2020), Gaia eDR3 parallaxes seem to have a systematic offset of $-17\mu$as – about a factor of 3 lower than in Gaia DR2. This offset was added to parallax values used in UniDAM processing.

3 Results and discussion

In Figure 2 we show how median uncertainties of distance modulus and log(age) derived by UniDAM with the use of Gaia eDR3 data compare with results obtained with Gaia DR2 parallaxes.

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1 UniDAM source code is available at https://github.com/minzastro/unidam
2 http://cdsxmatch.u-strasbg.fr
Table 1: Total number of sources with 2MASS/AllWISE photometry, and Gaia eDR3 overlap for different surveys.

| Survey         | Input catalogue size | Stars with estimates done using Gaia eDR3 parallaxes | Reference                  |
|----------------|----------------------|---------------------------------------------------|----------------------------|
| APOGEE (DR16)  | 473,307              | 326,884                                           | Ahumada et al. (2020)      |
| Bensby         | 714                  | 547                                               | Bensby et al. (2014)       |
| Gaia-ESO (DR3) | 25,533               | 20,127                                            | Gilmore et al. (2012), G.Gilmore & S.Randich (2016) |
| GALAH (DR3)    | 564,620              | 505,403                                           | Buder et al. (2020)        |
| GCS            | 13,565               | 7,633                                             | Casagrande et al. (2011)   |
| LAMOST (DR6)   | 5,581,266            | 4,377,103                                         | Luo et al. (2015)          |
| LAMOST MRS (DR6)| 328,187              | 223,407                                           | Luo et al. (2015)          |
| RAVE (DR6)     | 491,349              | 347,211                                           | Stemmetz et al. (2020)     |
| SEGUE          | 235,595              | 180,012                                           | Yanny et al. (2009)        |
| Total (unique sources) | 5,856,273          | 4,616,931                                         |                            |

Most surveys show very similar distance modulus uncertainty behaviour, as distance modulus uncertainty depends primarily on the parallax uncertainty. There are some clear exceptions though. SEGUE, LAMOST and Gaia-ESO surveys show larger uncertainties, when compared to other surveys. This is because these surveys target larger fraction of main sequence stars that are typically much fainter at the same distance. Those fainter stars have systematically larger Gaia eDR3 parallax uncertainties and hence larger derived distance modulus uncertainties. On the other side, APOGEE stars have much lower distance modulus uncertainty at $\mu_d > 15^{\text{m}}$. At this distances, a smaller uncertainty in surface gravity that APOGEE stars have starts to play a role. With Gaia eDR3 parallaxes becoming more uncertain for distant stars, UniDAM constrains distance mainly from spectrophotometric data – and thus having lower uncertainties in surface gravity for APOGEE provides lower uncertainty in distance modulus.

Uncertainty of log(age) shown in the right panel of [Figure 2](#) depends not only on the uncertainties in spectrophotometric parameters and parallaxes, but also on the positions of stars in the Hertzsprung-Russell diagram: for stars on the main sequence age is much less constrained by spectrophotometric data. Hence the larger is the fraction of main-sequence stars in the given distance bin – the larger the median uncertainty in log(age). As distance modulus increases, the fraction of main sequence stars decreases, and with it decreases the median uncertainty in log(age). With distance modulus increasing beyond $\mu_d \approx 10^{\text{m}}$, median uncertainty in log(age) starts to increase, due to uncertainties of spectrophotometric data increasing with distance. This upturn happens at larger distances ($\mu_d \approx 15^{\text{m}}$) for SEGUE survey, as its main-sequence sample extends to larger distances.

In [Figure 3](#) we compare uncertainties in distance modulus and log(age) without parallax data (where available), with Gaia DR2 data and Gaia eDR3 data to show the improvement we get from the newest Gaia eDR3. It is clear that Gaia eDR3 parallaxes allow to decrease uncertainties.

We publish results of UniDAM with Gaia eDR3 parallaxes on [Mints (2020)](#). An important feature of UniDAM is that it can produce more than one solution for a given star. This allows to separate out solutions for different evolutionary stages or, more generally, for cases when posterior distributions in distance modulus or log(age) are multi-modal. Values reported for each solution allow detailed reconstruction of posterior distribution in every parameter (see UniDAM homepage[4] for details). In total, our data contains 5988327 solutions for 4616931 unique stars. This is about 20 percent less than the size of the input catalogue, because for many stars no isochrone fit is possible. There may be several reasons for that, for example:

- Incomplete spectroscopic data in the survey.
- There are no 2MASS/AllWISE photometry for the star – it is either too faint, too bright or suffer from some photometric issues.

[https://github.com/minzastro/unidam](https://github.com/minzastro/unidam)
Figure 1: Distribution in galactic coordinates of unique sources in the published catalogue.

- No Gaia eDR3 parallax available – it is either too faint, too bright or suffer from some astrometric issues.
- There is no model that fits spectroscopic parameters. This can happen if the star is outside of PARSEC model range (it spans, for example, only metallicities between -2.18 and +0.5 dex). Unusual and non-stellar spectra can also produce a combination of spectroscopic parameters that has no match in PARSEC models – for such objects no solution is found too.
- There are inconsistencies in the input data. These can arise for example when the observed object is a binary or a blend of two or more stars (and thus is brighter than expected from spectroscopic parameters and parallax). Inconsistency can also be a sign of either an outlier in the input data or erroneous match between spectroscopic survey and 2MASS, AllWISE and Gaia catalogues.

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Figure 3: Uncertainties of UniDAM results in distance modulus and log(age)s for several surveys. Plots show data without parallaxes (where available, grey line), with Gaia DR2 parallaxes (blue line) and with Gaia eDR3 parallaxes (red line).