Deep Photometry of Open Clusters

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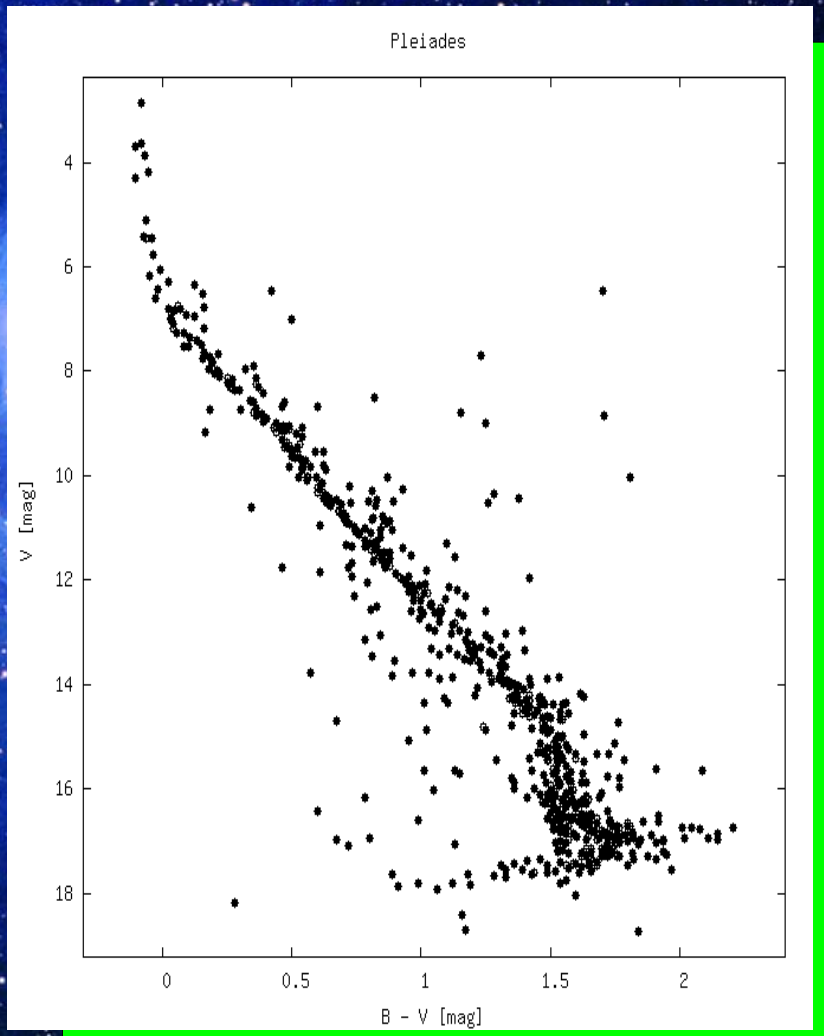
Stellar Clusters

- *Significant number of stars*
- *Same origin (age, composition)*

Stellar Clusters

- *Significant number of stars*
- *Same origin (age, composition)*

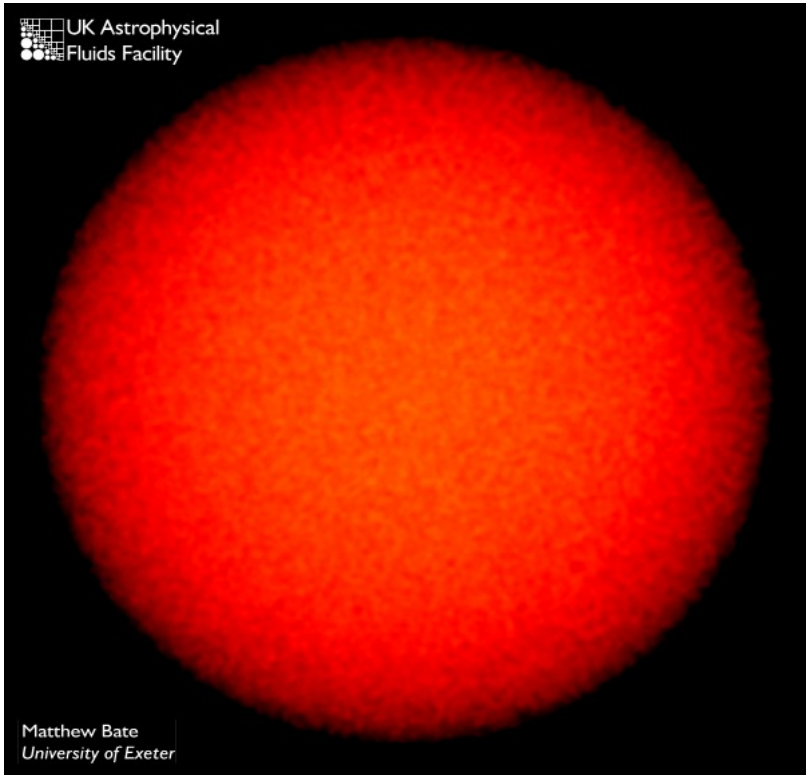
- *Wide span of mass and luminosity*
- *Outcome of Star Formation*



Star Formation

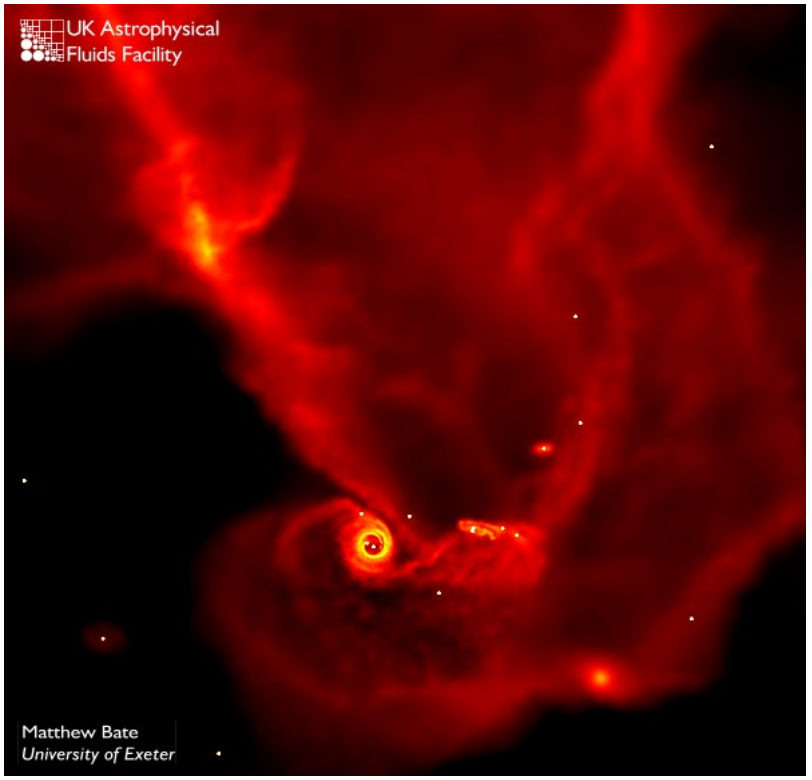
The Bate, Bonnell, Bromm 2003 Simulation - 1

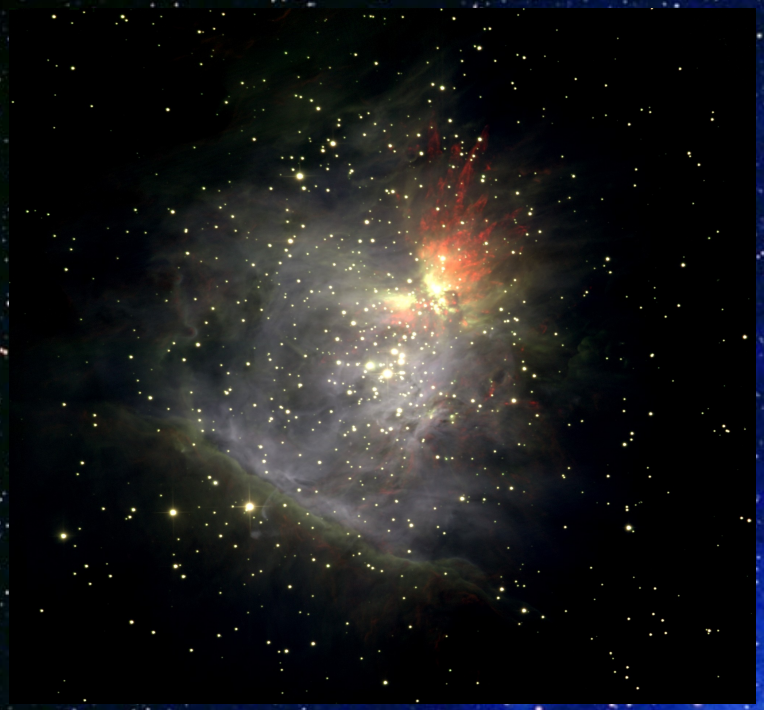
- Matthew Bate, Ian Bonnell, and Volker Bromm [MNRAS 339, 577, 2003] have calculated the collapse of a 50 Msun cloud core with a diameter of 0.375 pc.
- The cloud is turbulent.
- The simulation runs for 266,000 years.
- It was carried out on the UK Astrophysical Fluid Facility, and required 100,000 CPU hours, about 10% of the total time available during one year.

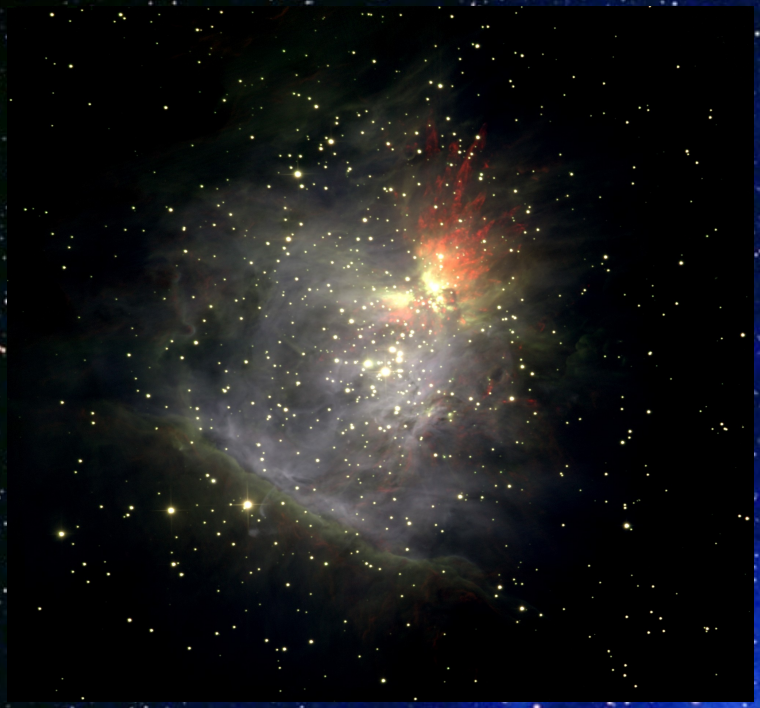


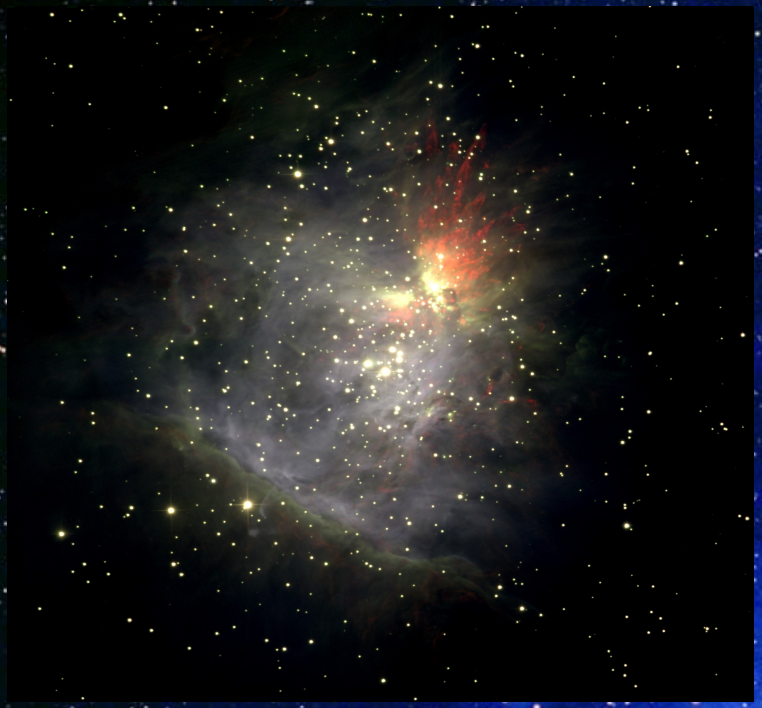
The Bate, Bonnell, Bromm 2003 Simulation - 15

- The simulation was terminated after 266,000 years.



