Determination of stellar ages from kinematic data

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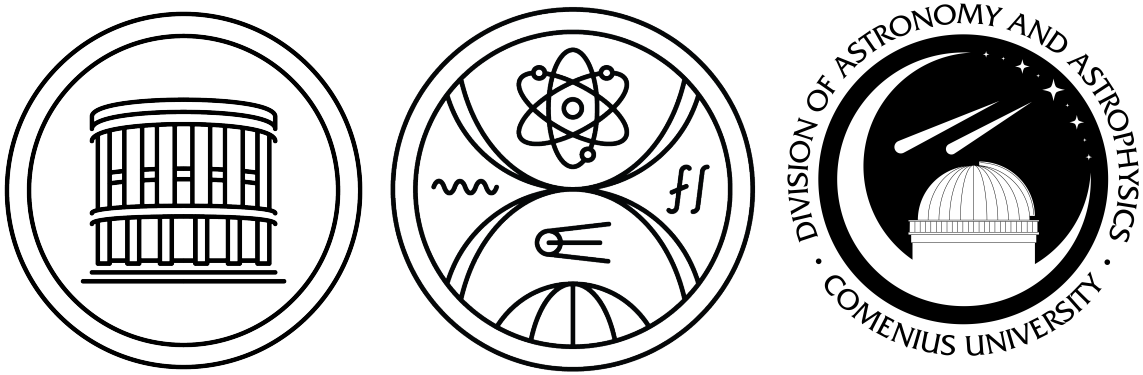

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Outline

The billion star surveyor

Gaia

The Global Astrometric Interferometer for Astrophysics was launched in 2013 as a successor of Hipparcos

Definite catalogue of the foreseeable future

Data collected by Gaia throughout its mission will be used to eventually build the most accurate three-dimensional map of the positions, motions, and chemical composition of stars in our Galaxy

Gaia data

EDR3 (3^{RD} of December 2020)

The full DR3 in will released in the 1^{st} half of 2022

- positions, parallaxes and proper motions for ~ 1.5 bil. stars
- photometry for 1.8 billion sources
- about 1.5 mil. celestial reference frame sources (quasars)
- cross-matches between EDR3 and: DR2, Hipparcos-2, Tycho-2, 2MASS PSC, SDSS DR13, Pan-STARRS1 DR1, SkyMapper DR1, GSC 2.3, APASS DR9, RAVE DR5, allWISE, and URAT-1 data on the other hand

Non-astrometric stellar parameters

- Non-astrometric stellar parameters could be appended via cross-matching Gaia data with other (spectroscopic, ...) surveys
- However, no other survey has such an immense database
- To add, for example ages to Gaia sources, we have to look for another method

Stellar age

With the the luminosity (calculable from Gaia data) could define star's position on the HR diagram, thus one can determine their type

Age determination from kinematic data

Almeida-Fernandes & Rocha-Pinto, (2018)

developed a method to determine stellar ages from peculiar velocities U, V and W and their eccentricities

- Velocity dispersion of a stellar group is larger, the older is the group (Rocha-Pinto, 2004)
- Result of gravitational perturbations experienced by the stars during their translations around the galactic center
- The Age-velocity dispersion relations can be approximated by laws of kind

$$\sigma(t) \propto bt^a$$

where t is the stellar age

The LSR and the (peculiar) motions

The Local Standard of Rest

Is a point that is always centered on the Sun and moves on a perfectly circular orbit around the Galactic center
(Or, the average motions of stars around the solar neighbourhood.)

The peculiar motions

The relative velocity of a star to the LSR is called *peculiar velocity*

Peculiar velocities from Gaia data

- The peculiar velocities U, V, W and their dispersions σ_U, σ_V, σ_W can be determined from astrometric parameters
- The parameters are: equatorial coordinates α and δ, proper motions in these coordinates μ_α and μ_δ, the parallax π and the radial velocities ρ - all are available in the Gaia data
- The trasformation formulas could be found in the following paper: Johnson, D.R. and Soderblom, D.R., 1987. Calculating galactic space velocities and their uncertainties, with an application to the Ursa Major group. The Astronomical Journal, 93, pp.864-867.

