Challenging Systems: Cautionary Tales in the Interpretation of Published Stellar Ages

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Take Home Messages

- Be a critical consumer of any inferred stellar ages. Ages are hard.
- Read the fine print
  - What method was used?
  - What are the the limitations of that method?
  - Are there other applicable methods that should be checked?

Why Are Ages Challenging?

- Ages are best determined where there is some age-related property that varies by a lot in the age and stellar mass regime you are interested in.
- If you are interested in an age range where no age-related property varies significantly, deriving a good age for your star will be “challenging”.
- The vast majority of known exoplanet host stars fall in the age regime where it is challenging to derive an accurate age estimate.

A Random Sample of EGP Host Ages

Table 1. Ages for Selected Exoplanet Host Stars

Name	Takeda age	Bryden Age	Saffe Age	Rotation Age	Holmberg Age
TauBoo	1.64 +/- 0.5	0.6	2.52/0.8		2.1 +/-0.4
51 Peg	6.76 +/- 1.5	7.3	6.6/2.2	5.0	6.0 +/- 2
mu And	7.6 +/- 4.5	6.7	5.3/2.3	2.5	3.1 +/- 0.3
55 CnC	> 7.2	7.2	5.5/1.2	7.0	
Rho CrB	11.0 +/- 0.8	4.5	6.9/8.5	3.7	10.4 +/- 1.5
HD177830	3.24 +/- 0.3	11.2	15.9/4.0	>9	
HD209458	2.44 +/-1.5	5.7	6.6 +/- 3	3.	4.4 +/- 1.5
HD 27442	2.84 +/- 0.5	10.9		>9	
HD 38529	3.28 +/- 0.3	5.8		5.7	
HD 69830	>12.	6.0		5.5	< 5.7

Takeda et al – ApJS 168, 297, 2007. YREC isochr. + SPOCS

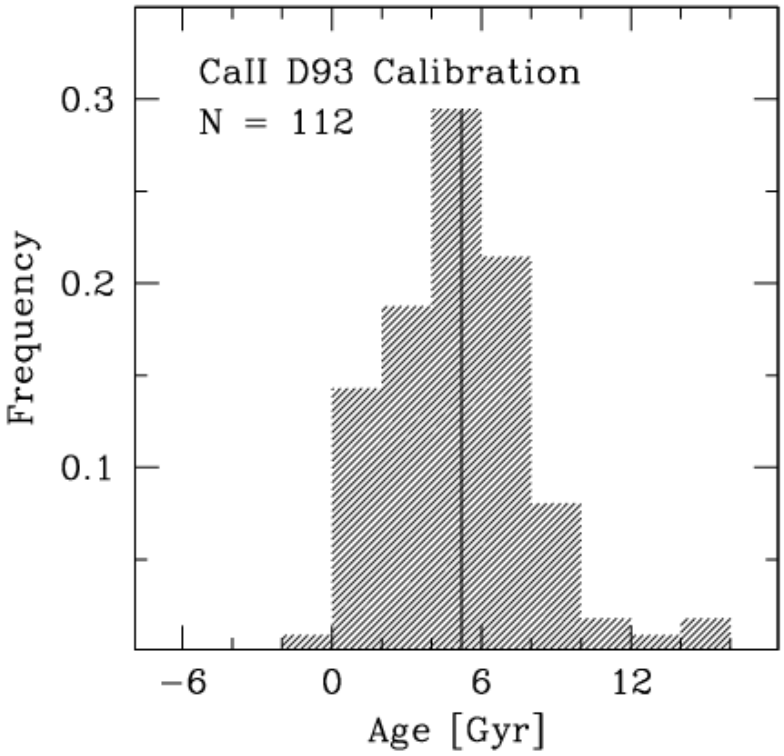
Bryden et al – ApJ705,1226,2009. R'HK + MH'08 calibration

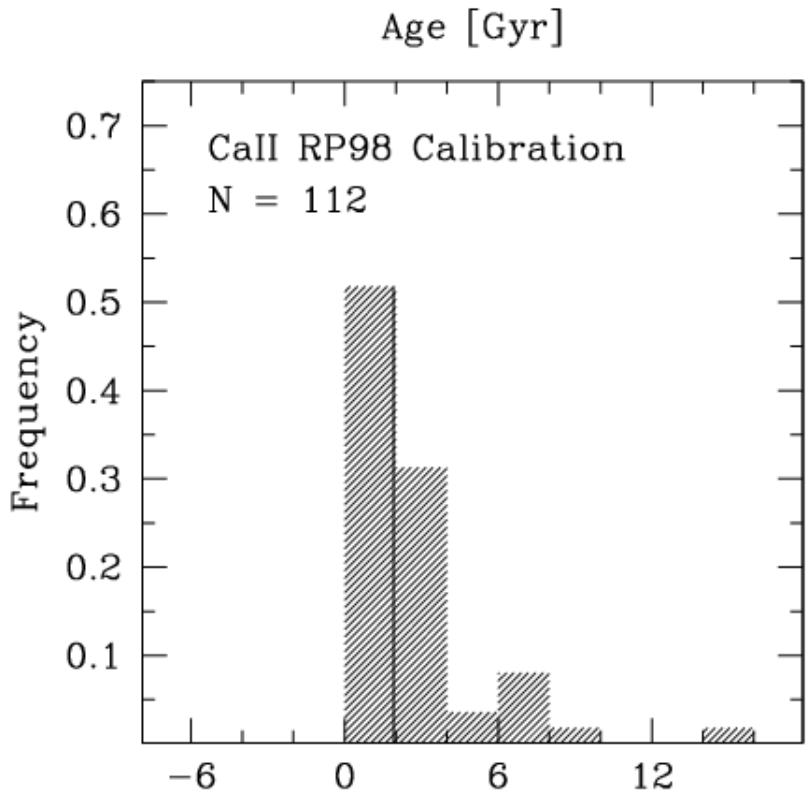
Saffe et al –AA443, 609, 2005. R'HK-D93 and RPM98 calib.