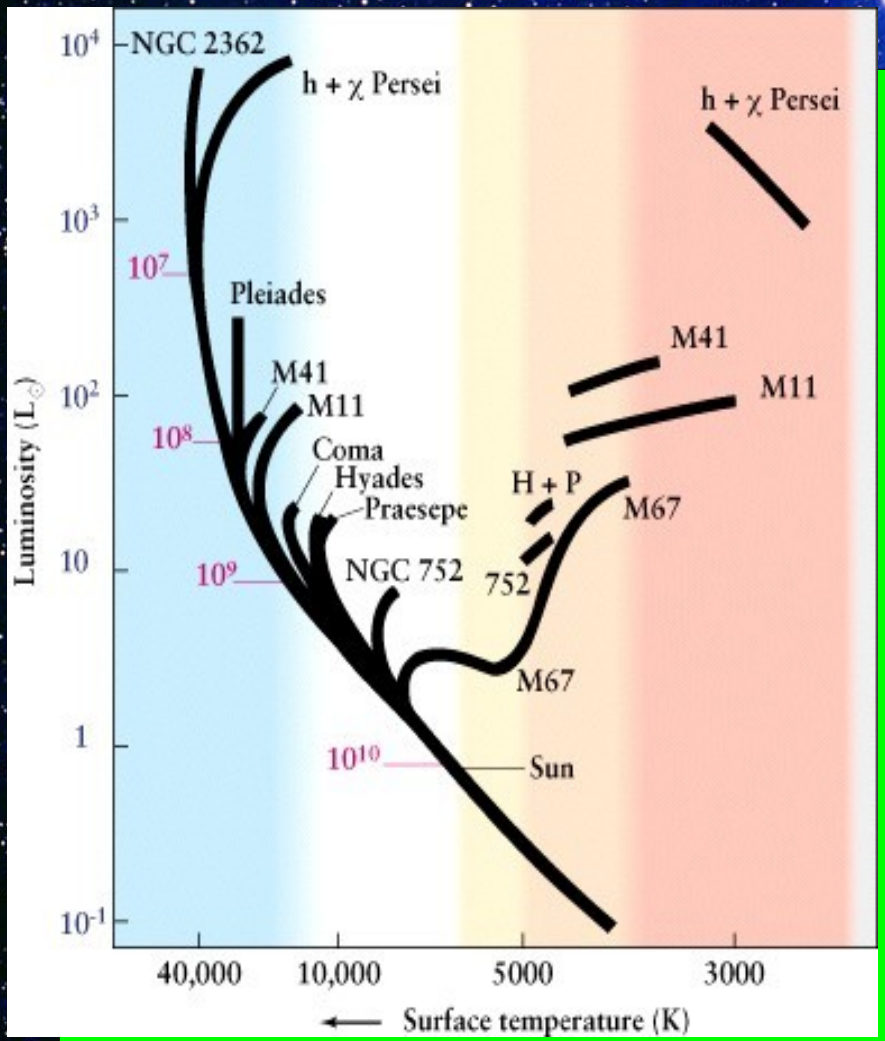


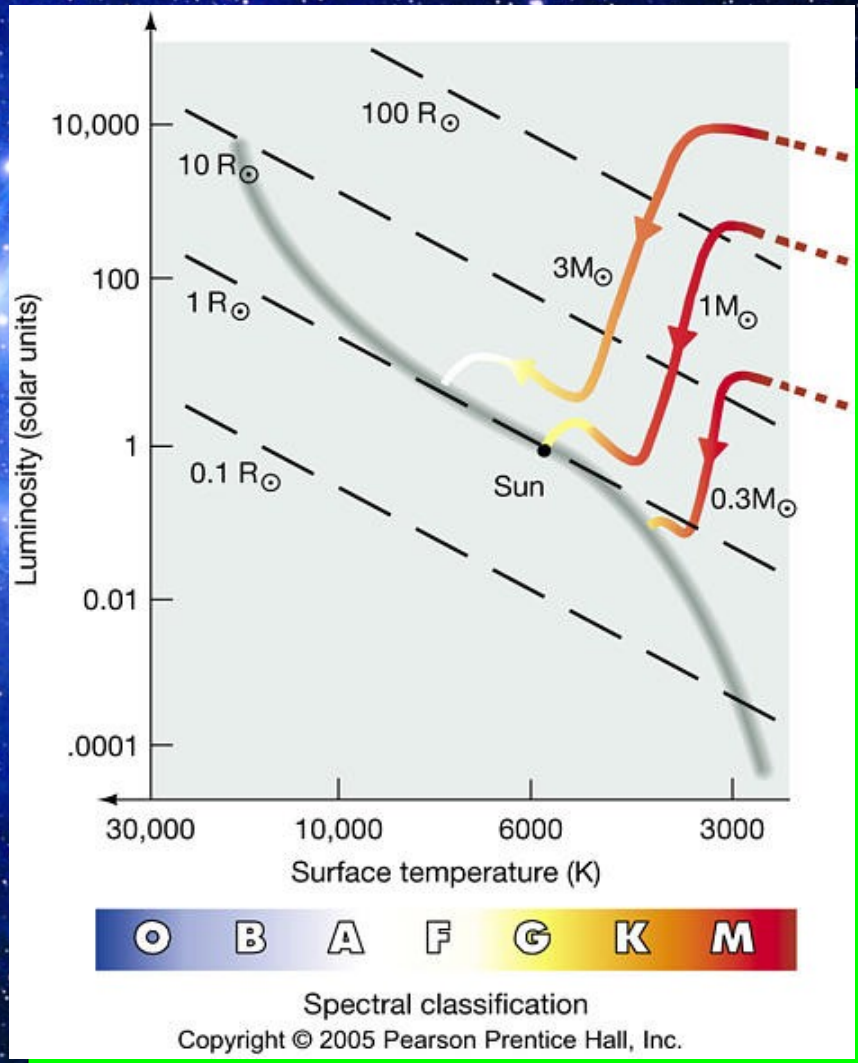




The Pleiades Problem

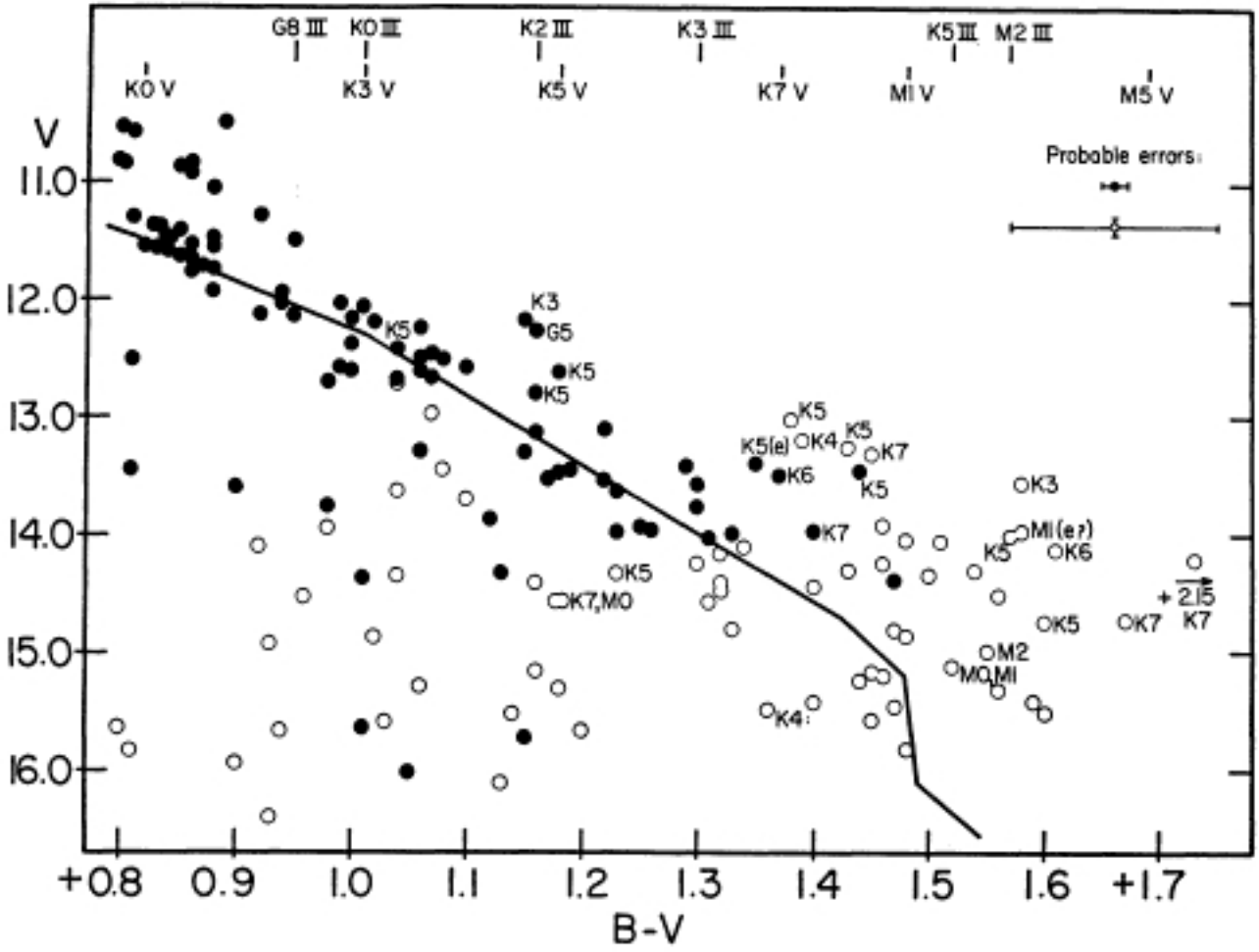
- Dating problem - turn-off and turn-on ages should be the same





The Pleiades Problem

- Dating problem – disagreement between high and low mass stars



- Herbig (1962)

Nuclear age
60 Myr

Contraction age
>220 Myr

Herbig, G.H.,1962, ApJ, 135, 736

The Pleiades Problem

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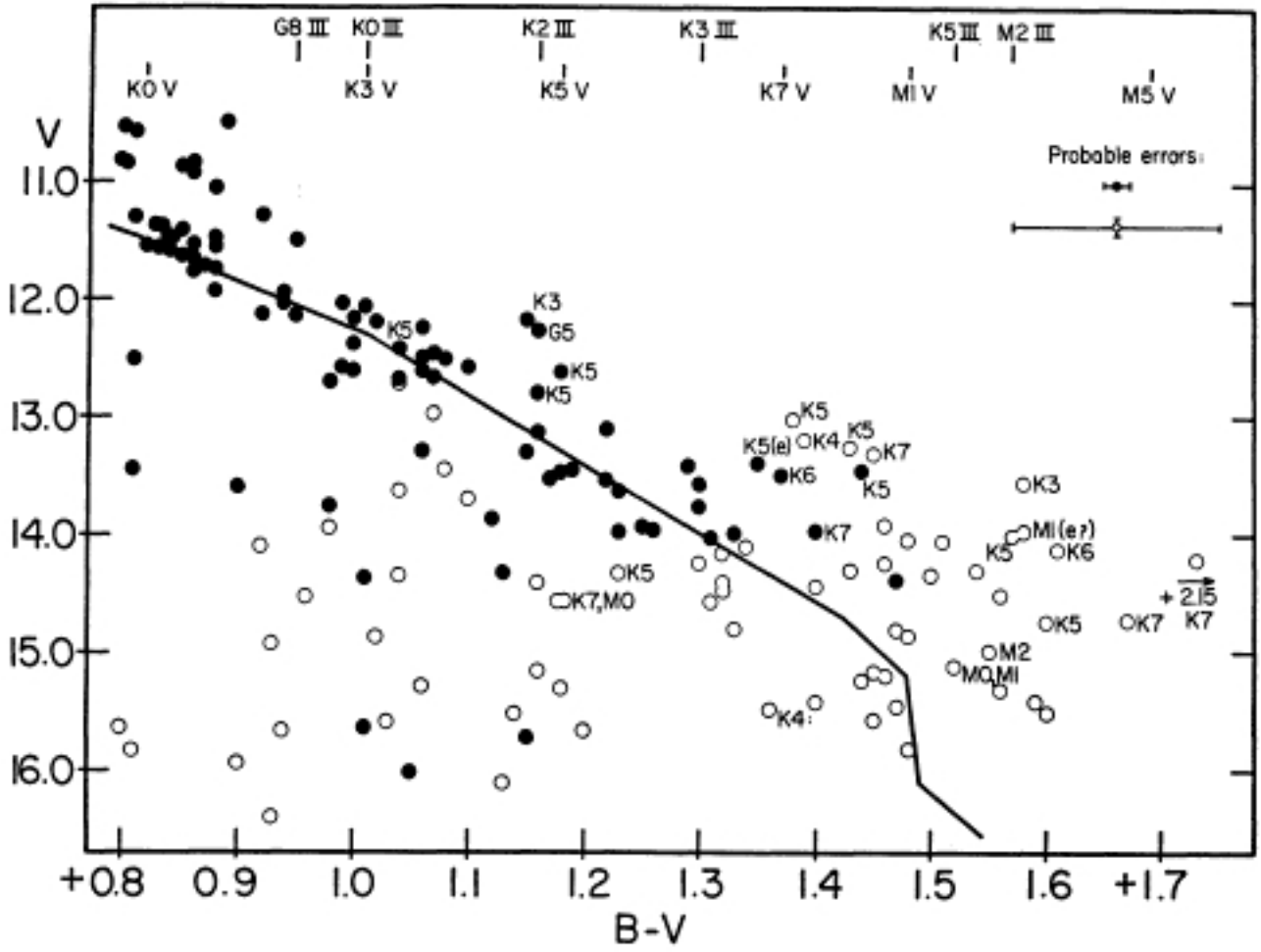

- Herbig (1962)

Nuclear age
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Contraction age
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"Bimodal" Star Formation

High mass stars form in a burst
Low mass stars form continuously

Herbig, G.H.,1962, ApJ, 135, 736

The Pleiades Problem

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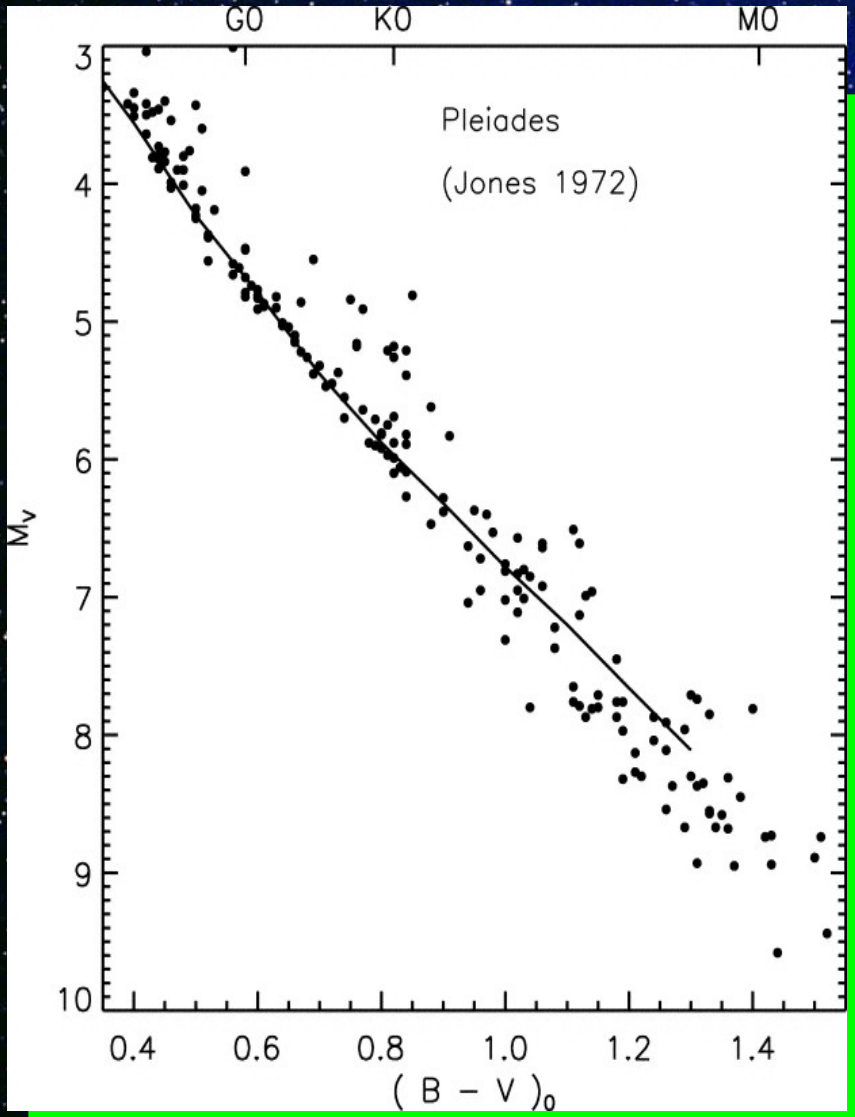
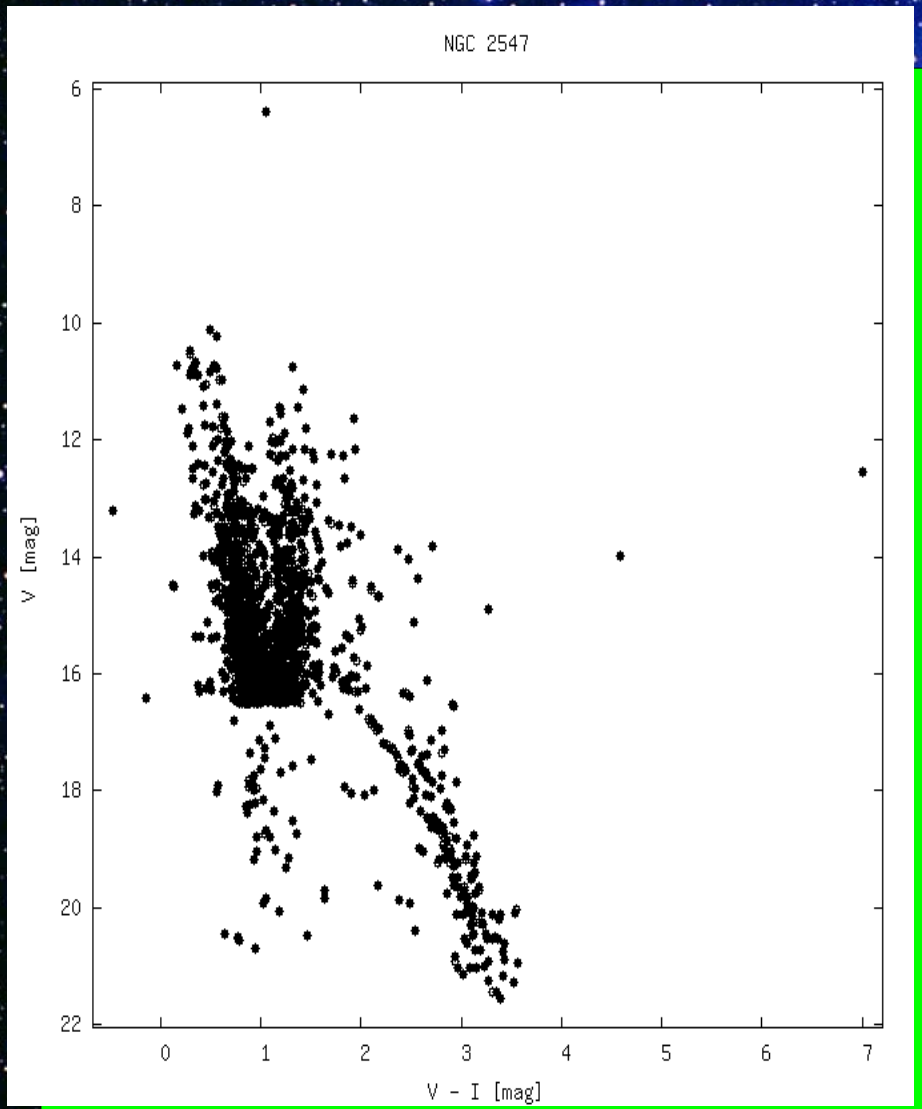