Determining the age-dispersion relation

The Age-velocity dispersion relations are of a kind $\sigma(t) \propto bt^a$

- The unknown parameters a and b are determined from a least-square fit to dispersions for each velocity component

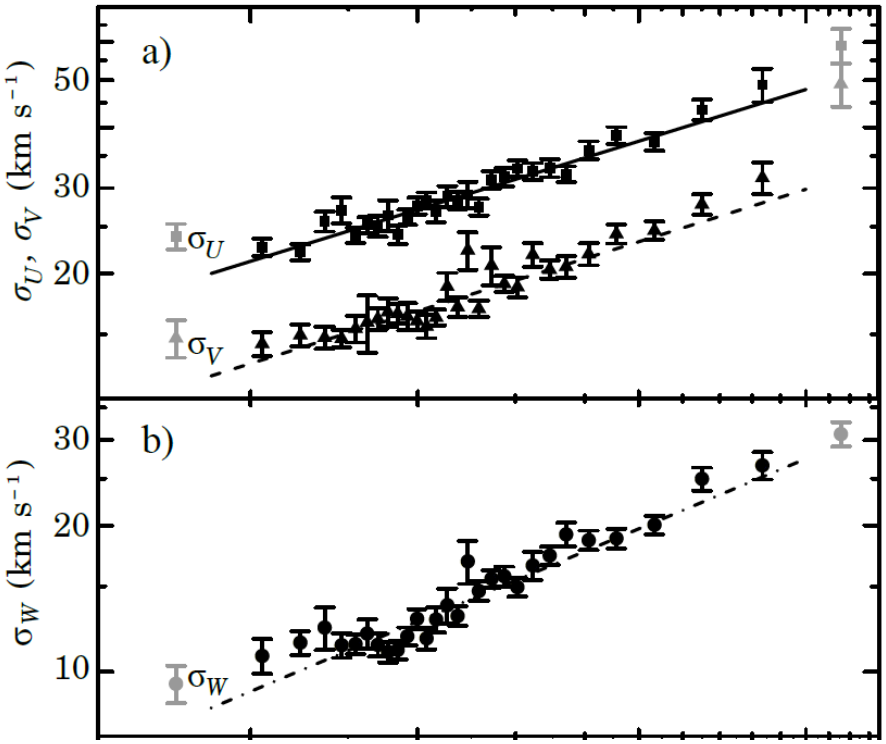


Figure: Velocity dispersion as a function of age. *Credit:* Almeida-Fernandes & Rocha-Pinto, (2018)

The velocity ellipsoid

The **line-of-sight velocity dispersion** is defined to be

$$\begin{aligned}\sigma_{\|}^2(\mathbf{x}_\perp) &\equiv \int \mathrm{d}v_{\|}\,(v_{\|}-\overline{v}_{\|})^2 F(\mathbf{x}_\perp, v_{\|}) \\ &= \frac{\int \mathrm{d}x_{\|}\mathrm{d}^3\mathbf{v}\,(\hat{\mathbf{s}}\cdot\mathbf{v}-\overline{v}_{\|})^2 f(\mathbf{x},\mathbf{v})}{\int \mathrm{d}x_{\|}\mathrm{d}^3\mathbf{v}\,f(\mathbf{x},\mathbf{v})}.\end{aligned} \tag{4.25}$$

The line-of-sight velocity dispersion is determined both by the variation in the mean velocity $\overline{v}_{\|}(\mathbf{x})$ along the line of sight, and the spread in stellar velocities at each point in the galaxy around $\overline{\mathbf{v}}(\mathbf{x})$. This spread is characterized by the **velocity-dispersion tensor**

$$\begin{aligned}\sigma_{ij}^2(\mathbf{x}) &\equiv \frac{1}{\nu(\mathbf{x})}\int \mathrm{d}^3\mathbf{v}\,(v_i-\overline{v}_i)(v_j-\overline{v}_j)f(\mathbf{x},\mathbf{v}) \\ &= \overline{v_i v_j}-\overline{v}_i\overline{v}_j.\end{aligned} \tag{4.26}$$

The velocity ellipsoid

The velocity-dispersion tensor is symmetric, thus at any point x we may choose a set of orthogonal axes $e_i(x)$ in which σ^2 is diagonal. The ellipsoid that has the diagonalizing coordinate axes $e_i(x)$ for its principal axes and σ_{11}, σ_{22} and σ_{33} for its semi-axis lengths is called **the velocity ellipsoid** at x.