Rotation age – periods from Watson et al-astroph1006.2069, calibration from Mamajek&Hillenbrand(2008,ApJ687,1264)

Holmberg et al – AA 501, 941,2009. Geneva isoch + Stromgren

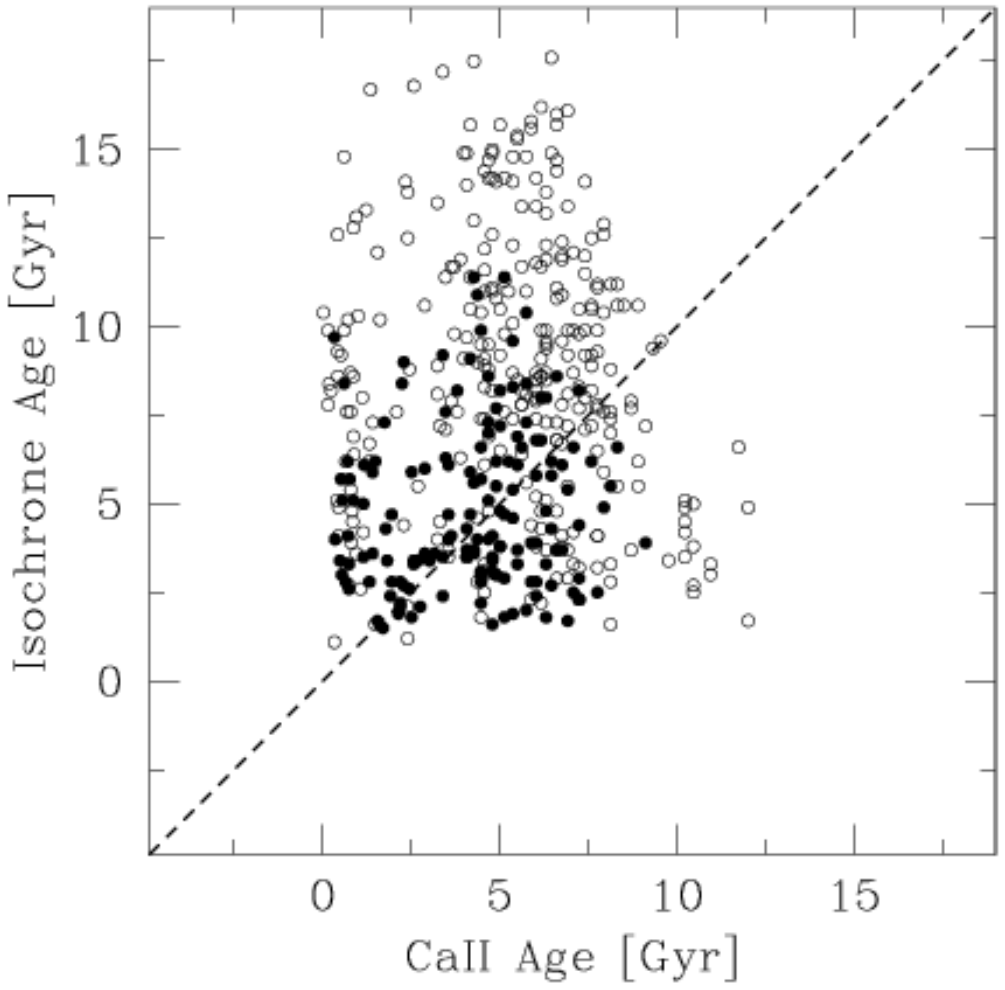
Calibration from Observable to Age is Critical, but Hard to Do





From Saffe et al (2005,AA443,609) – same set of exoplanet host stars, same R'hk data – different conversions from R'hk to age. RP98 incorporates Fe/H correction – imp. for EGP's

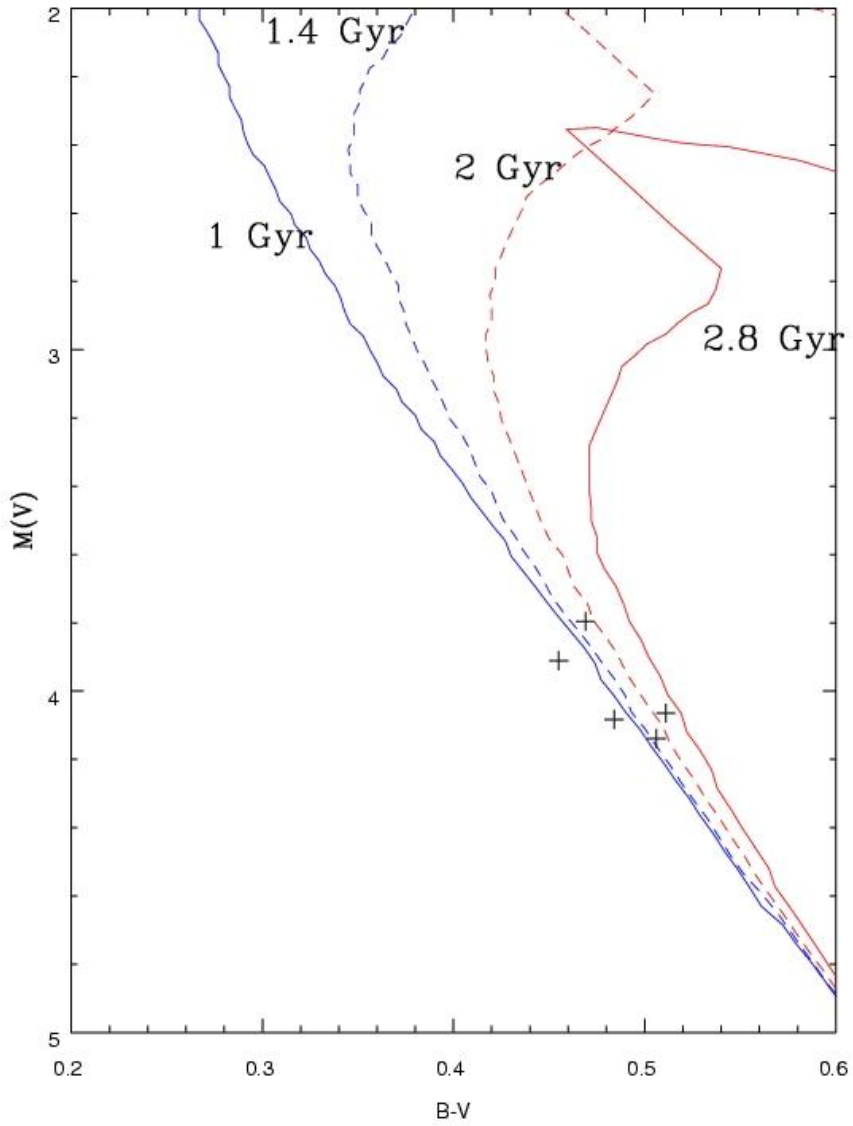
Agreement Between Isochrone and R'hk ages is not stunningly good



Source: Saffe et al, 2005,AA443,609.