- Jones (1972)

fainter than the Main Sequence (!)

The Pleiades Problem

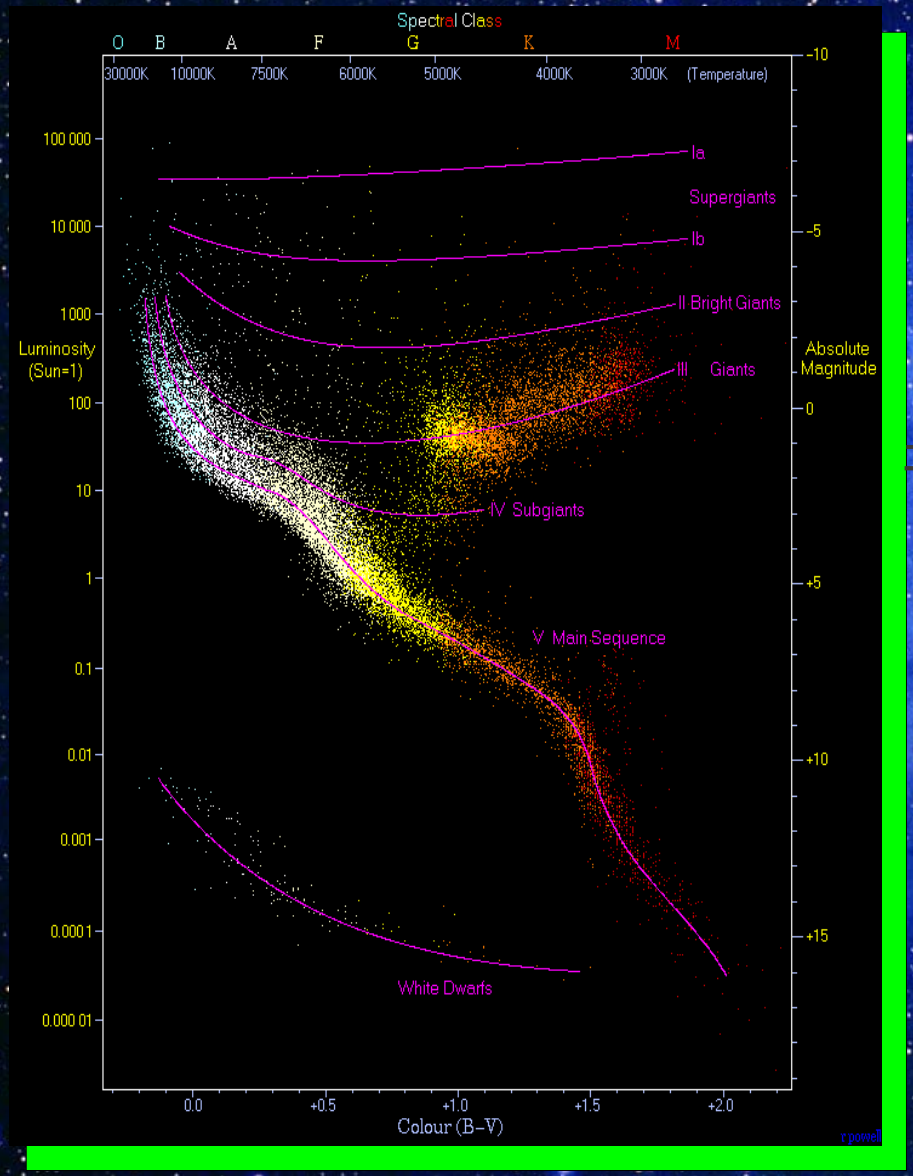
- Dating problem – disagreement between high and low mass stars



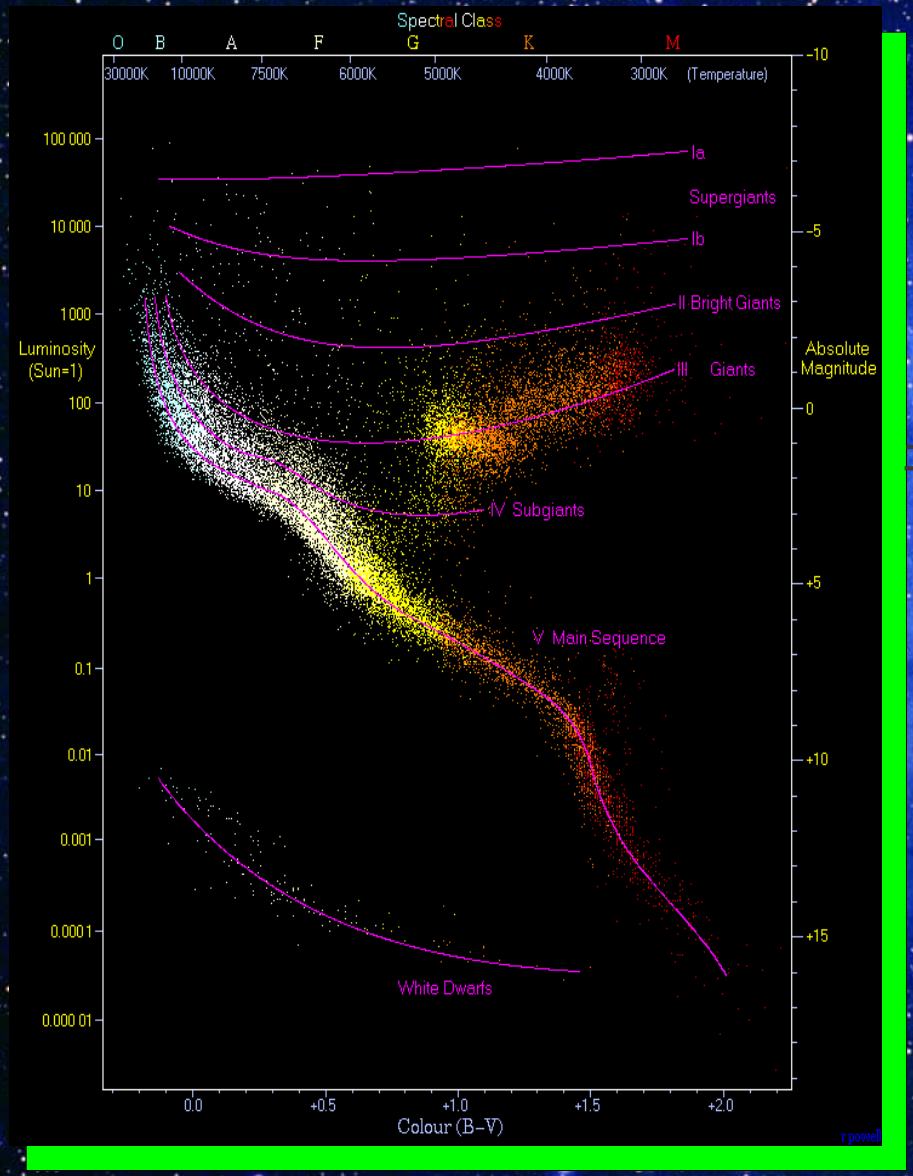
- Nuclear Age -> 55 ± 25 Myr
- Contraction Age -> 14 ± 4 Myr

V-I contraction age is *younger*

Early Stellar Evolution

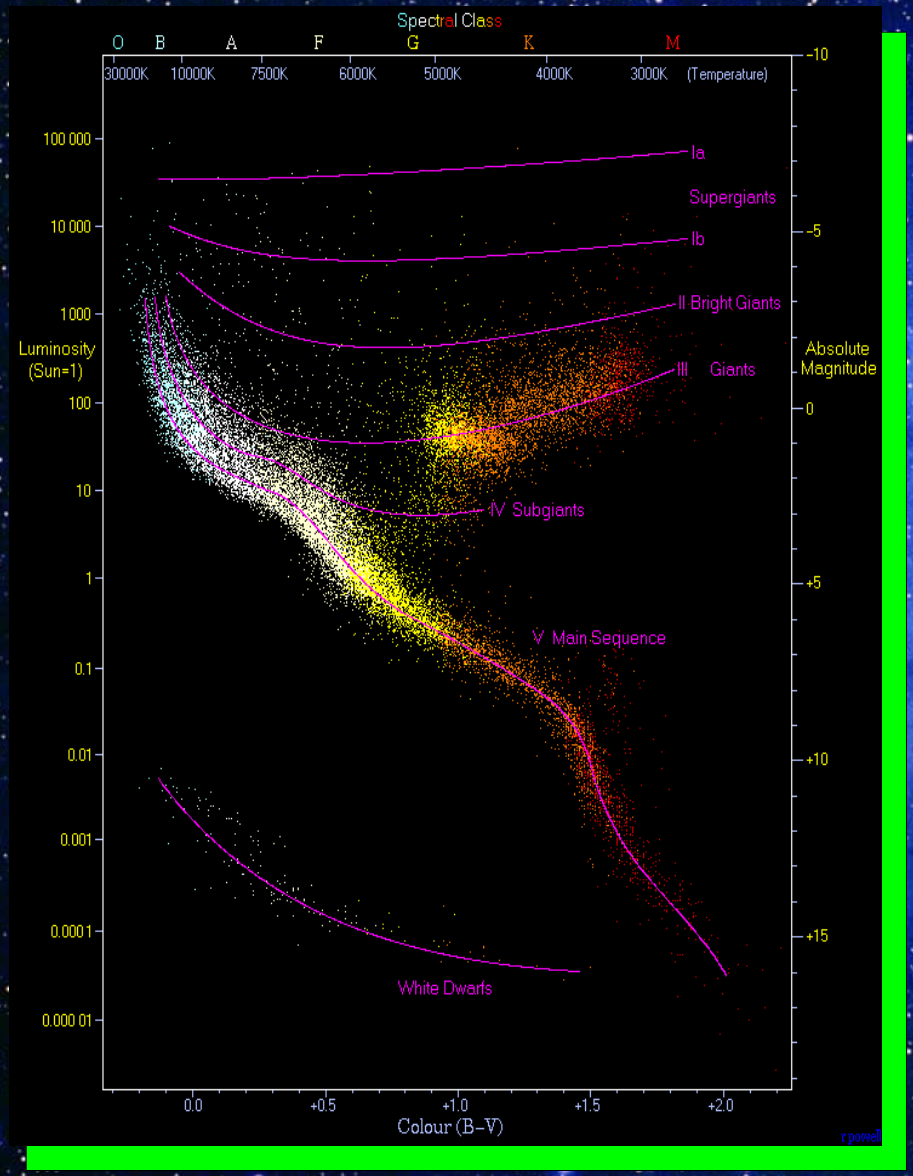


Early Stellar Evolution



- PMS phase is quick for high mass stars

Early Stellar Evolution



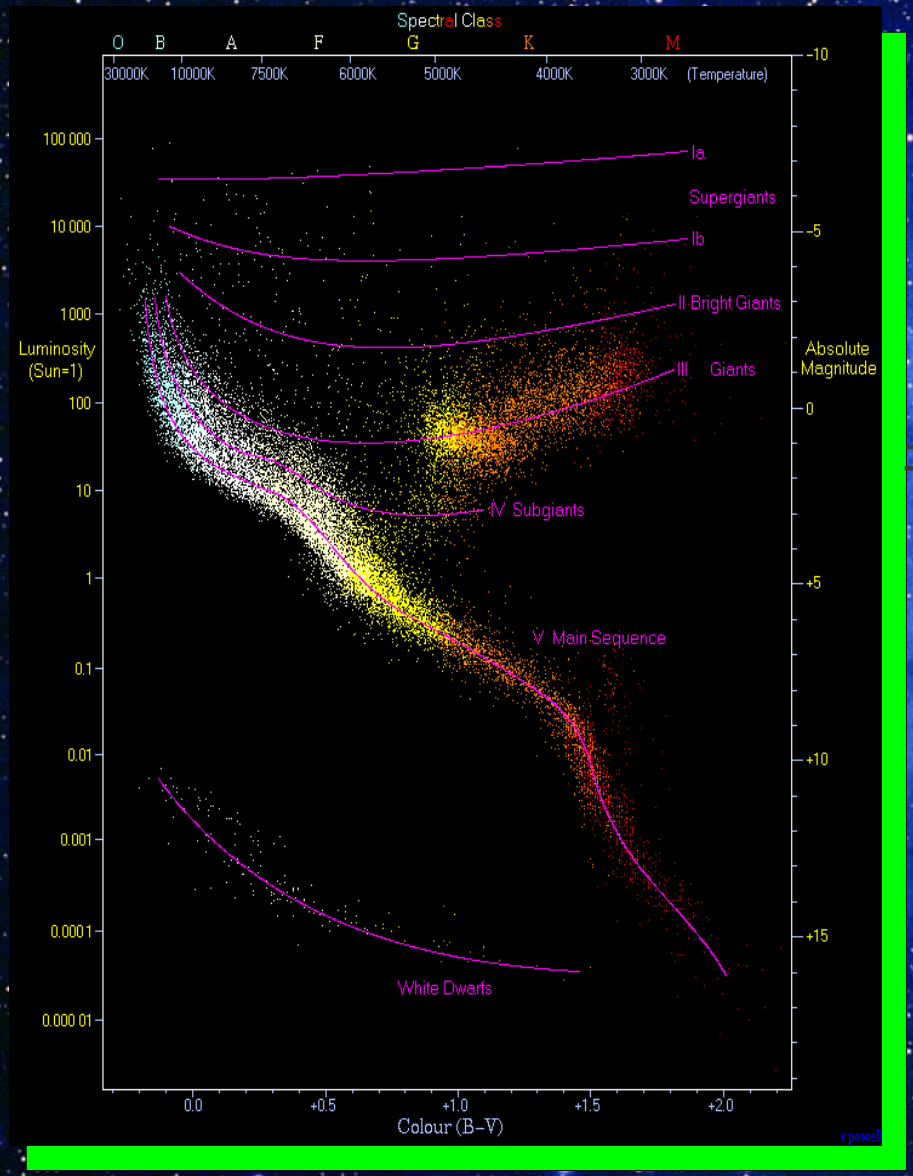
- PMS phase is quick for high mass stars

