CHRONOSTAR: UNSUPERVISED, BLIND DISCOVERY AND AGEING OF STELLAR ASSOCIATIONS

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Jonah Hansen “... practically didn’t do anything” - J. Hansen
Murphy et al. 2015
MOTIVATION

• Vast majority of young-ish (<200 Myr) stars are unbound
• Kinematic analysis promises to find the origins of all these stars and assign an age
WE NEED A METHOD THAT

Can derive
• Initial location
• Initial distribution
• A consistent age

But also
• Is not sensitive to membership selection
• Can handle partial memberships
• Can handle complicated formation histories
• Is robust to measurement uncertainties
CLASSICAL APPROACH
EXPANSION AGES

\[ \frac{\text{km s}^{-1}}{\text{pc}} \sim \frac{1}{\text{time}} \]

BPMG
Mamajek and Bell 2014
<table>
<thead>
<tr>
<th>Reference</th>
<th>Age (Myr)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrado y Navascués et al. (1999)</td>
<td>20 ± 10 Myr</td>
<td>CMD isochronal age (KM stars)</td>
</tr>
<tr>
<td>Zuckerman et al. (2001)</td>
<td>$12^{+8}_{-4}$ Myr</td>
<td>H–R diagram isochronal age (GKM stars) + Li depletion</td>
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<tr>
<td>Ortega et al. (2002)</td>
<td>11.5 Myr</td>
<td>Traceback age</td>
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<tr>
<td>Song et al. (2003)</td>
<td>12 Myr</td>
<td>Traceback age</td>
</tr>
<tr>
<td>Ortega et al. (2004)</td>
<td>10.8 ± 0.3 Myr</td>
<td>Traceback age</td>
</tr>
<tr>
<td>Torres et al. (2006)</td>
<td>~18 Myr</td>
<td>Expansion age</td>
</tr>
<tr>
<td>Makarov (2007)</td>
<td>22 ± 12 Myr</td>
<td>Traceback age</td>
</tr>
<tr>
<td>Mentuch et al. (2008)</td>
<td>21 ± 9 Myr</td>
<td>Li depletion</td>
</tr>
<tr>
<td>Macdonald &amp; Mullan (2010)</td>
<td>~40 Myr</td>
<td>Li depletion (magnetoconvection models)</td>
</tr>
<tr>
<td>Binks &amp; Jeffries (2014)</td>
<td>21 ± 4 Myr</td>
<td>Li depletion boundary</td>
</tr>
<tr>
<td>Malo et al. (2014)</td>
<td>26 ± 3 Myr</td>
<td>Li depletion boundary</td>
</tr>
<tr>
<td>Malo et al. (2014)</td>
<td>21.5 ± 6.5 Myr (15–28 Myr)</td>
<td>H–R diagram isochronal age (KM stars)</td>
</tr>
<tr>
<td>This work</td>
<td>22 ± 3 Myr</td>
<td>CMD isochronal age (FG stars)</td>
</tr>
<tr>
<td>Final</td>
<td>23 ± 3 Myr (1σ)</td>
<td>Li depletion boundary and isochronal age (FGKM stars)</td>
</tr>
</tbody>
</table>

[±2 Myr (statistical), ±2 Myr (systematic)]
CHRONOSTAR
BAYESIAN APPROACH – TRACEFORWARD
SCORING THE MODEL

\[ p(C|D) \propto p_{\text{prior}}(C)p(D|C) \]

\[ p(D|C) \propto \prod_{i=1}^{N} \int N(\theta; \mu_i, \Sigma_i)N(\theta; \mu_c, \Sigma_c) \, d\theta \equiv \prod_{i=1}^{N} \Omega_{i,c} \]
Use synthetic data to test accuracy of this method

Generate stars from a 6D Gaussian (that matches assumptions)
Project them forward in time through the galactic potential
Measure stars in current epoch
  • Using median Gaia DR2 uncertainties as synthetic uncertainties

Variable star count, age, spread and velocity dispersion
SYNTHETIC RESULTS
BAYESIAN APPROACH
COMPARISON TO CLASSICAL TRACEBACK

True age = 50 Myr
Convert data to XYZUVW

n = n + 1

Initialise component parameters

Perform EM fit with n components

Calculate membership probabilities

Expectation

Maximise each of the n components

Maximise Comp A

Maximise Comp B

Maximise Comp C

Has fit converged?

No

Yes

Has extra component improved the BIC?

No

Yes

Return previous fit as the best fit
Chronostar's BPMG age: $17.8^{+1.2}_{-1.2}$ Myr

M&B14 age: $23 \pm 3$ Myr
SUMMARY

• Chronostar accurately and reliably retrieves kinematic ages from Gaussian initial conditions up to 100 Myr
• Can reliably decompose complicated combinations of synthetic associations
• First kinematic ages that are consistent with chemical ages
• Able to blindly rediscover BPMG (and Tucana Horologium!)
• Able to decompose massive, complicated associations with sensible results
• RVs not needed!
• Allow for **non-isotropic** initial velocity dispersion
• Methodically go through all known moving groups/associations and calculate kinematic ages from current membership lists
• Decompose large complicated associations (e.g. Sco-Cen)
• Improve performance (epicyclic approximations, action space)
• Search through all of Gaia DR2