Nordstrom – Geneva isochrone age; D93 calibrated R'HK ages. For a sample of FGK field stars.

F Star Rapid Rotators – Young, or Not?



I am working on a paper on a set of rapidly rotating late F stars. Based on my plot of Geneva isochrones, I think they have ages ~ 1 Gyr.

However, Holmberg etal(2009) find ages – using Geneva isochrones – of 3-5 Gyr?

How can that be?

My Fiducial System – the Pleiades

I take the Pleiades as a _mostly_ “solved” system –

- Age = 100-125 Myr from UMS turnoff and lithium depletion boundary
- Distance = 133 pc from HST trig. Parallax and from astrometric binaries (and MS fitting)
- Fe/H = solar

Can therefore use observations of the Pleiades as an empirical 100 Myr fiducial to compare to other objects. Can similarly use Hyades or Praesepe data as fiducials for 650 Myr objects.

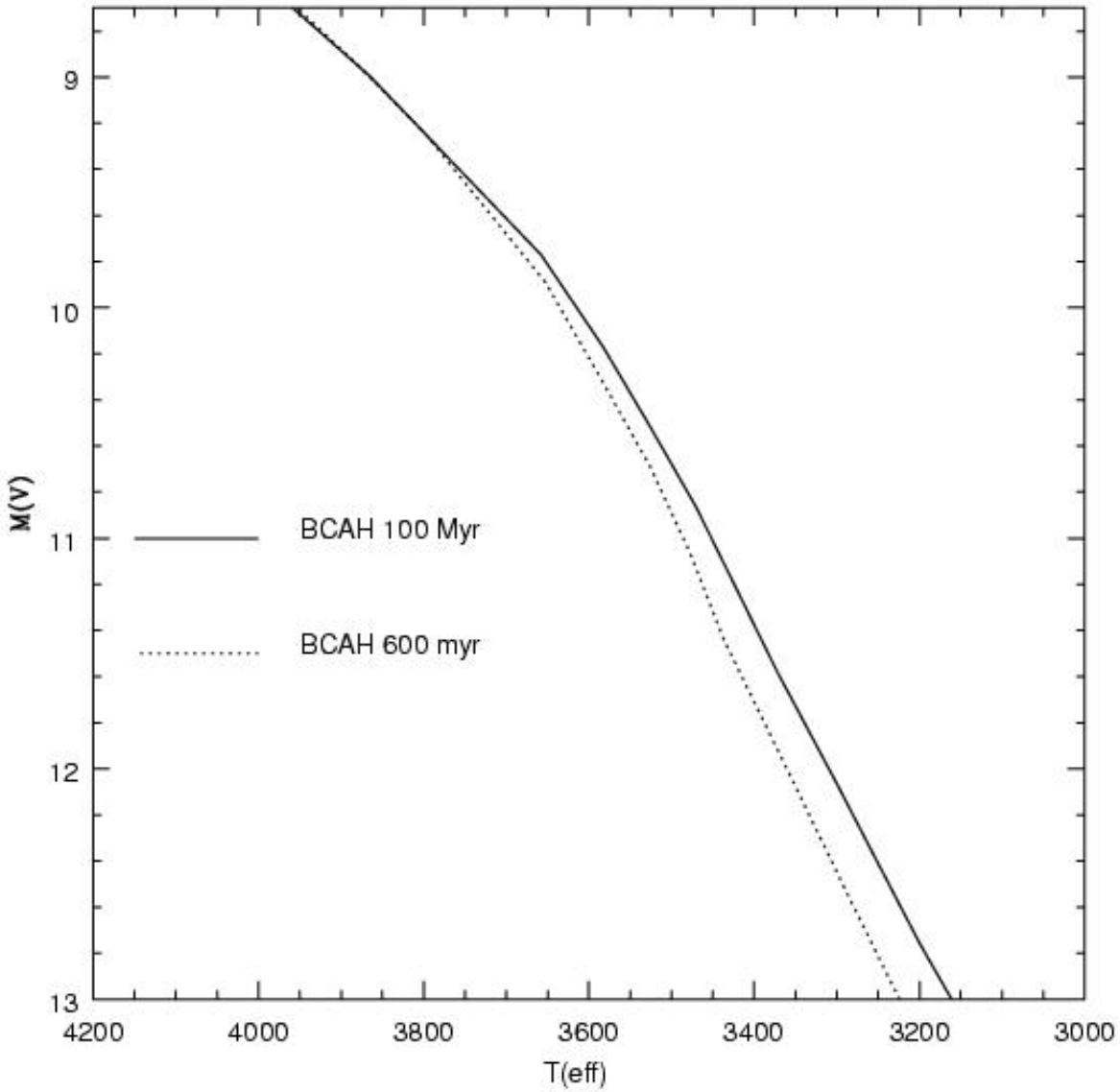
Solving Age Challenges by Direct Empirical Comparisons to "Known" Systems

In many cases, it is sufficient to compare the properties of your star of uncertain age with properties of open cluster stars of different "known" ages.

This allows you to at least say "this star probably has an age between about X and Y"

However, even the fiducial open clusters have some challenges in the interpretation of their relative ages.