- Low mass PMS stars

Difficult to Observe

Faint

Early Stellar Evolution



+

- PMS phase is quick for high mass stars

- Low mass PMS stars

Difficult to Observe

Faint

Difficult to Model

Molecular Lines

Fully Convective

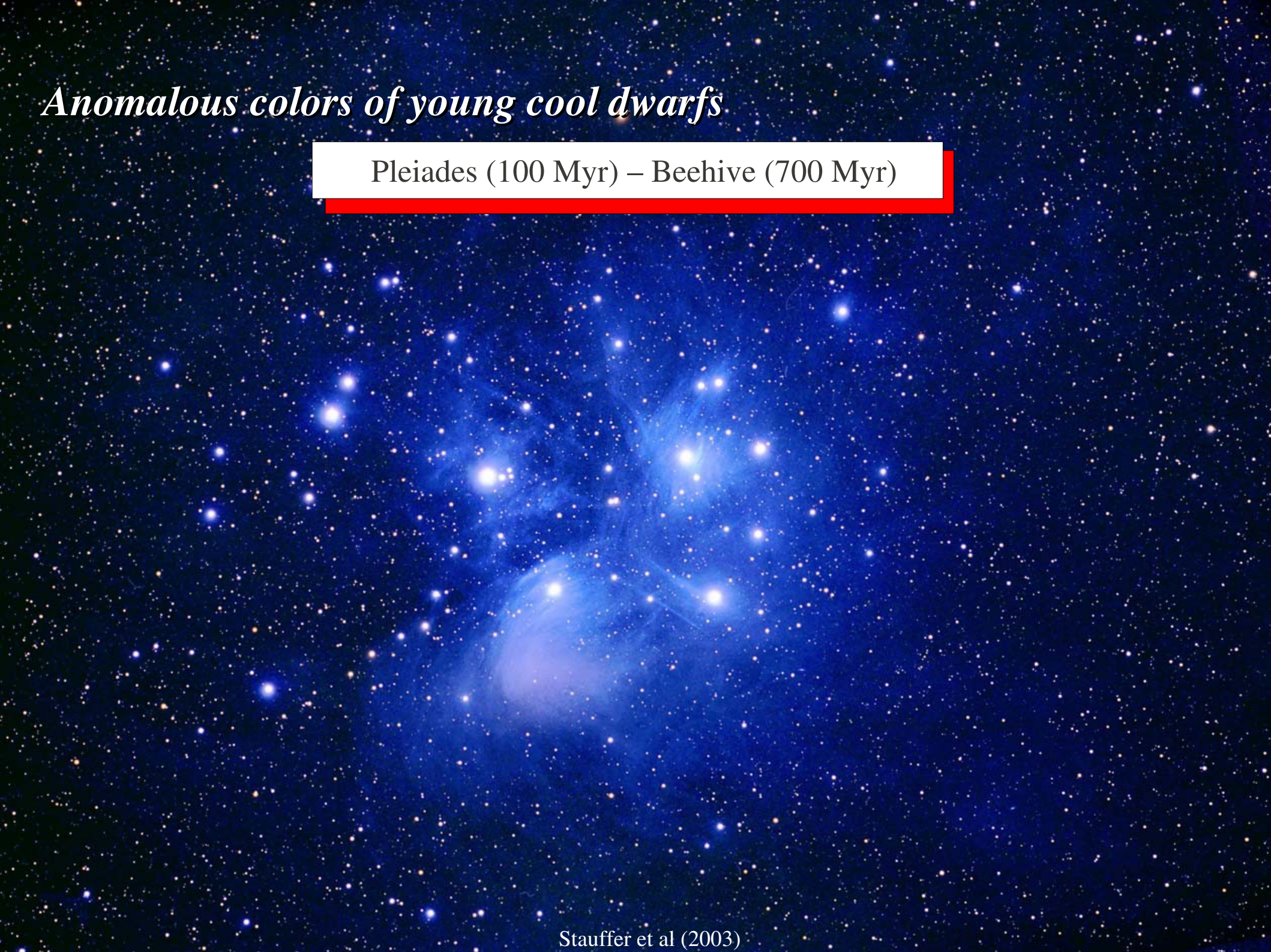
Magnetic

Non-LTE

Accreting Processes

Anomalous colors of young cool dwarfs

Pleiades (100 Myr) – Beehive (700 Myr)



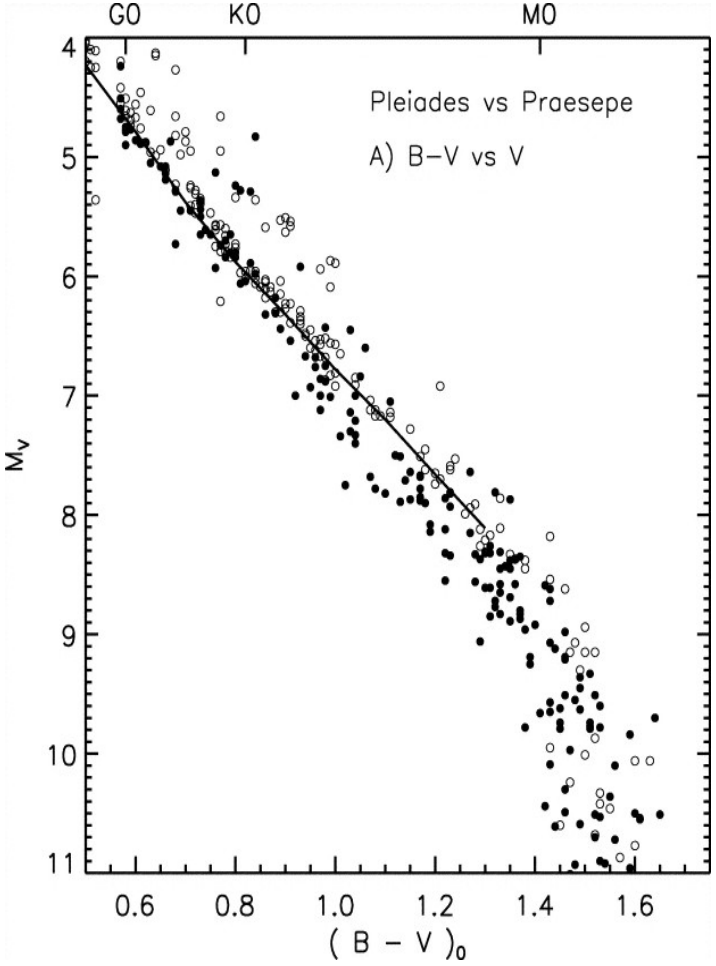
Stauffer et al (2003)

Anomalous colors of young cool dwarfs

Pleiades (100 Myr) – Beehive (700 Myr)

The K dwarfs

are *bluer* in *B-V*



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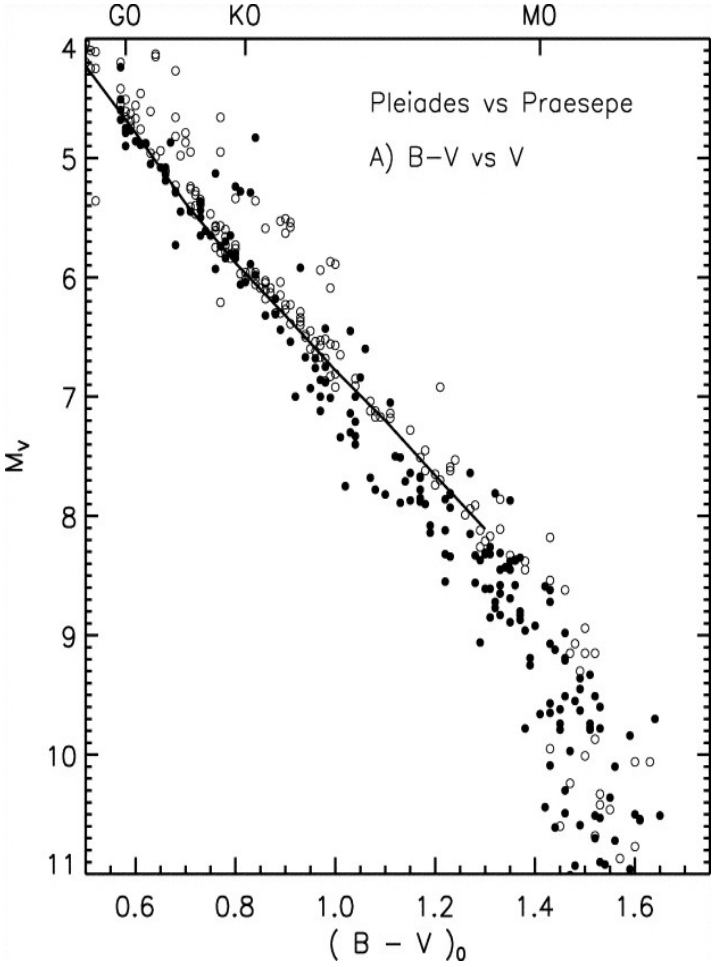
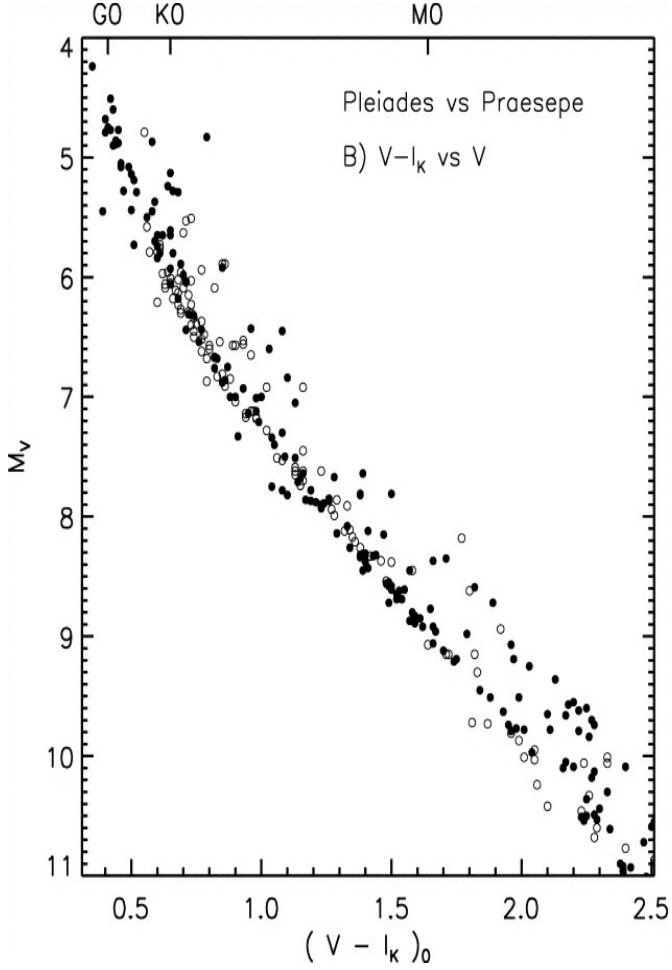


match in *V-I*



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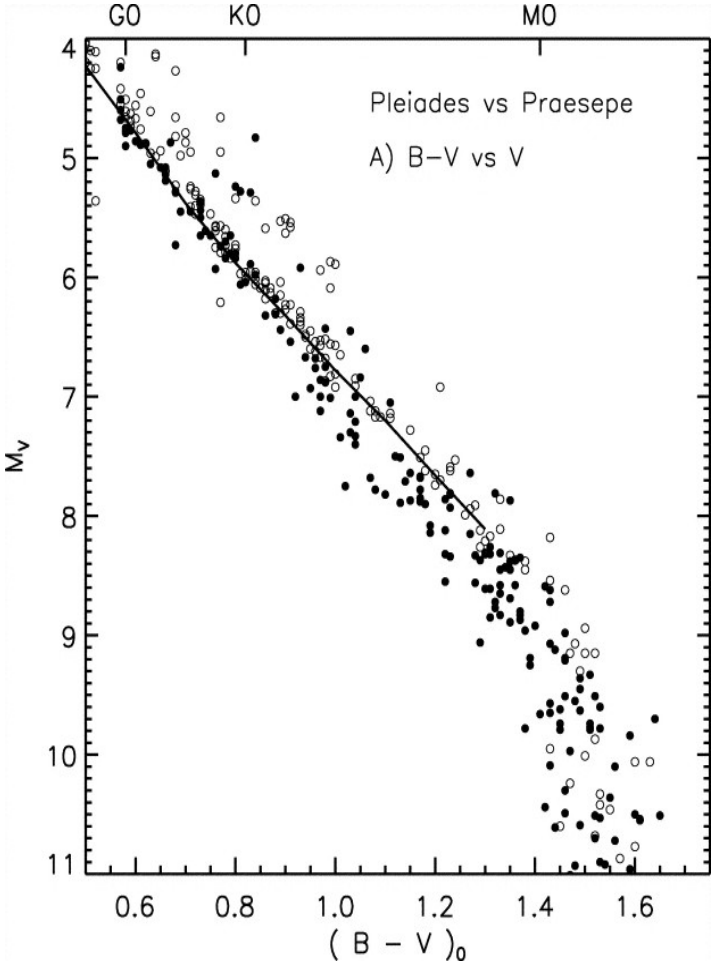

