Dynamical traceback age of the β Pictoris moving group

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The age is a fundamental parameter to understand many astrophysical processes such as planet formation and disc evolution. We combined extremely precise Gaia DR2 astrometry with ground-based radial velocities measured in an homogeneous manner to trace the orbits of members of the β Pictoris moving group back in time and we determined a dynamical traceback age of $18.5^{+2.0}_{-2.4}$. We investigated the spatial substructure of the association at birth time and we propose the existence of a core of stars more concentrated. We also provide precise radial velocity measurements for 81 members of β Pic, including ten stars with the first determination of their radial velocities. Our dynamical traceback age is three times more precise than previous traceback age estimates and, more important, for the first time, reconciles the traceback age with the most recent estimates of other dynamical, lithium depletion boundary, and isochronal ages.

Context

Young local associations are small aggregates of stars
- **Shearing dynamical** properties and **chemical** composition
- With a **common origin**

Their youth and proximity allow a detailed study of their properties and constitute anchors to study the stellar formation and evolution process.

The **β Pictoris moving group** is one of the **closest** (~40 pc) and **richest** (~200 members) associations. Several discs, exoplanets, and exocomets have been confirmed to surround members of β Pic.

Dynamical ages have the advantage that are **independent of evolutionary models**. The main assumption is that the stars were formed together, in the past, at a time when the association was most concentrated.
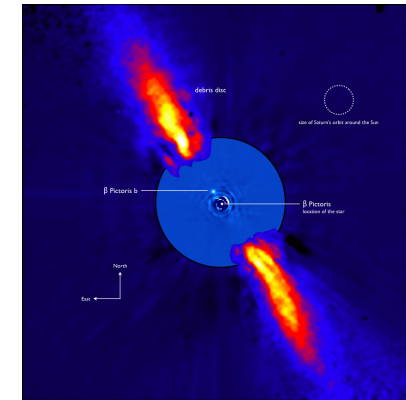
Composite image of the close environment of the β Pic star. The image shows a dust disc and a planetary mass companion.

Credit. ESO/A.-M. Lagrange et al.
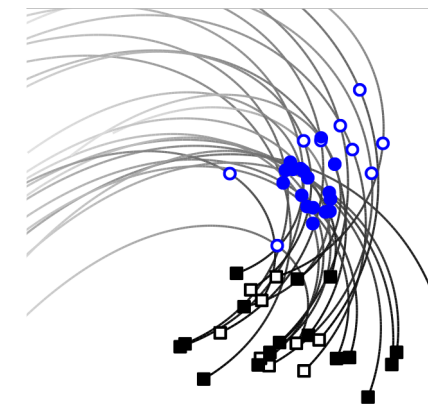
Membsers of β Pic. The stars were more concentrated at birth (blue) than in the present (black)

Methodology

1. Compilation of β Pic candidate members
2. Determine positions in the 6D space phase
   - **Gaia DR2 astrometry** → V_{tan} error = 0.05 km/s
   - Determine **uniform RV** → V_{rad} error = 0.3 km/s (our observations + archival data)
3. Select **kinematic members**
4. Integrate orbits of kinematic members with a **Galactic potential**
5. Orbital analysis:
   - find **time** when the association was **most concentrated in space**
   - study the **substructure at birth time**
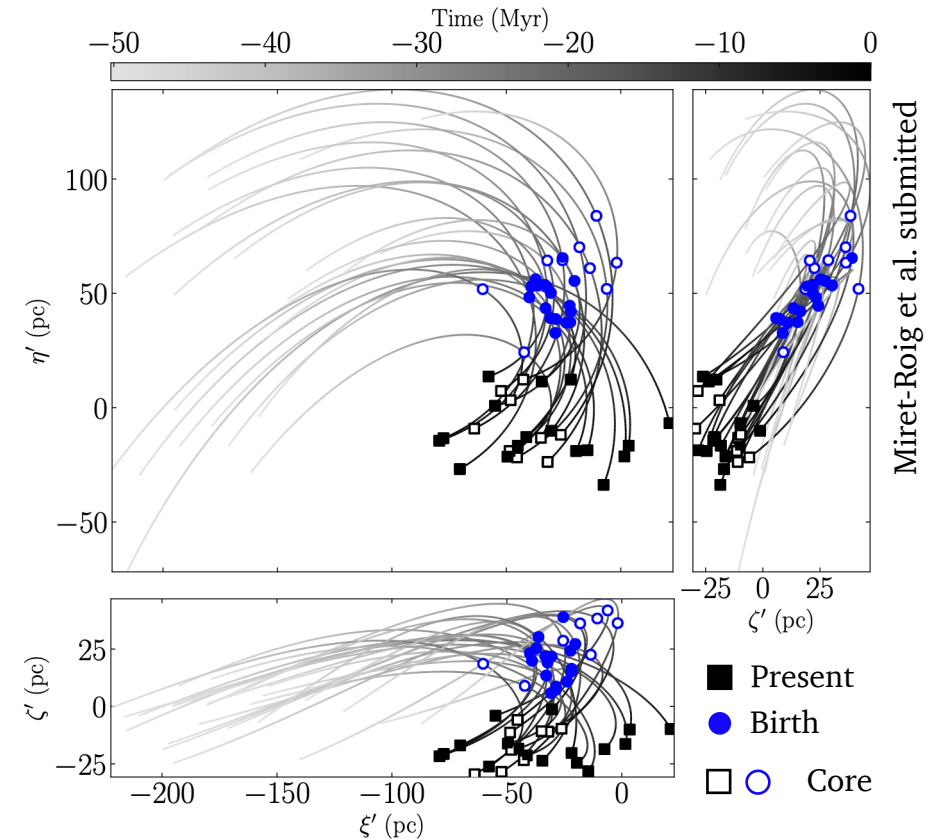
Orbital projection in the Galactic plane (top left) and in the two vertical planes (bottom left and top right) of our bona fide sample of 26 members of β Pic, integrated back in time 50 Myr, with a Galactic potential .