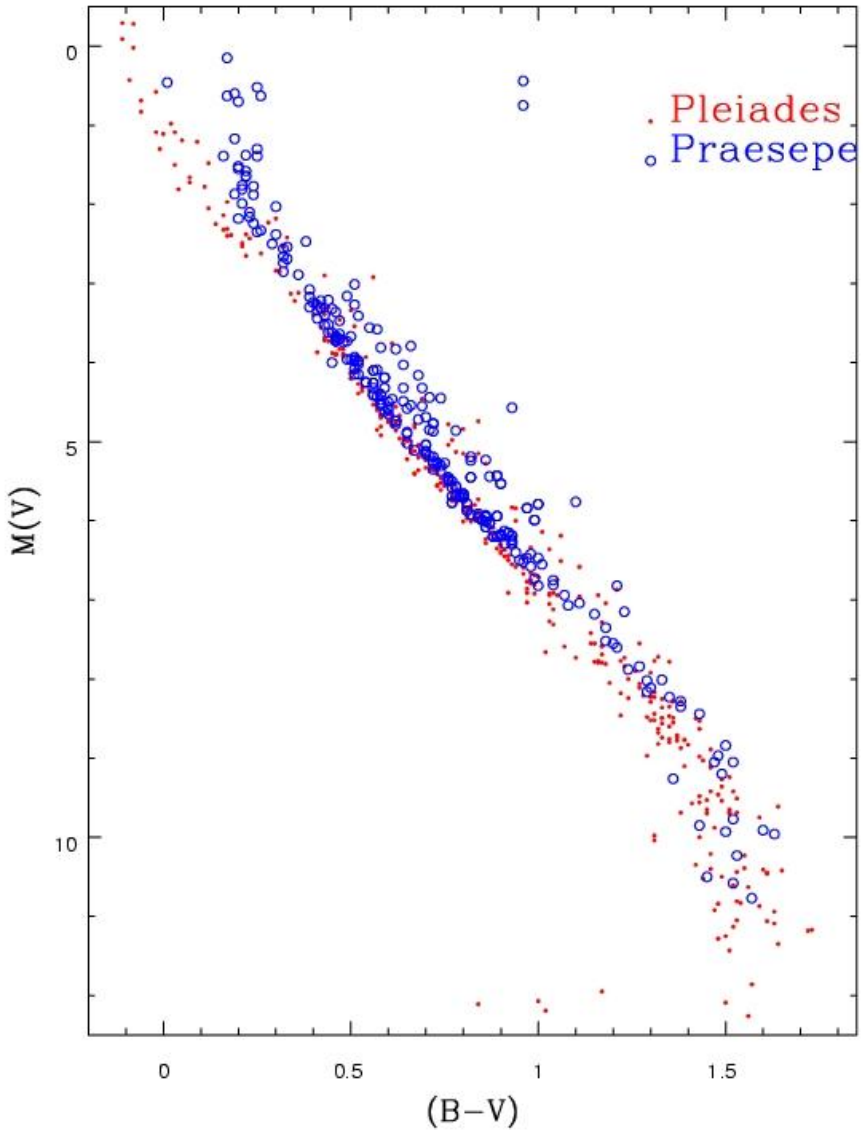
Even the Pleiades can be Challenging



Expect PMS turnon point at Mv~9.5

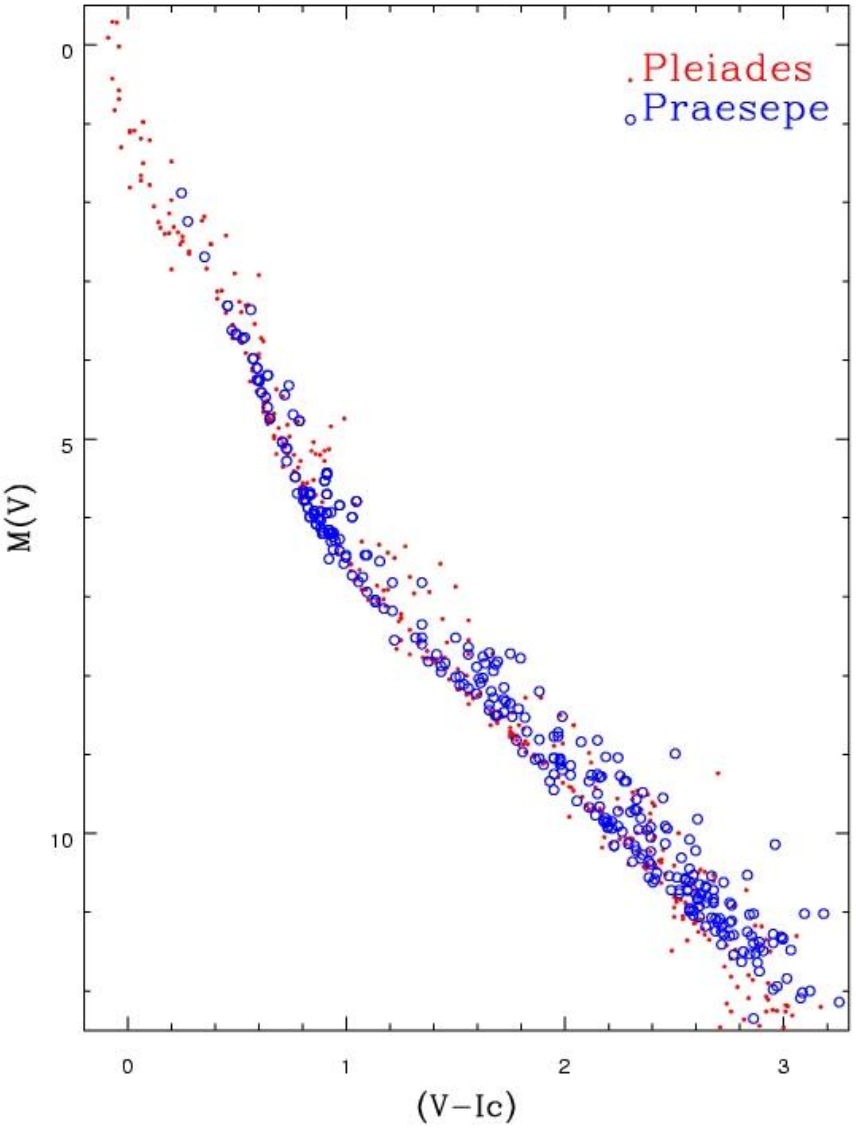
Pleiades single-star locus at Mv~12 should lie ~0.4 mag above Praesepe single star locus.