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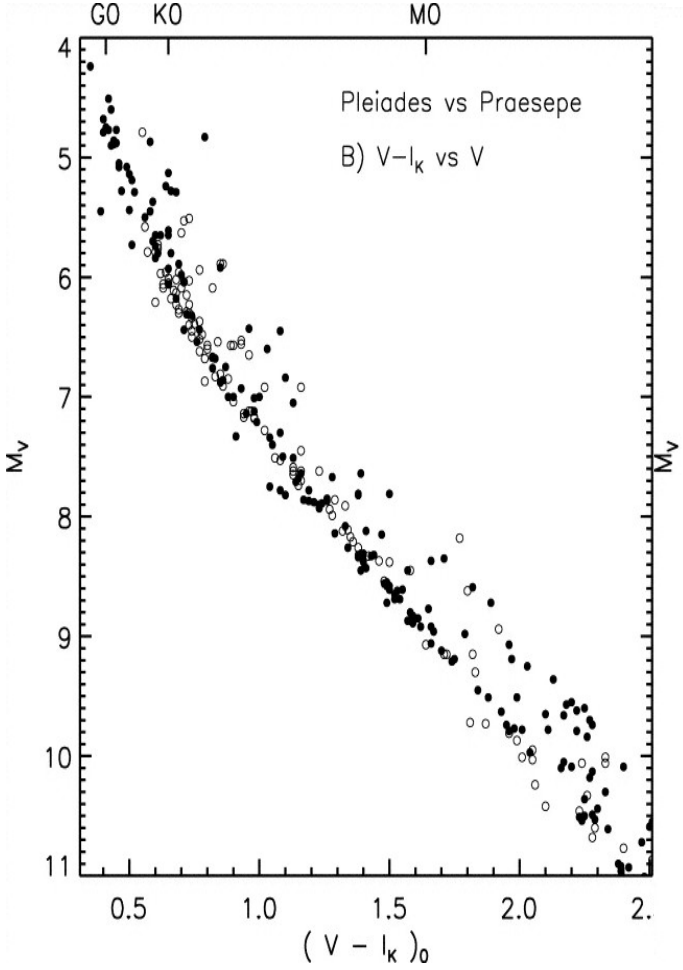
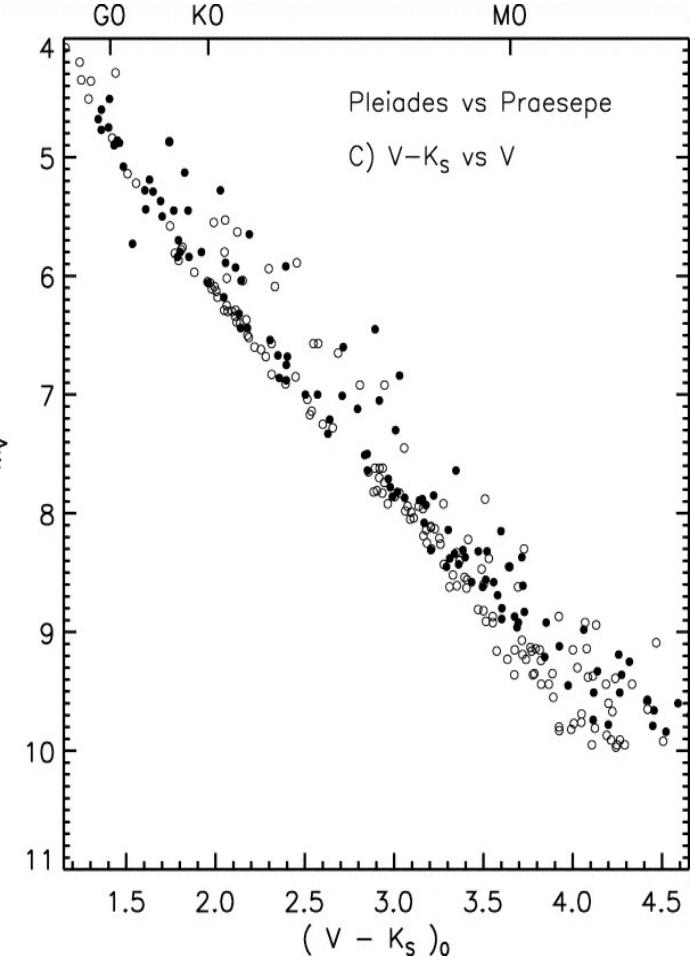


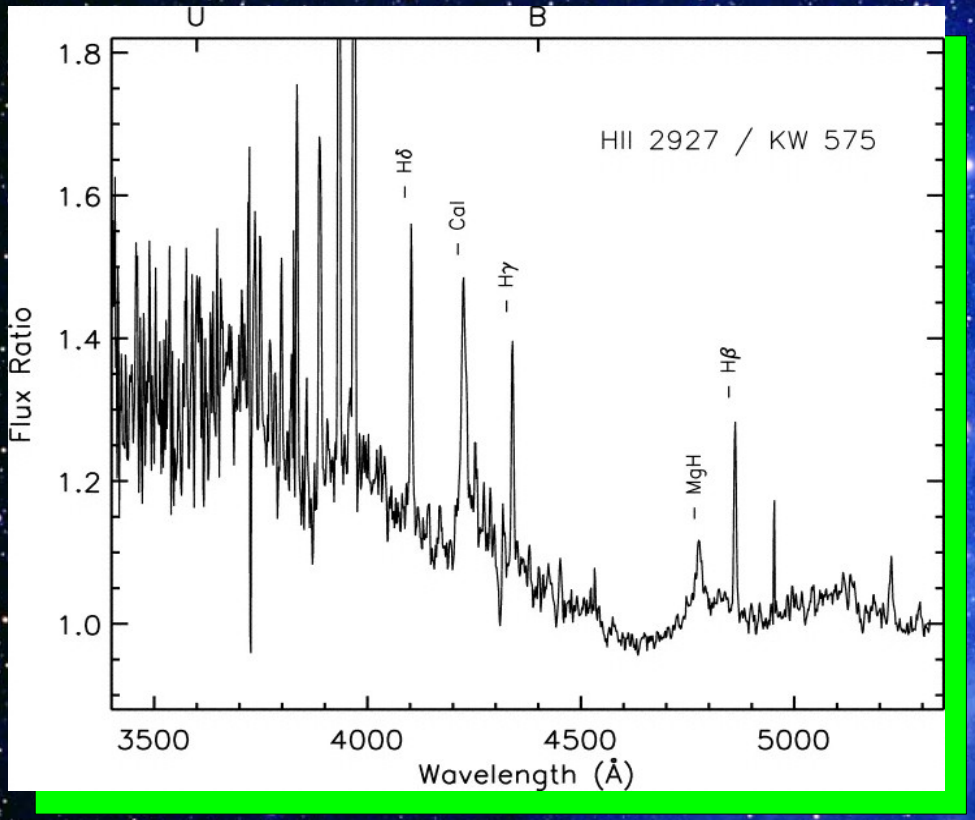
are *redder* in *V-K*

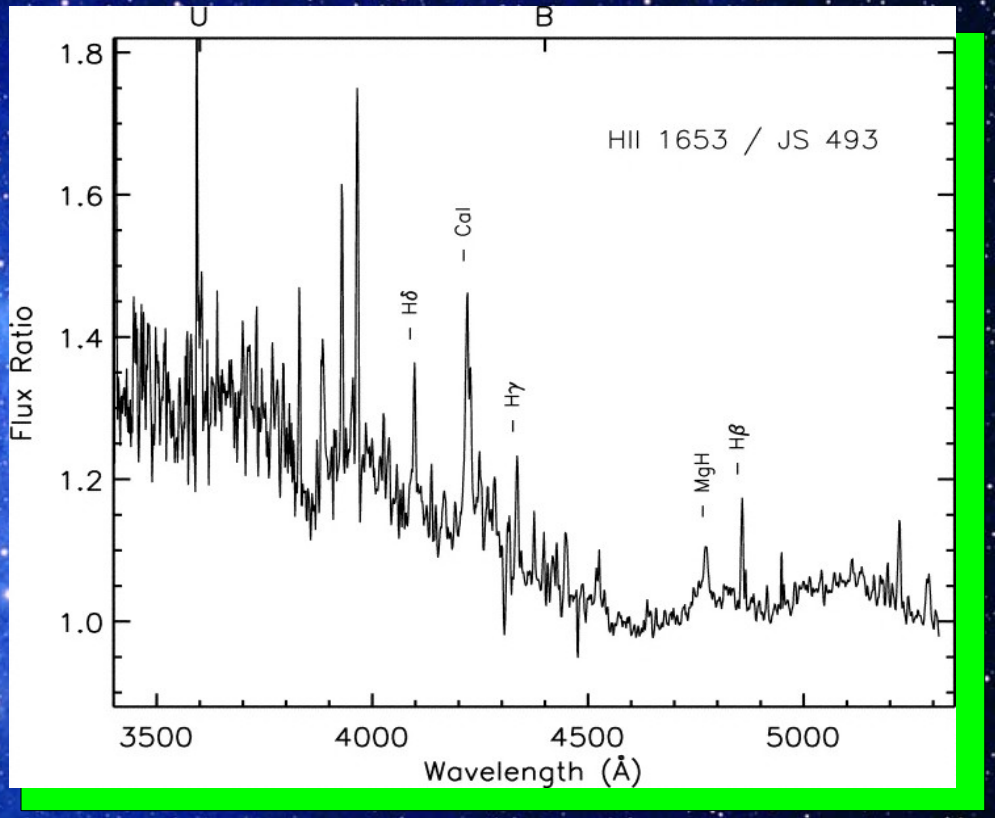


Stauffer et al (2003)

Spectroscopic Confirmation of the Color Anomaly

A *pleiad* K dwarf when compared to a *bee* K dwarf of same *V-I* is





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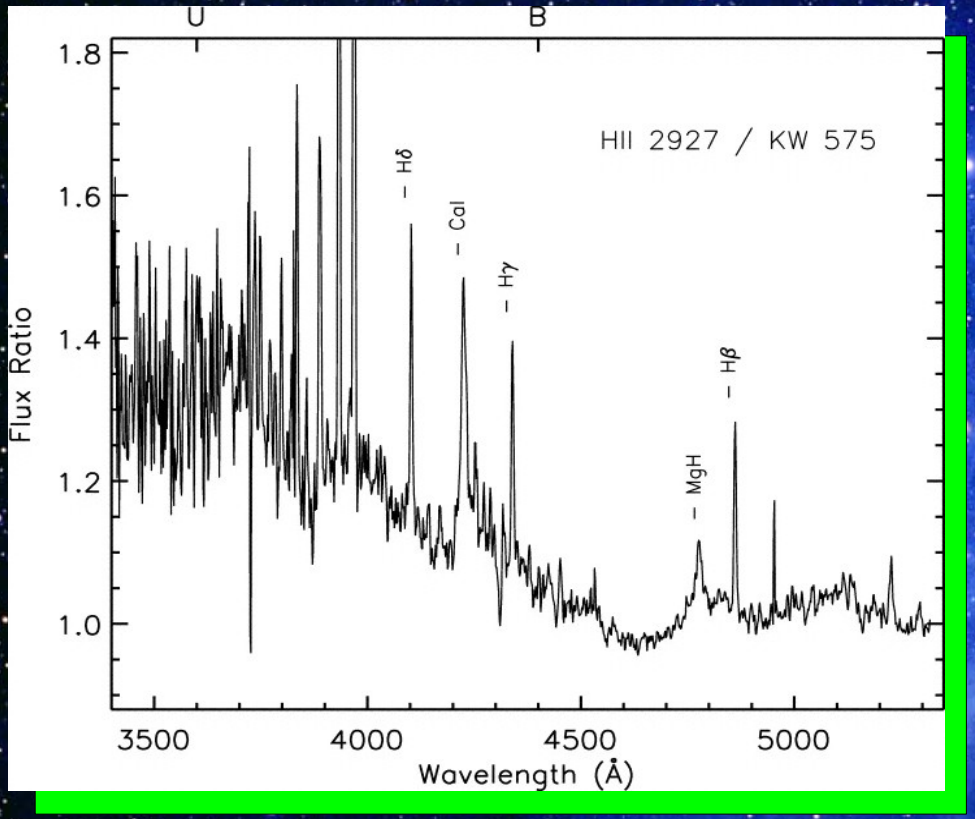

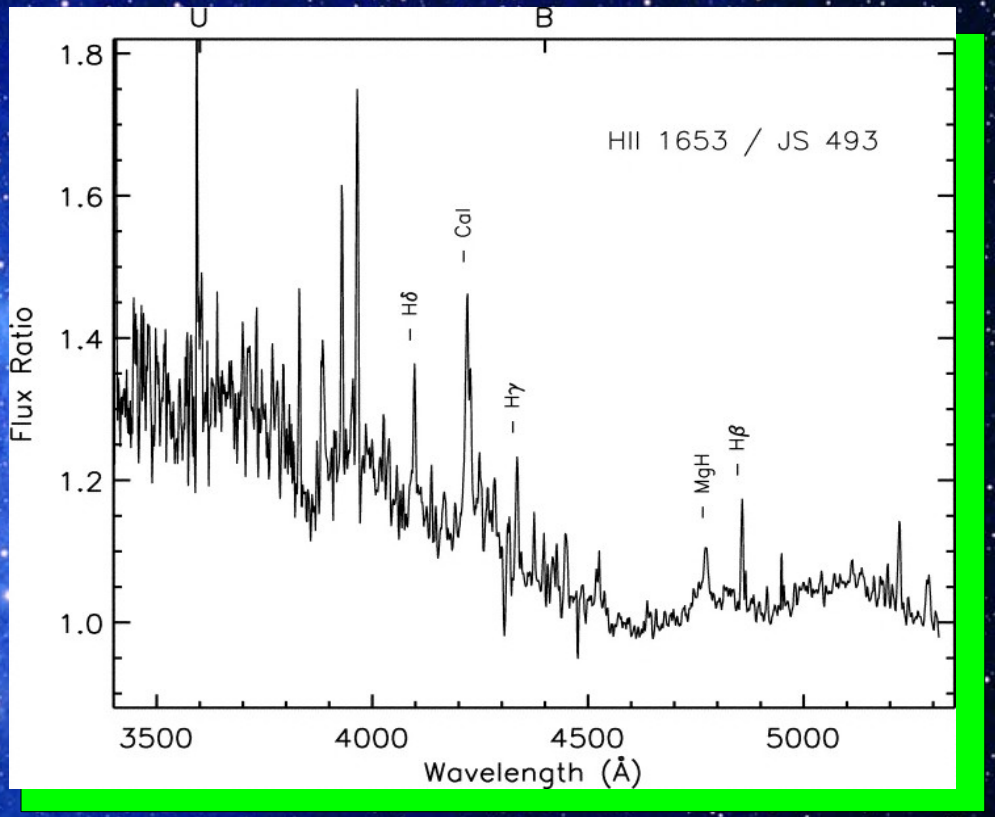

10% brighter in *B*
0.1 mag bluer in *B-V*

Stauffer et al (2003)

