The Ages of Massive Stars and Young Clusters from Rotating Stellar Models

Sagan Symposium

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κ And b, companion to B9 star

Carson et al., 2013, ApJL, 763, 32
“Planet:” $13 \ M_{\text{Jup}}$? $50 \ M_{\text{Jup}}$?
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Star: $30 \text{Myr}$? $200 \text{Myr}$?
“Planet:” 13 $M_{\text{Jup}}$? 50 $M_{\text{Jup}}$?
Star: 30 Myr? 200 Myr?

Based on **kinematics**, **H-R diagram placement**

Vega and Altair are rotating at \( \sim 90\% \) of critical

Monnier et al., 2007, Science, 317, 342
Stars $\gtrsim 1.5 \, M_\odot$ do not spin down

Rapid rotation:

1. Flattens the star
2. Produces large pole-equator differences in temperature
3. Extends stellar lifetimes
4. Increases stellar luminosity

Large rotating evolutionary grids are now available

Marginalized posterior probability distributions:
How much does it matter? **Case Study: the Hyades**

![Graph showing the Hyades case study with labeled points and axes: $M_v$ on the y-axis and $(B-V)$ on the x-axis.]

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Now do the Bayesian calculation

Each star: \( \mathcal{L}_{\text{star}}(M, Z, \tau, i, \Omega \mid \text{mags, } v \sin i, \varpi) \)

Marginalize over \( M, i, \Omega \Rightarrow \mathcal{L}_{\text{star}}(Z, \tau) \)

\[
\mathcal{L}_{\text{cluster}}(Z, \tau) = \prod_{\text{stars}} \mathcal{L}_{\text{star}}(Z, \tau)
\]

Prior on \( Z_{\text{cluster}} \) from FGK members \( \Rightarrow p(\tau) \)
Hyades and Praesepe

No Rotation

Praesepe

dp/dt (× constant)

V_T < 0.9
0.9 < V_T < 1.8
1.3 < V_T < 1.8
V_T > 1.8

All

Age (Myr)

500 600 700 800 900 1000
Hyades

Praesepe
Two Possibilities:

1. The Hyades formed over hundreds of Myr
2. The stellar models are wrong
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Rotation: a consistent picture at an older age
NGC 1806: LMC cluster

Doesn’t match any isochrone

Two possibilities:
NGC 1806: LMC cluster

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Two possibilities:

1. ~300 Myr age range
NGC 1806: LMC cluster

Doesn’t match any isochrone

Two possibilities:
1. \(~300\) Myr age range
2. Stellar models are wrong
Rotation is crucial for dating massive stars

1. Bayesian ages for your favorite *Hipparcos* A stars
2. Consistent ages in the Hyades, Praesepe
3. No need for age spread in LMC clusters

**Stellar evolution still has surprises!**

Thank you