But - Even the Pleiades has some Challenges



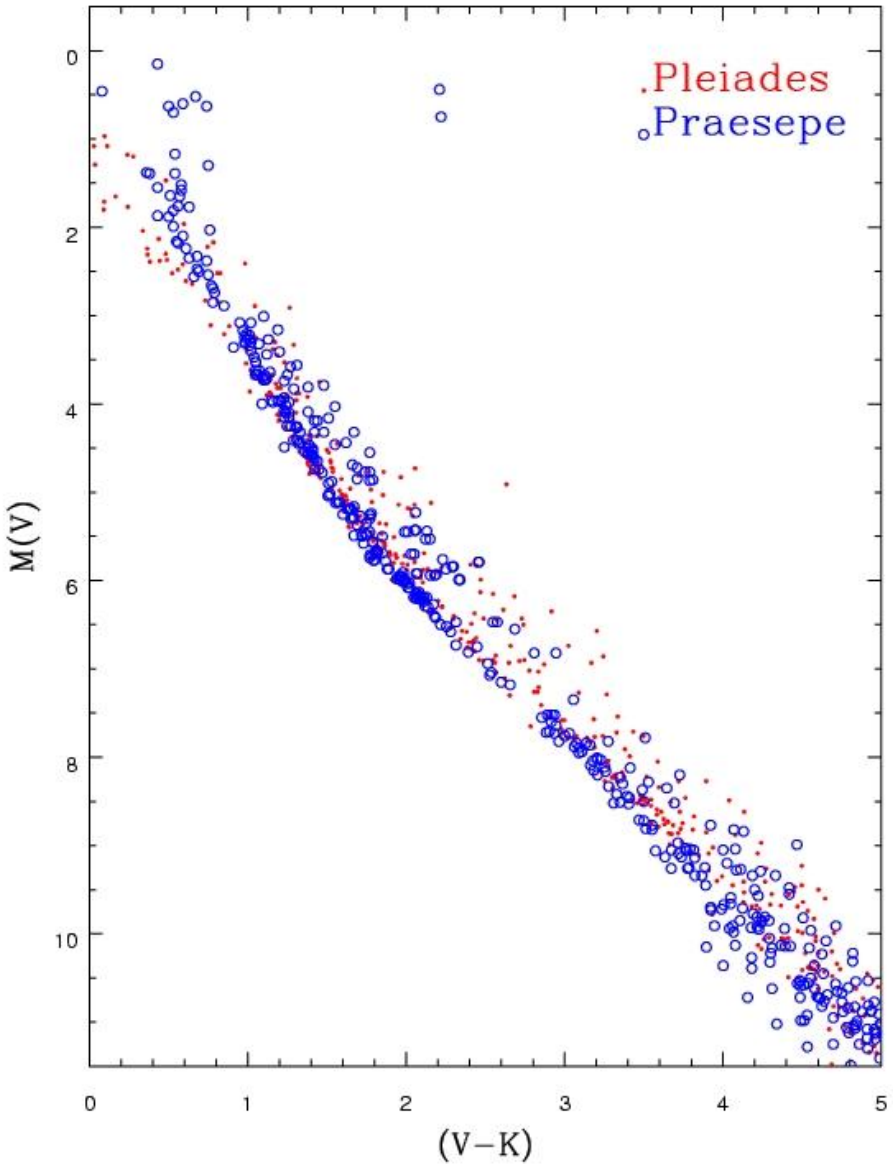
In an Mv vs. B-V diagram, instead see Pleiades stars fainter than Mv ~6.5 fall systematically BELOW the Praesepe sequence.

But - Even the Pleiades has some Challenges



In an Mv vs. V-I diagram, instead see Pleiades Praesepe sequences are essentially coincident to Mv ~ 11.

But - Even the Pleiades has some Challenges



In an Mv vs. V-K diagram, the Pleiades sequence begins to systematically fall above the Praesepe sequence above Mv ~8.