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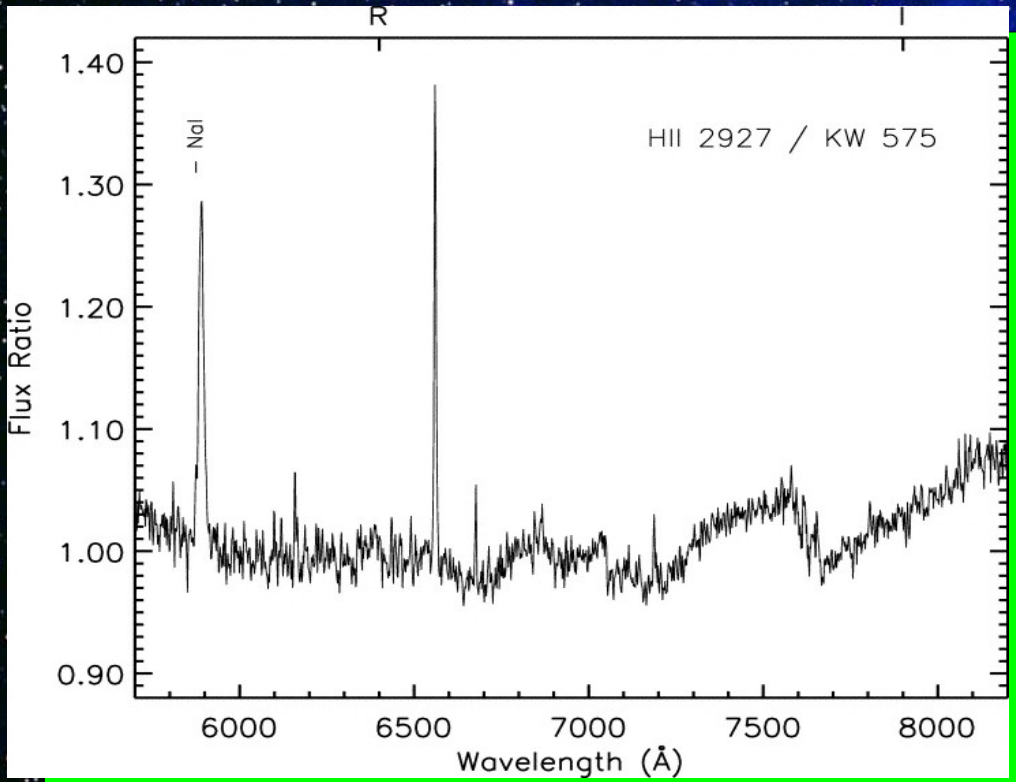
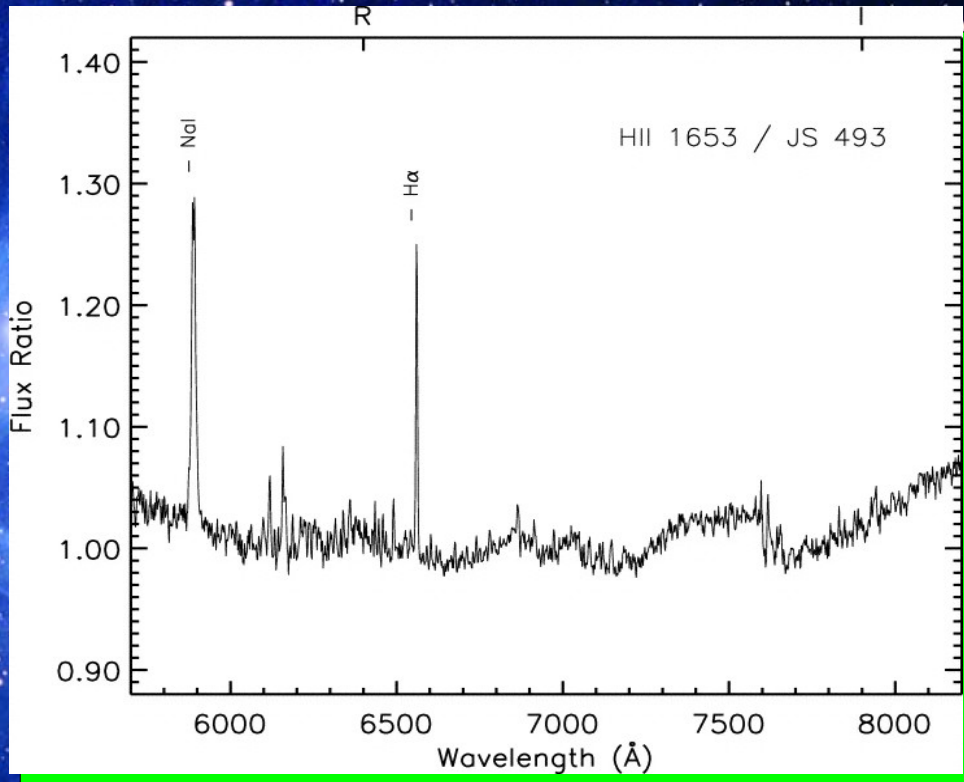
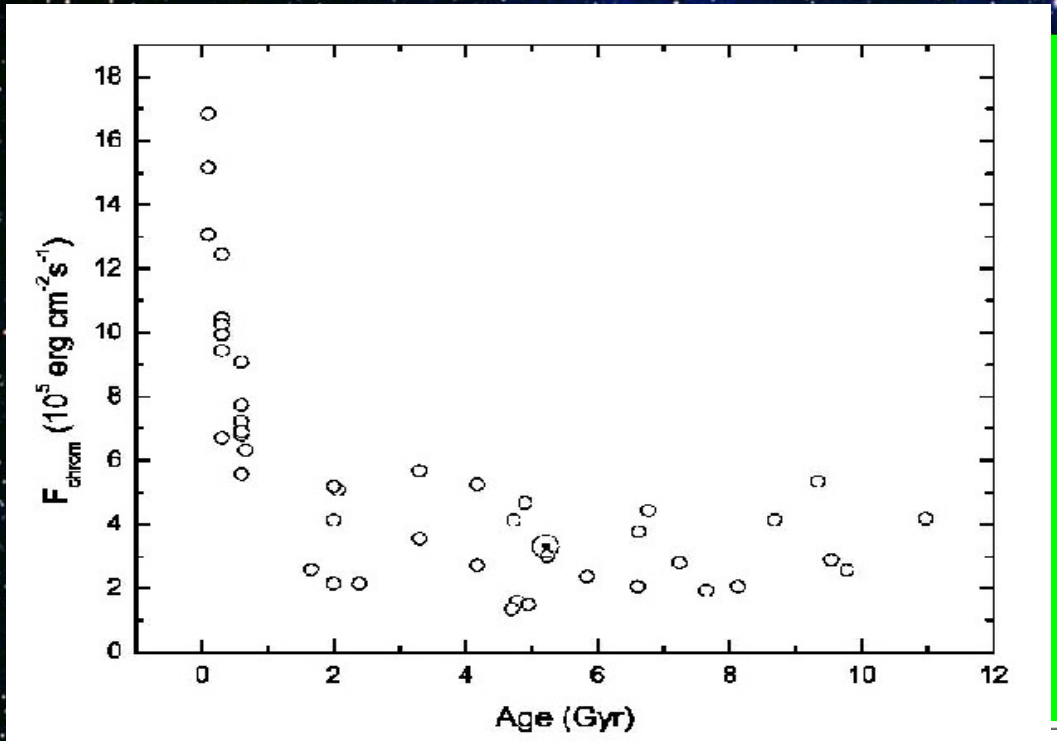




similar in *R* and *I*

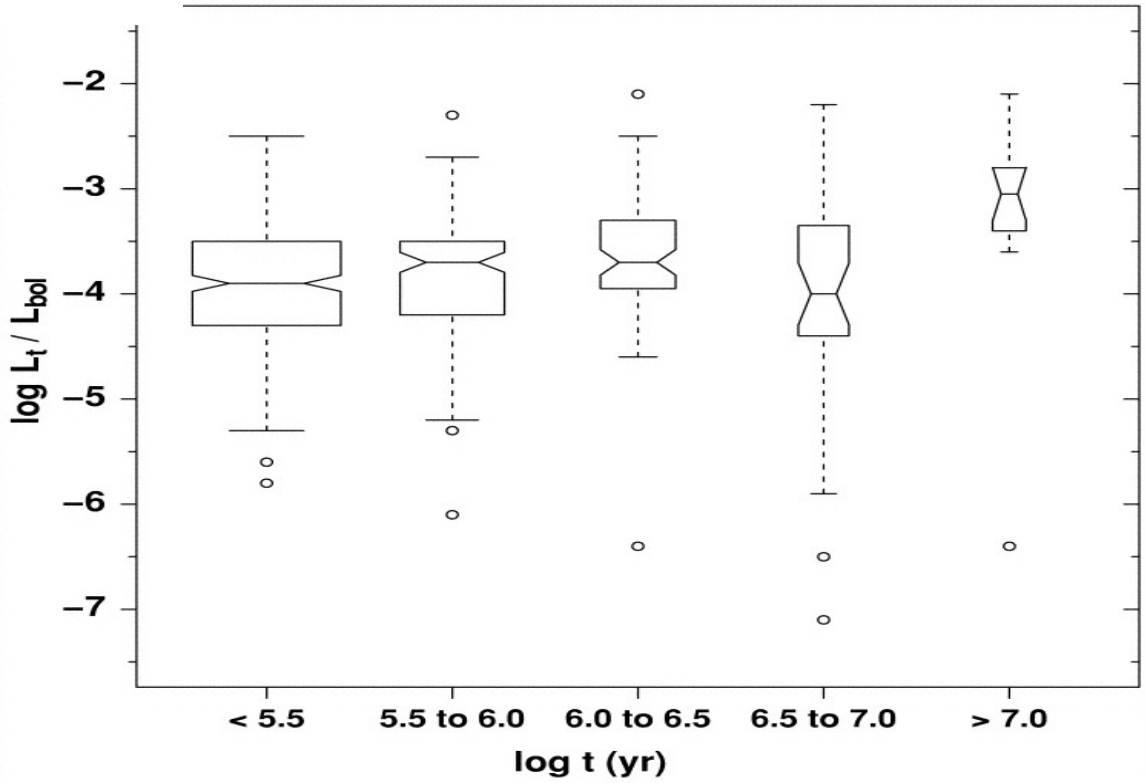
Stauffer et al (2003)



Age-Activity

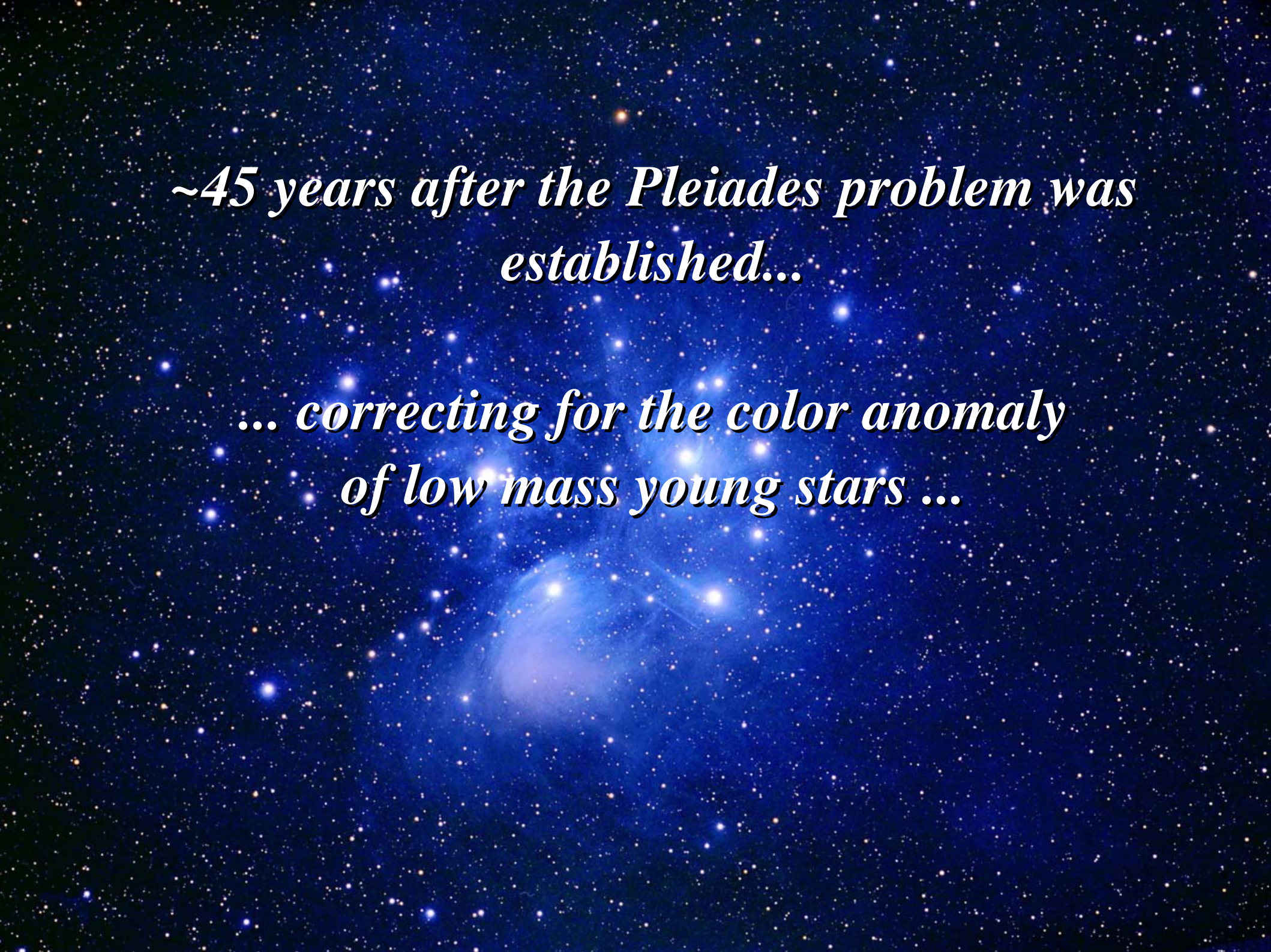
Young stars are magnetically active

The dynamo is saturated for the youngest stars (>50% of the area is covered with spots)



Lyra & Porto de Mello (2005)
Feigelson et al. (2003)


~45 years after the Pleiades problem was established...


~45 years after the Pleiades problem was established...
... correcting for the color anomaly of low mass young stars ...

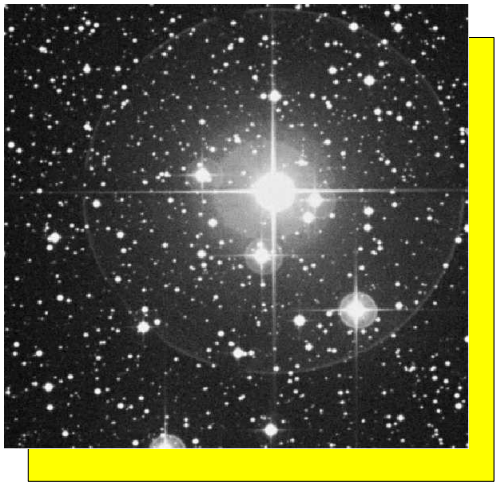
~45 years after the Pleiades problem was established...

... correcting for the color anomaly of low mass young stars ...

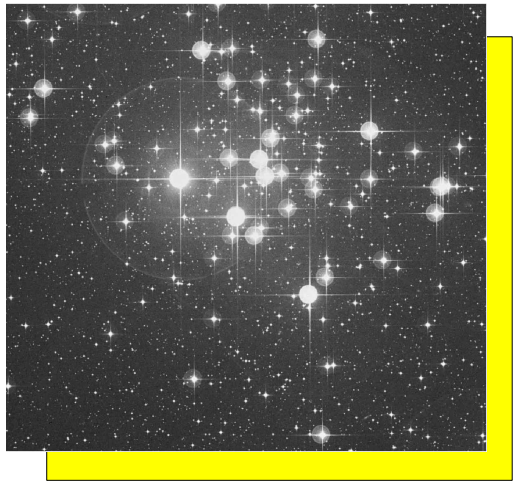
... will the nuclear and contraction ages finally match ?