Results

We demonstrate that a **robust estimate of the covariance** matrix, which is **less sensitive to outliers*** in the dataset than a classical empirical covariance matrix, is fundamental to determine an accurate traceback age.
*sources which deviate from the central locus of the association which are not necessarily contaminants

The different **Galactic potentials produce differences** in the dynamical traceback age which are **smaller than the age uncertainties**.
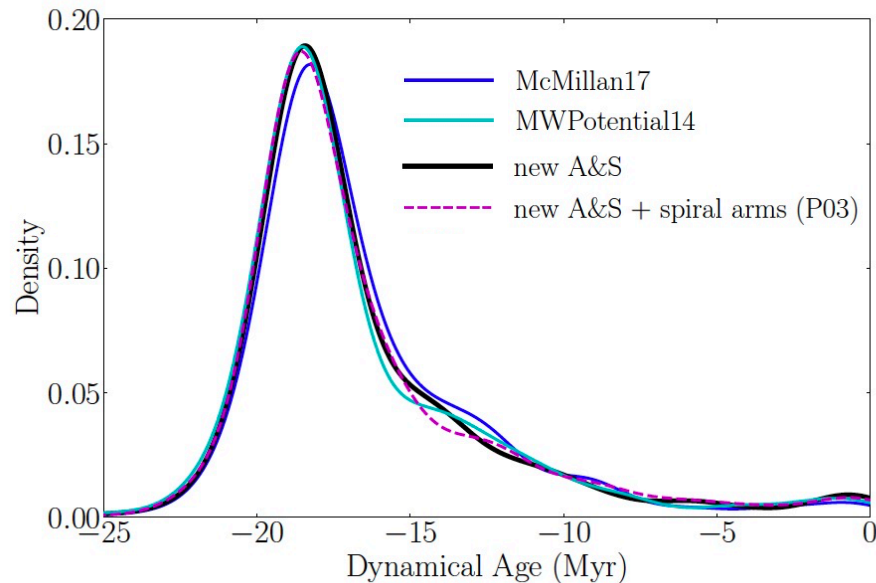
Dynamical age distribution of β Pic obtained with different axisymmetric Galactic potentials (solid lines) and with a Galactic potential with spiral arms (dashed line).

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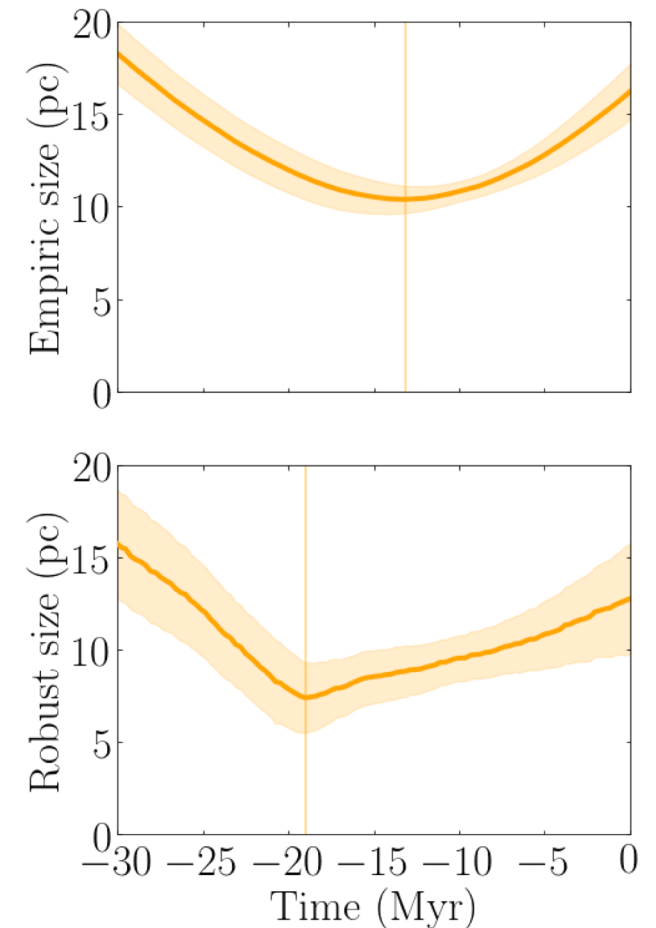
Size of the Pic association as a function of backwards time computed with the empirical covariance estimate (top) and the robust covariance estimate (bottom).

Impact and future prospects

We measured a **dynamical, traceback age** of the β Pic moving group of $18.5^{+2.0}_{-2.4}$ Myr. This is the **first traceback age compatible with ages based on evolutionary models** (i.e. lithium depletion boundary, isochrone fitting).

We **measured RV** for 81 members of β Pic in a **uniform manner**.

Our thorough orbital analysis allowed us to **propose the existence of a central core** of 17 stars which appeared more concentrate at birth time.

In the future, we plan to use these tools to **study other young local associations** to determine a precise **dynamical traceback age** and study their **internal structure**. This results are important to improve our understanding of **the star formation process**.