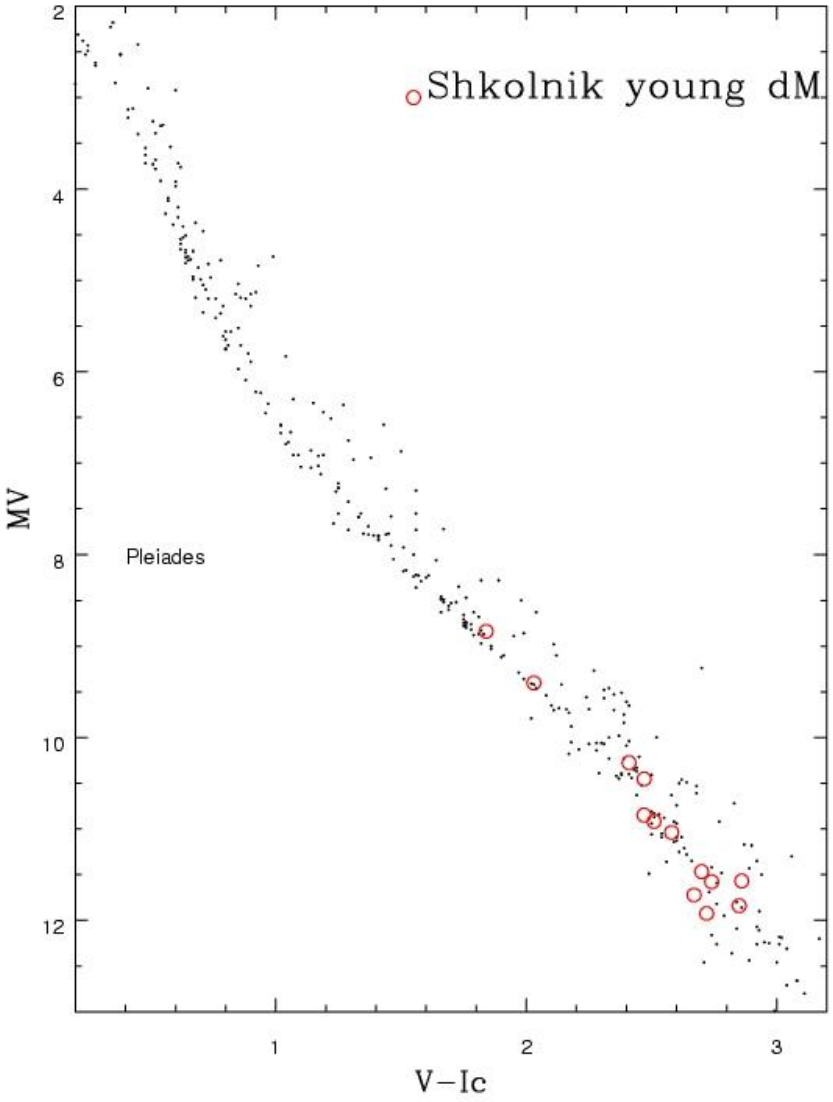
Conclusions re: Pleiades Isochronal Age

- The Pleiades K and M dwarfs are rapidly rotating compared to older stars
- Their rapid rotation induces chromospheric activity and a high covering factor for spots and plages
- Both factors cause the SEDs of these stars to differ from old stars of the same Teff
- There is no straightforward way to therefore determine an accurate PMS age for the cluster (or any similar age cluster)
- This doesn't prevent one from using young clusters as empirical age fiducials.

Comparison to Fiducial Clusters

- Even if we do not entirely understand how “activity” is affecting the colors and radii of young, low mass stars – can still use open clusters of “known” age as fiducials.
- Example:
  - Shkolnik et al (ApJ 699, 649, 2009) identified 185 young, low mass stars within 25 pc.
  - Their age estimates were derived from spectroscopic youth indicators (surface gravity, lithium, and H alpha)
  - They did not use CMD location, however.

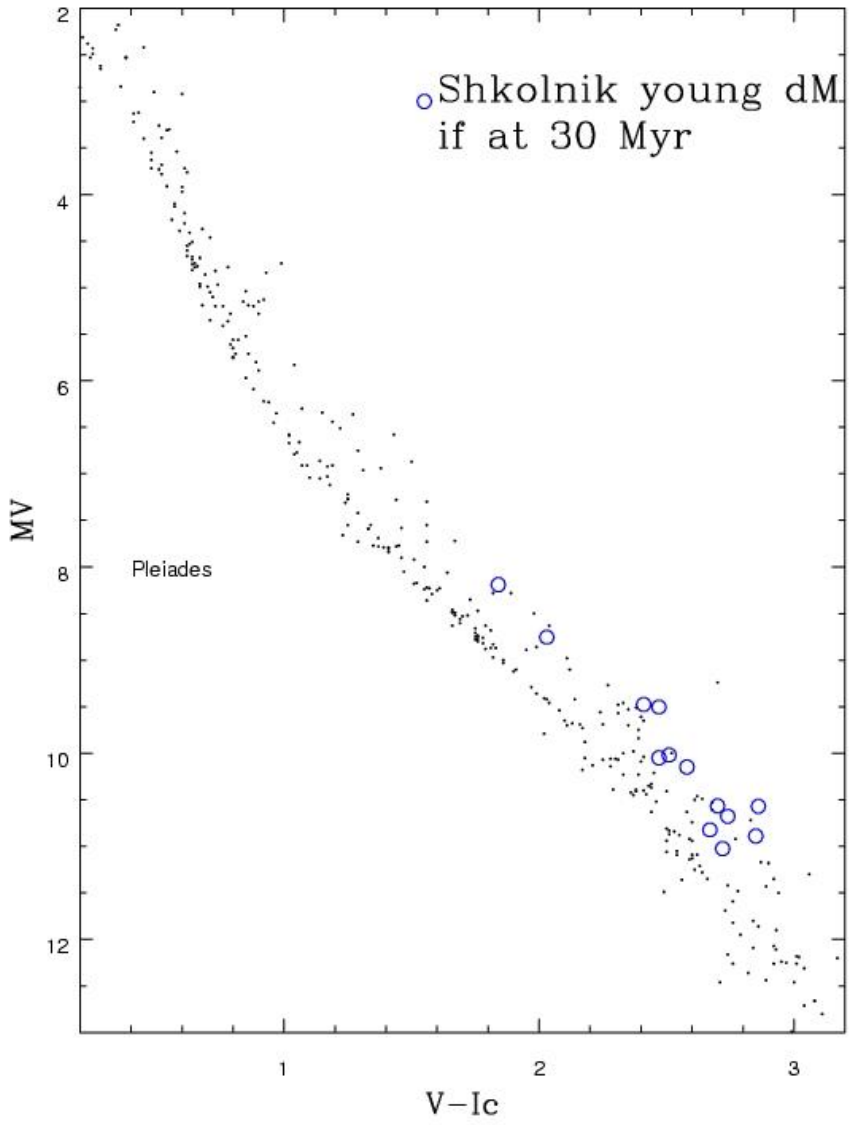
Empirical Comparisons Are Sometimes Enough



All of the red open dots are young, field stars from Shkolnik et al with listed minimum ages of <40 Myr