Observations

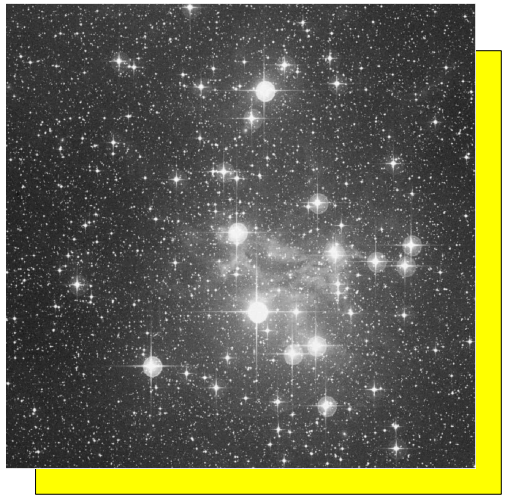
0.9 m CTIO (FOV 13' x 13', 0".39 px-1)
7 nights on Feb 2003
4 open clusters in the age range 10-150 Myr



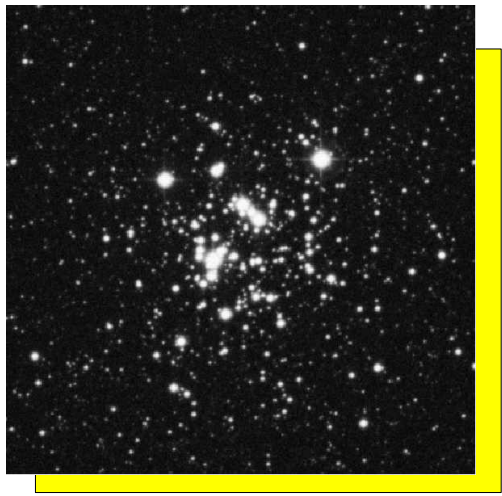
NGC 2232
13' x 13'
~30 Myr
~350 pc



NGC 2516
26' x 26'
~150 Myr
~400 pc



NGC 2547
26' x 26'
~50 Myr
~400 pc



NGC 4755
13' x 13'
~10 Myr
~2000 pc

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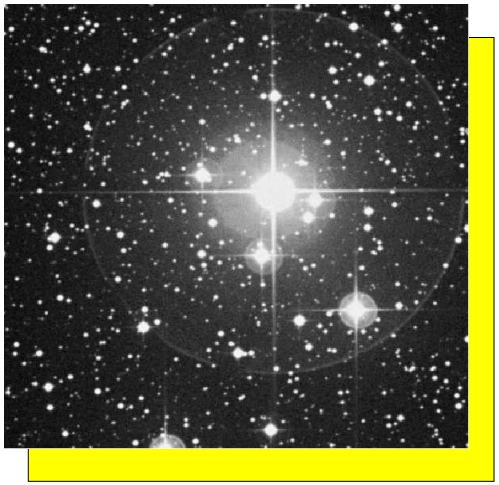

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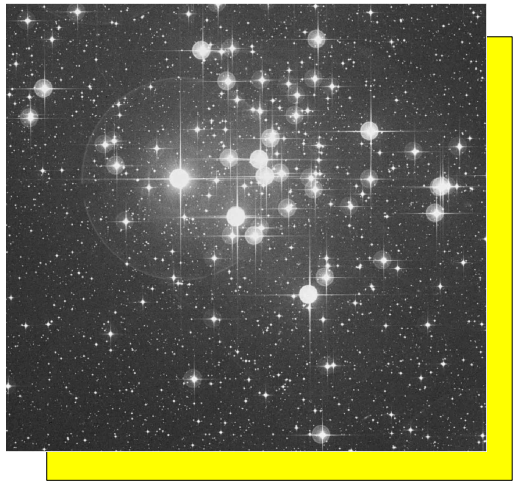

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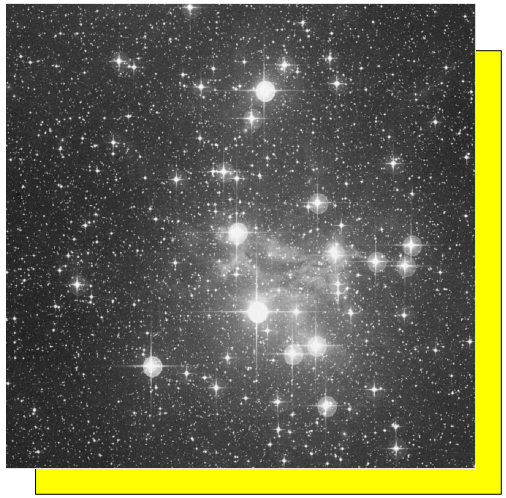

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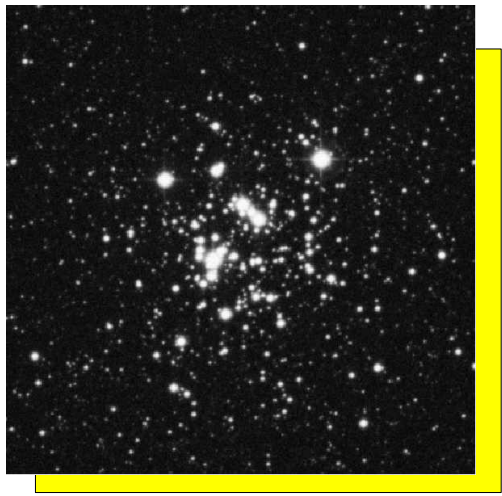

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U:900s *B*:390s *V*:240s *R*:300s *I*:400s

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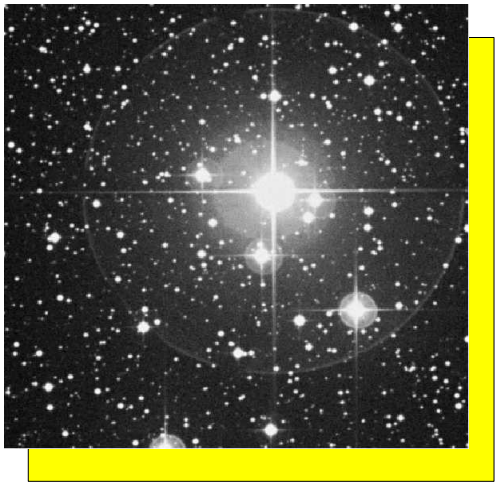

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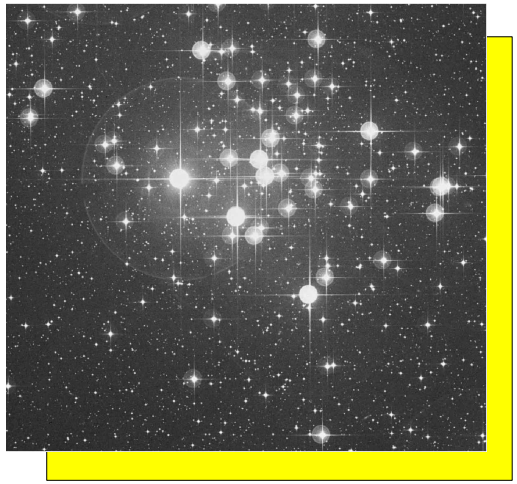

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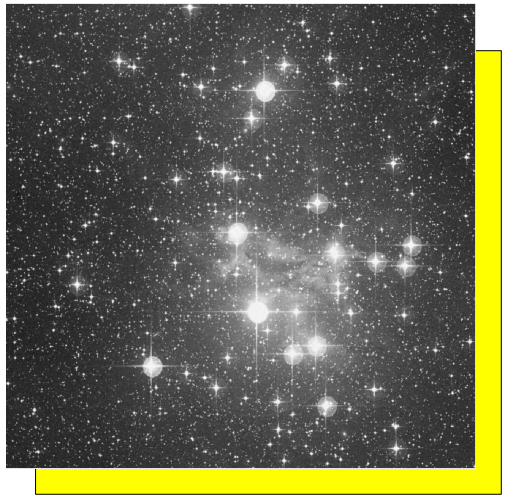

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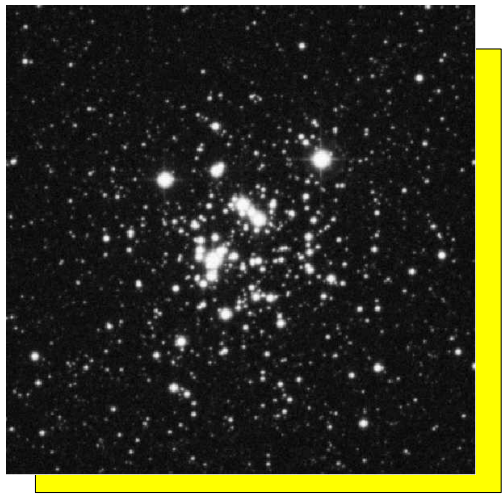

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U:900s *B*:390s *V*:240s *R*:300s *I*:400s

206 clusters images
99 control field images

gain 3.e e-/adu
readout noise 4.9 e-

30 standard stars
in 2 Landolt (1992) fields

Photometry

Aperture Photometry for
NGC 2232, NGC 2516, NGC 2547

Aperture radius = FWHM (~5 px)

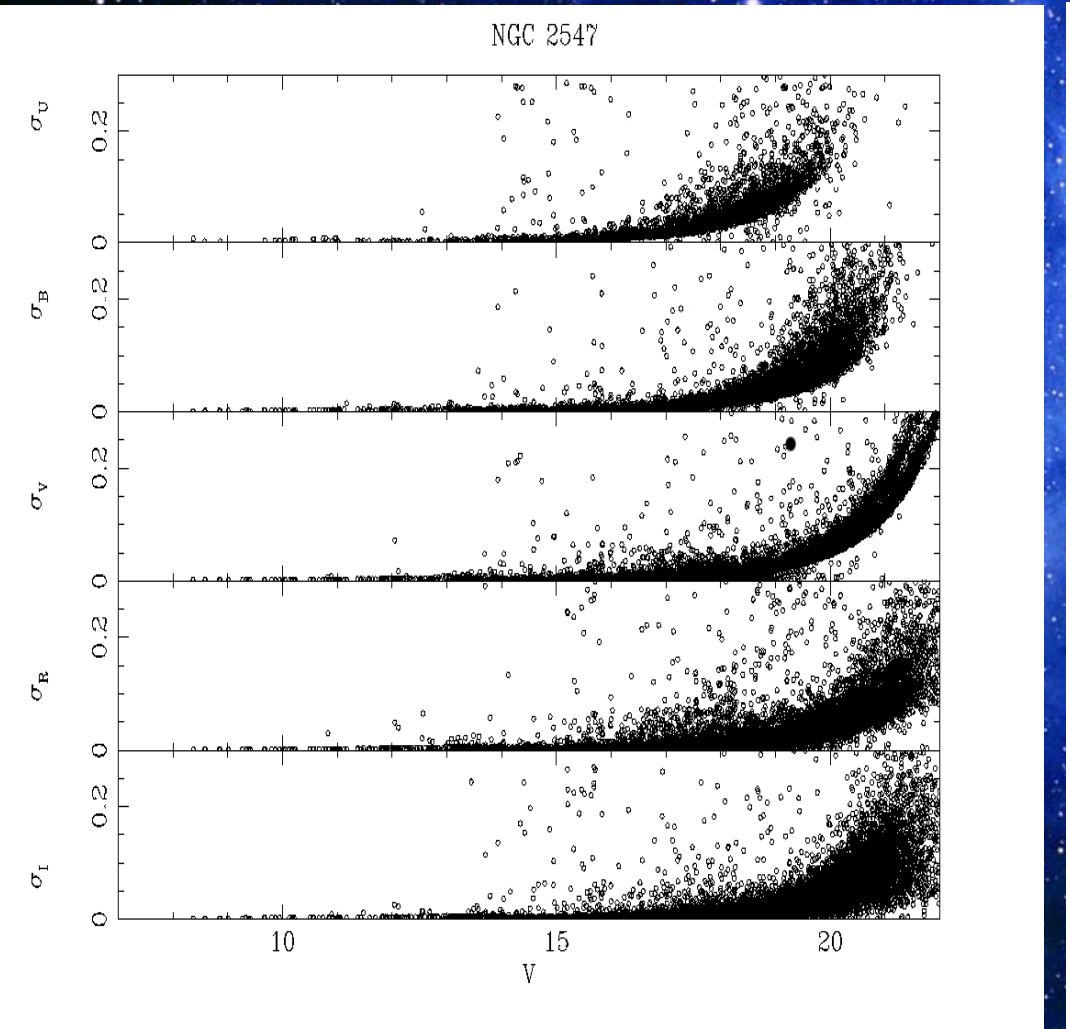
40 isolated stars for aperture correction (17 px)

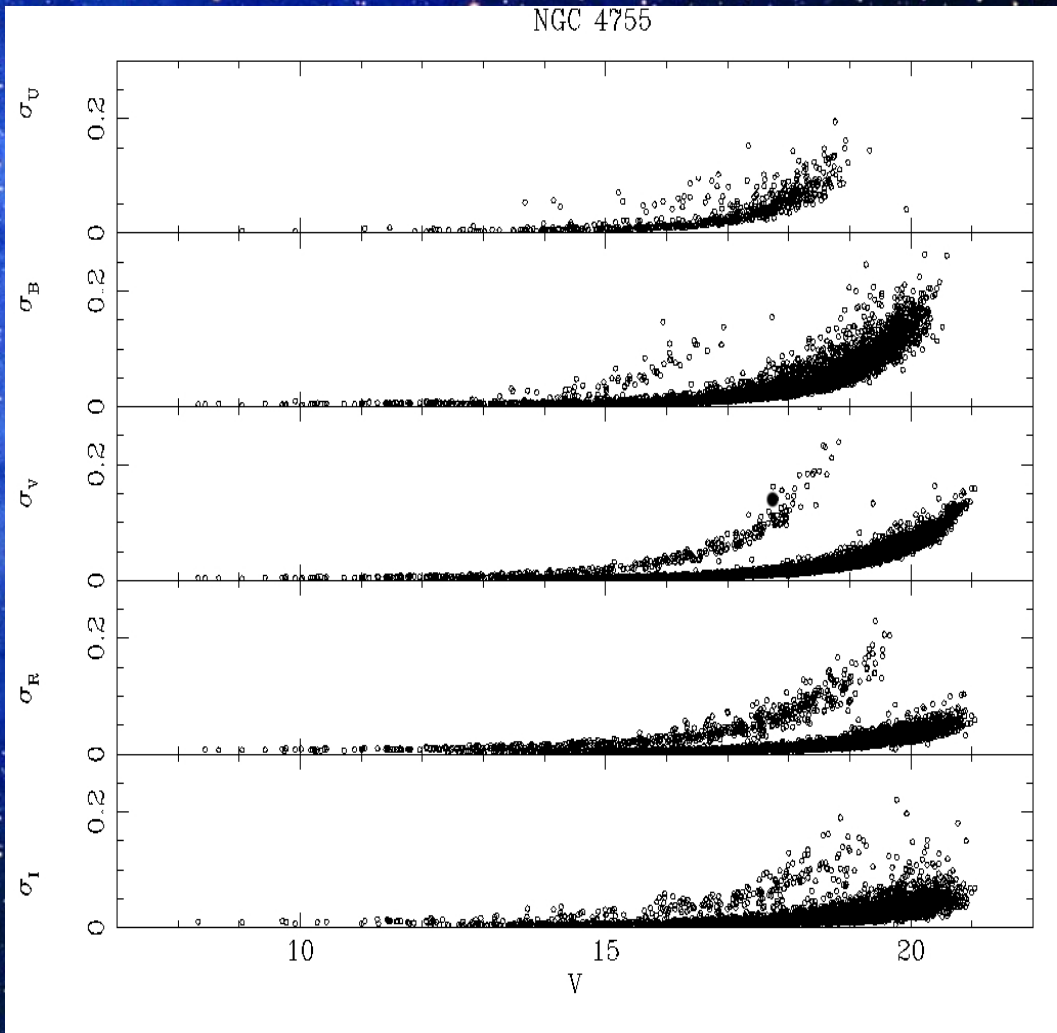
3408* in NGC2232 - 3461* in NGC2516, 12813* in NGC2547