The velocity ellipsoid - age determination

The equations in this method are simplified by working with the components of the velocity ellipsoid, $v1$, $v2$ and $v3$, instead of U, V, W.

$$v_1 = (U + U_\odot)\cos\ell_v + (V + V'_\odot)\sin\ell_v\,,$$
$$v_2 = -(U + U_\odot)\sin\ell_v + (V + V'_\odot)\cos\ell_v\,,$$
$$v_3 = W + W_\odot\,,$$

where

$$\ell_v = \frac{1}{2}\arctan\left(\frac{2\,\sigma_{UV}}{\sigma_U^2 - \sigma_V^2}\right).$$

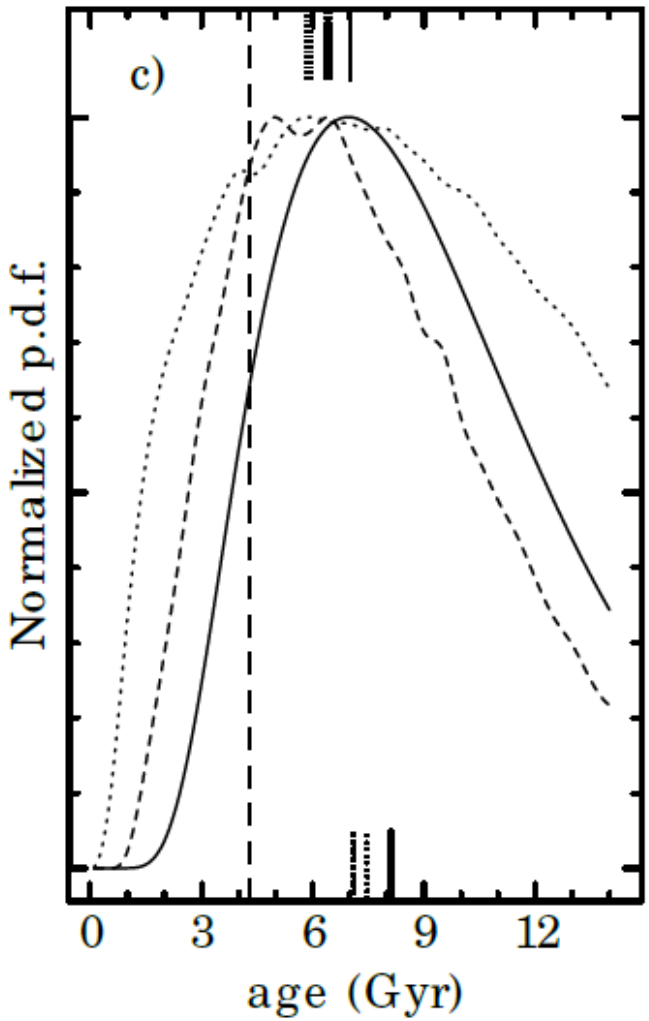
Age determination

- Finally, we build and age probability distribution function calculating the probability $p(t|U,V,W)$ for different ages
- Gaussian distribution is assumed, and probability is given as follows:

$$p(t|U,V,W) \propto \prod_{i=1,2,3} \left[\frac{1}{(2\pi)^{1/2}\sigma_i(t)} \exp\left(-\frac{v_i^2}{2\sigma_i(t)^2} \right) \right]$$

Age determination

Probability density function obtained by the method UVW (solid line), for four representative stars.The vertical marks at the top axis represents the most likely age for each method and those at bottom axis represents the expected ages. *Credit:* Almeida-Fernandes & Rocha-Pinto, (2018)



Summary

- This method allows a relatively quick determination of the most probable stellar ages from astrometric data
- However, radial velocities must be known
- Currently, only a fraction of Gaia data has radial velocities (~ 7 million objects)
- In the upcoming DR3 much more RVs will be released

Thank you for your attention