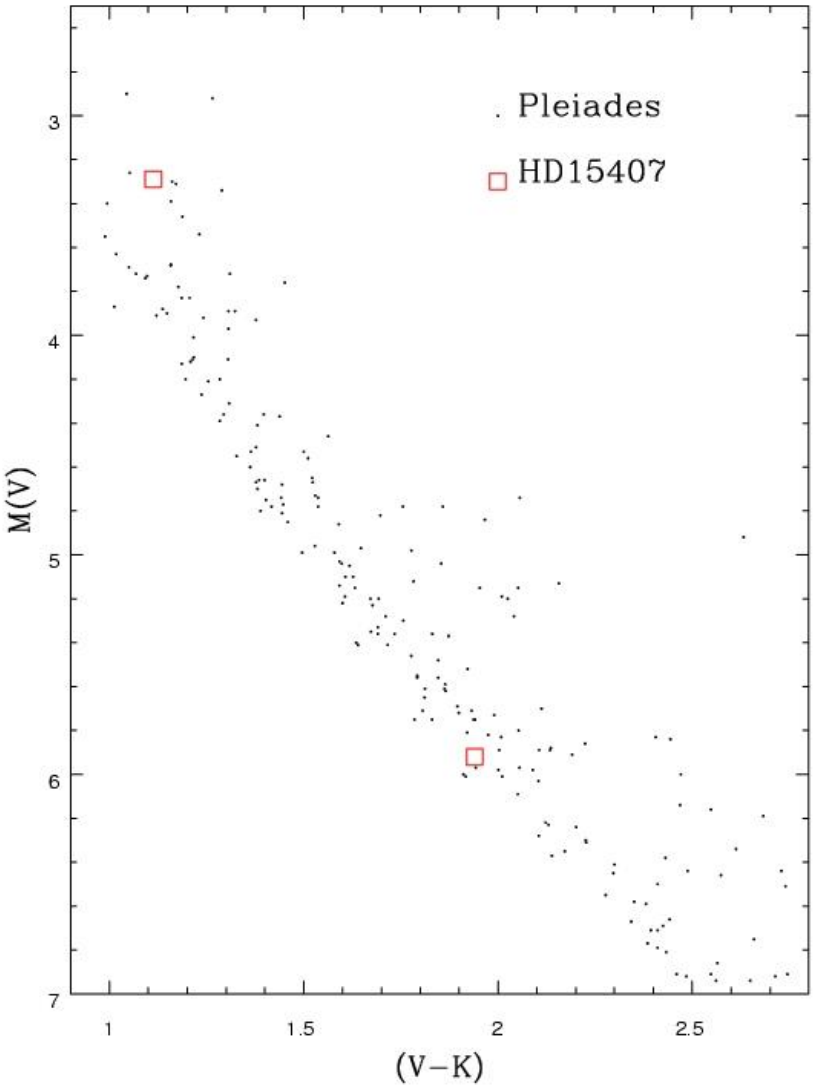
Based on the location of these stars in the CMD relative to the Pleiades, most of these stars are on or below the Pleiades single star locus – and hence their minimum age ~ 100 Myr.

Empirical Comparisons Are Sometimes Enough



The blue open dots show where the Shkolnik stars would be if at 30 Myr.

Empirical Comparisons Can Help Interpret Apparent Anomalies



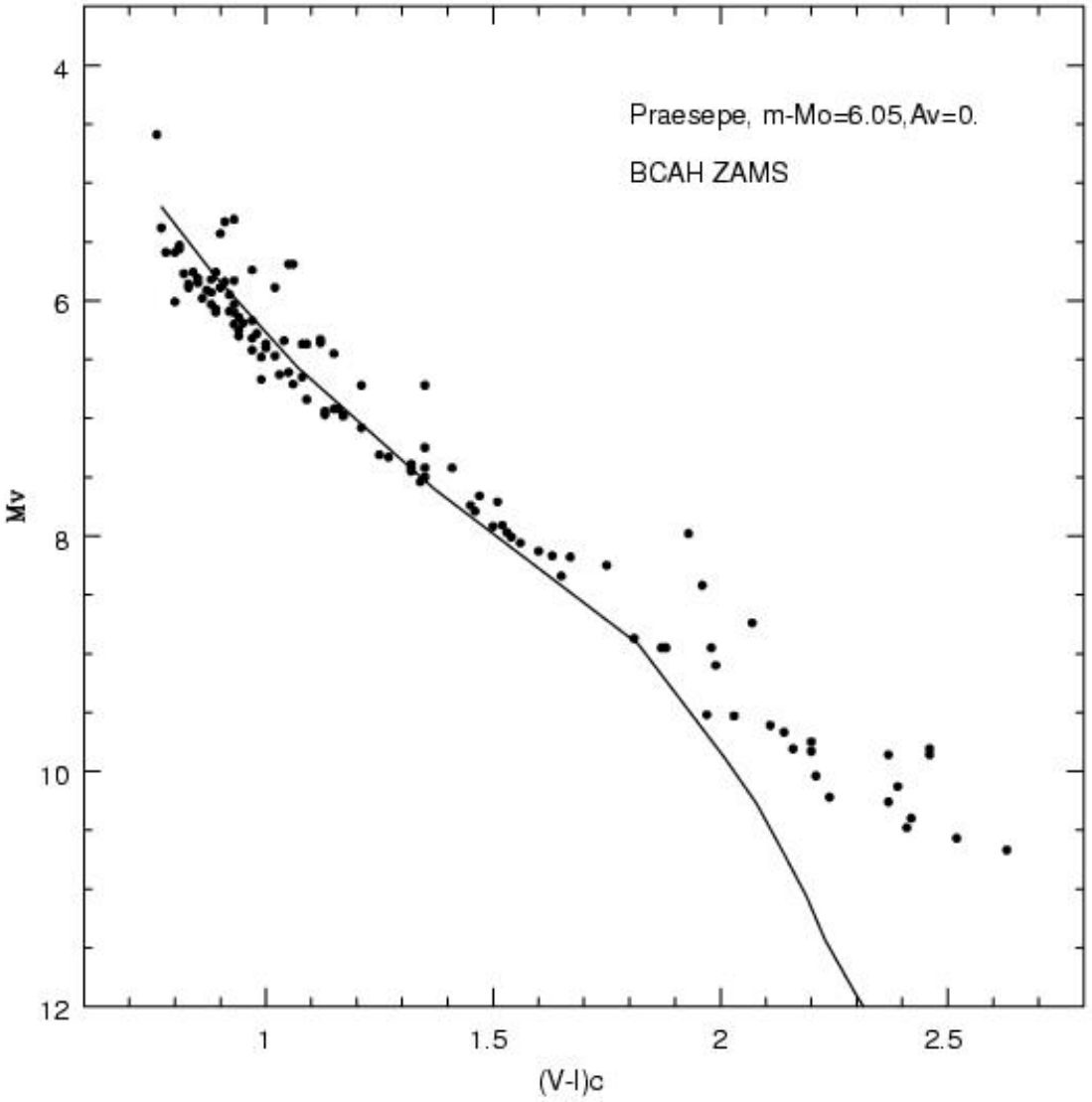
Melis et al – astroph1005.2451

HD15407 – a binary system where the primary has a large 24 micron excess. Age ~80 Myr from lithium and xrays.

BUT – no mention of CMD location of A and B in paper.

A is itself a close binary?

Use Due Care when Interpreting Comparisons to Theoretical Isochrones



Theoretical isochrones are much better than they used to be – but they are still not perfect.

The BCAH ZAMS does not match an empirical ZAMS in Mv vs. V-I. No reason to expect it to work at young ages.

Is the Age of the Beta Pic Moving Group 12 Myr or 40 Myr old?

- The most commonly quoted age for the Beta Pic moving group is about 12 Myr, based on location of its stars in an HR diagram (Zuckerman et al 2001). Lithium data for the M dwarfs in the group however seem to favor an older age (Yee and Jensen, ApJ 711, 303, 2010)
- However, MacDonald and Mullan (astroph1006.1308) have recently proposed an age of 40 Myr, based on new PMS evolutionary models which incorporate a prescription for how B fields might inhibit convection in low mass stars, thereby increasing their radii and reducing their lithium depletion. By tuning the amount of convective inhibition, they can bring the lithium and CMD age into agreement – at about 40 Myr.

Is the Age of the Beta Pic Moving Group 12 Myr or 40 Myr old?

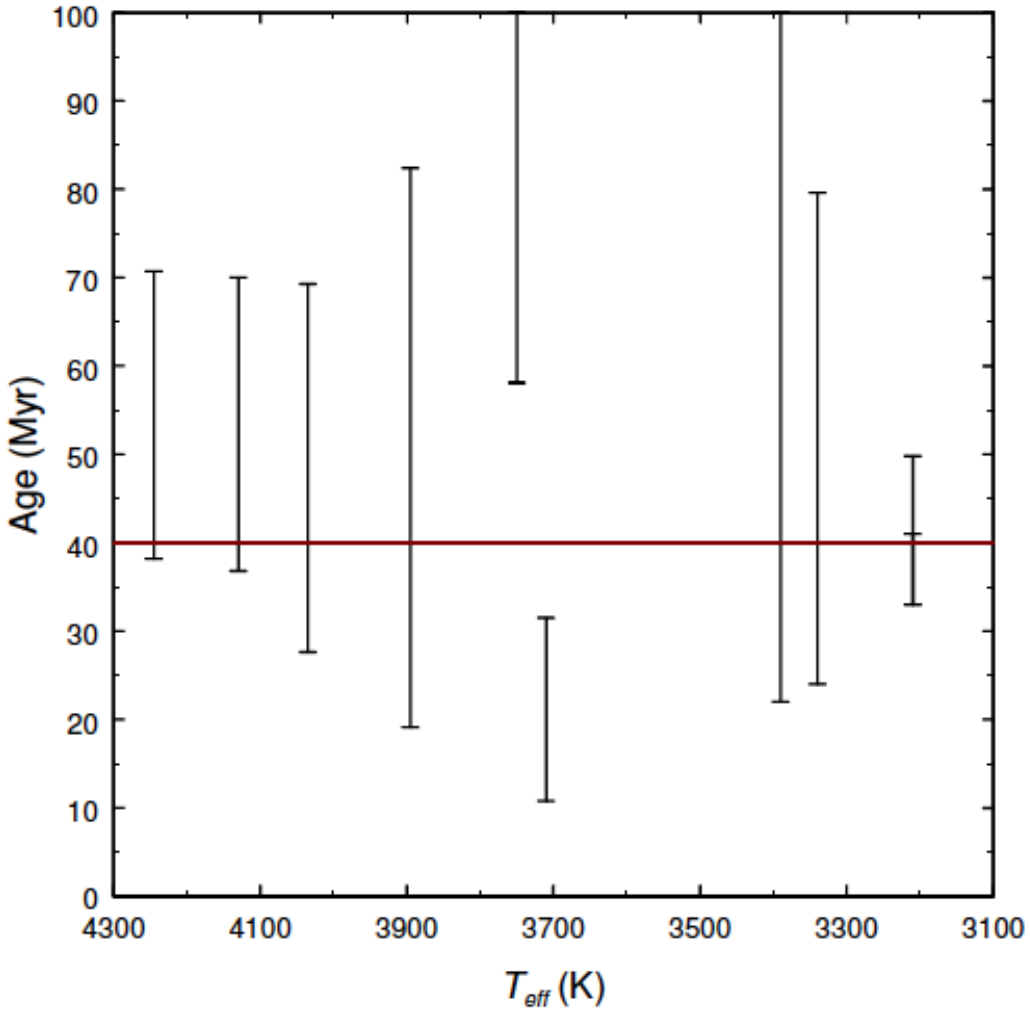


Fig.7 of MacDonald and Mullan 2010. The age is their best fit to the CMD and Lithium age for the star based on tuning the amount of B field inhibition of convection.

Is the Age of the Beta Pic Moving Group 12 Myr or 40 Myr old?

- There is, however, another way to estimate the age of the Beta Pic moving group – and it is one of the "Semi-Fundamental" methods mentioned by Soderblom. This other method is kinematic traceback.
- Moving groups are unbound, but are moving with nearly the same space motion. Can traceback their positions to a time when they are closest in space – i.e. when the association from which they were born was disrupted (the gas removed).
- The traceback age for the Beta Pic moving group is 11.5 Myr (Ortega et al. 2002), when the cluster members fit within a sphere three times smaller in radius than at the present epoch.
- I think this age "trumps" the others – making it unlikely that B fields have nearly as much effect as predicted in MM2010.

Conclusions

- Each age estimation technique has its own strengths and weaknesses. It is good to try them all – but then use their products with due care. Which technique is best depends on the star's mass, age, distance, etc.
- Ages are, unfortunately, just really hard to determine accurately for most of the stars in the sky. Ages for M dwarfs will be even harder than for FGK dwarfs.
- The good thing about this for those attending this workshop is that it means there is a lot of room for improvement in the published ages of stars.
- GAIA may help a lot.
- The bad thing is that even with better data, ages will remain very hard to determine accurately for most stars for the forseeable future.

Reserve slides