PSF photometry for NGC 4755

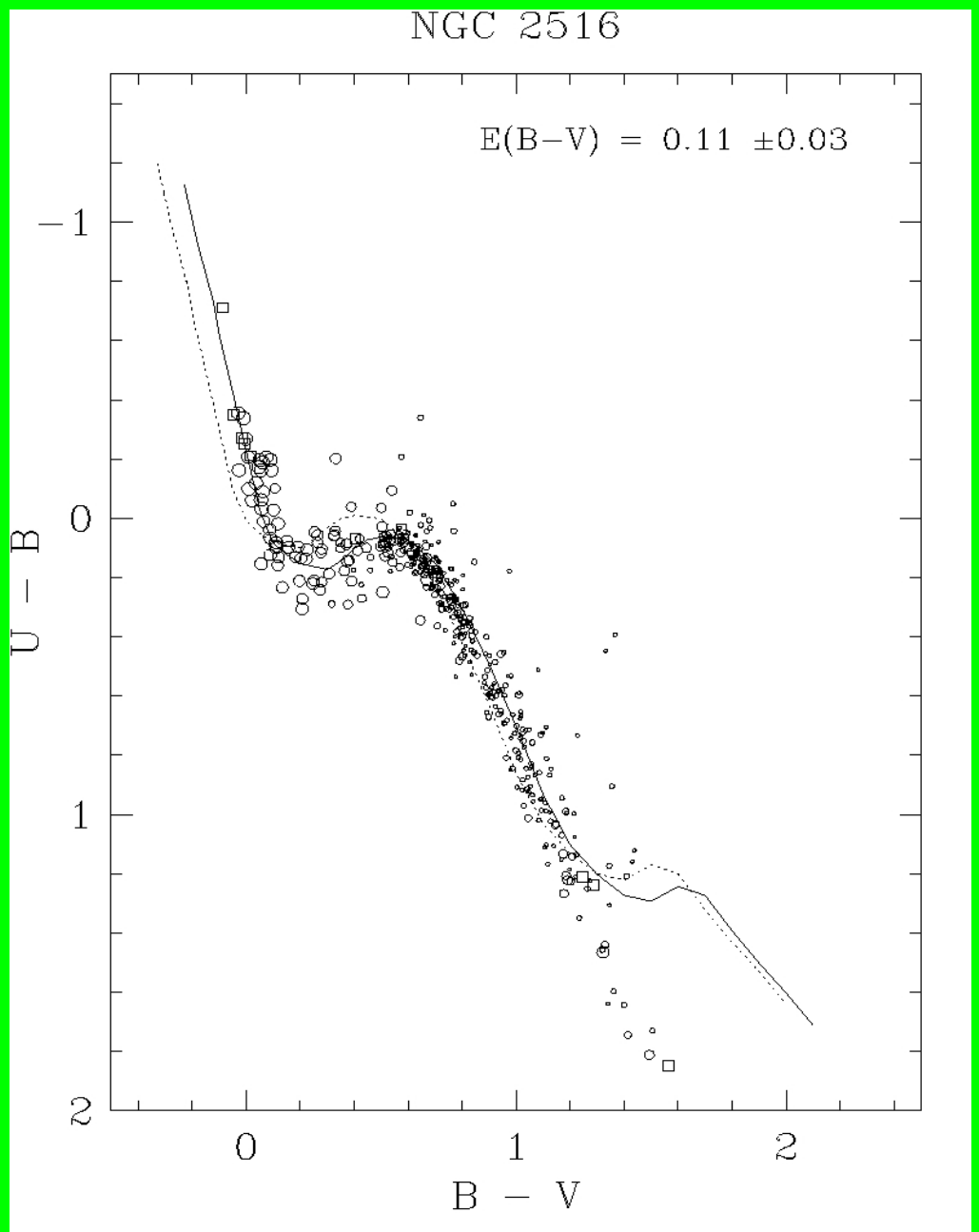
- 50 to 200 stars for computing quadratically variable PSF

7188* in NGC4755





Reddening, Distance, and Nuclear Age



Adopted Parameters

E(U-B)/E(B-V) = 0.72

Rv = 3.1

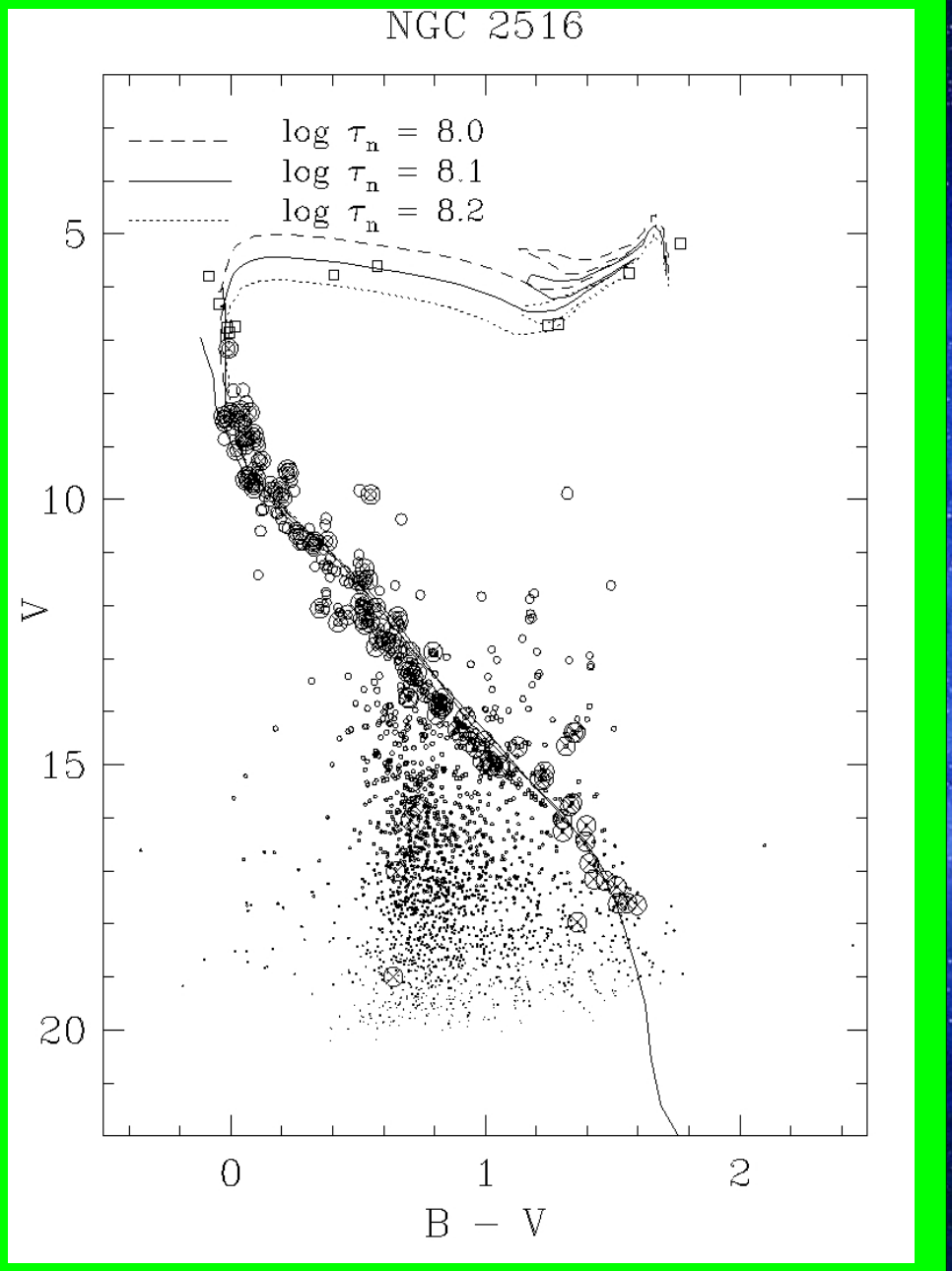
Schmidt-Kaler (1982) empirical ZAMS

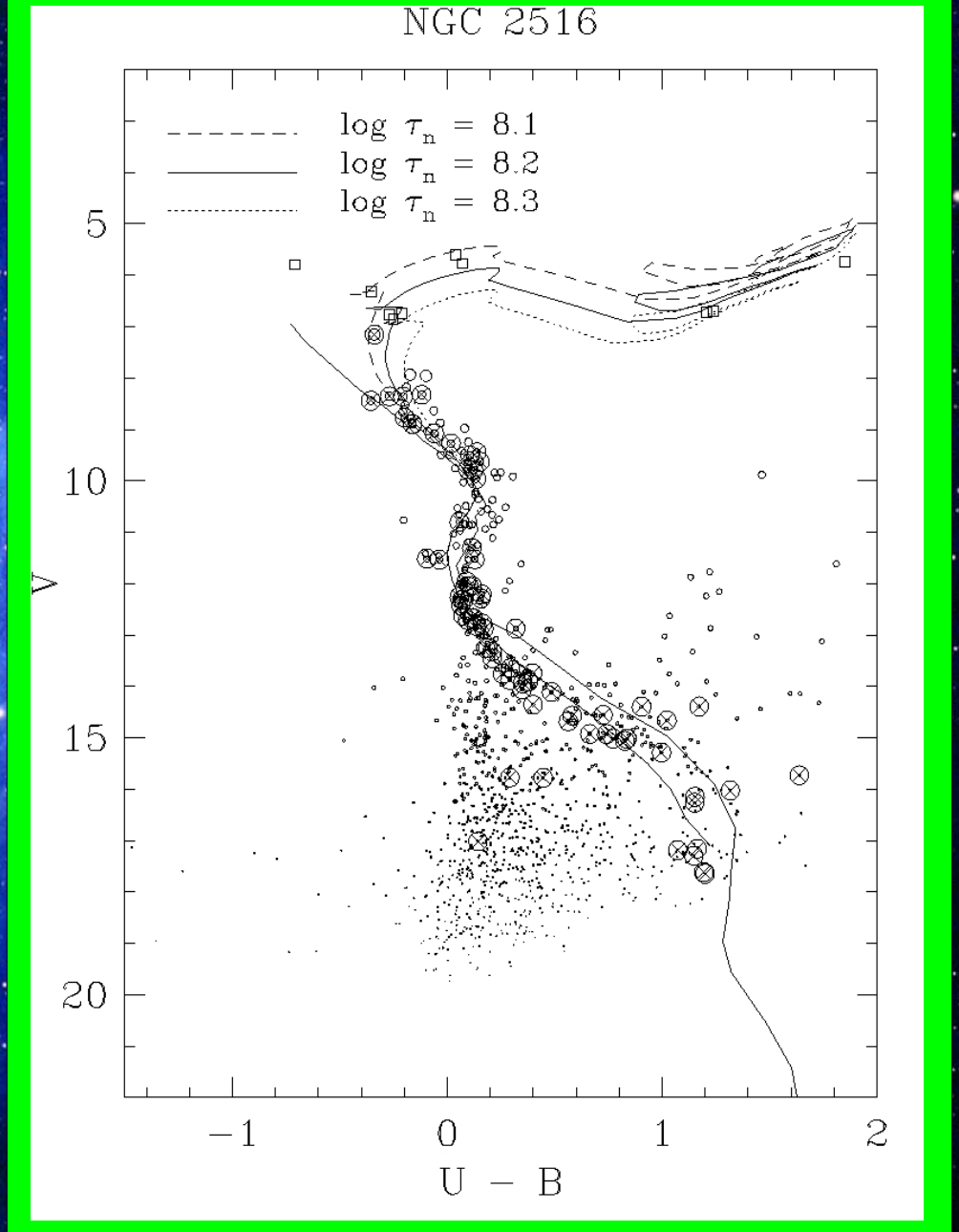
Girardi et al (2000) model isochrones for Post-Main Sequence fitting

- core overshoot

- solar recipe

Reddening, Distance and Nuclear Age





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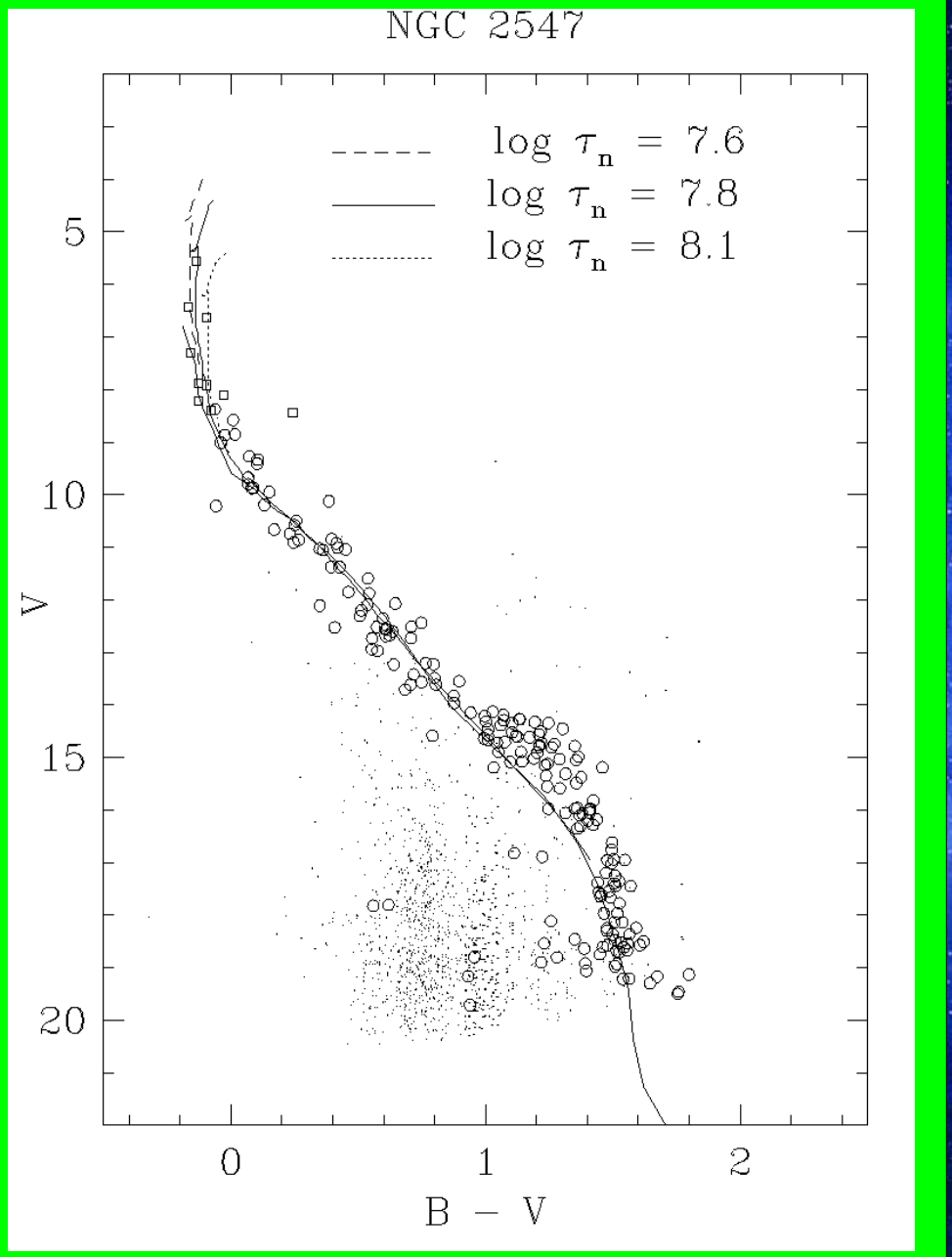

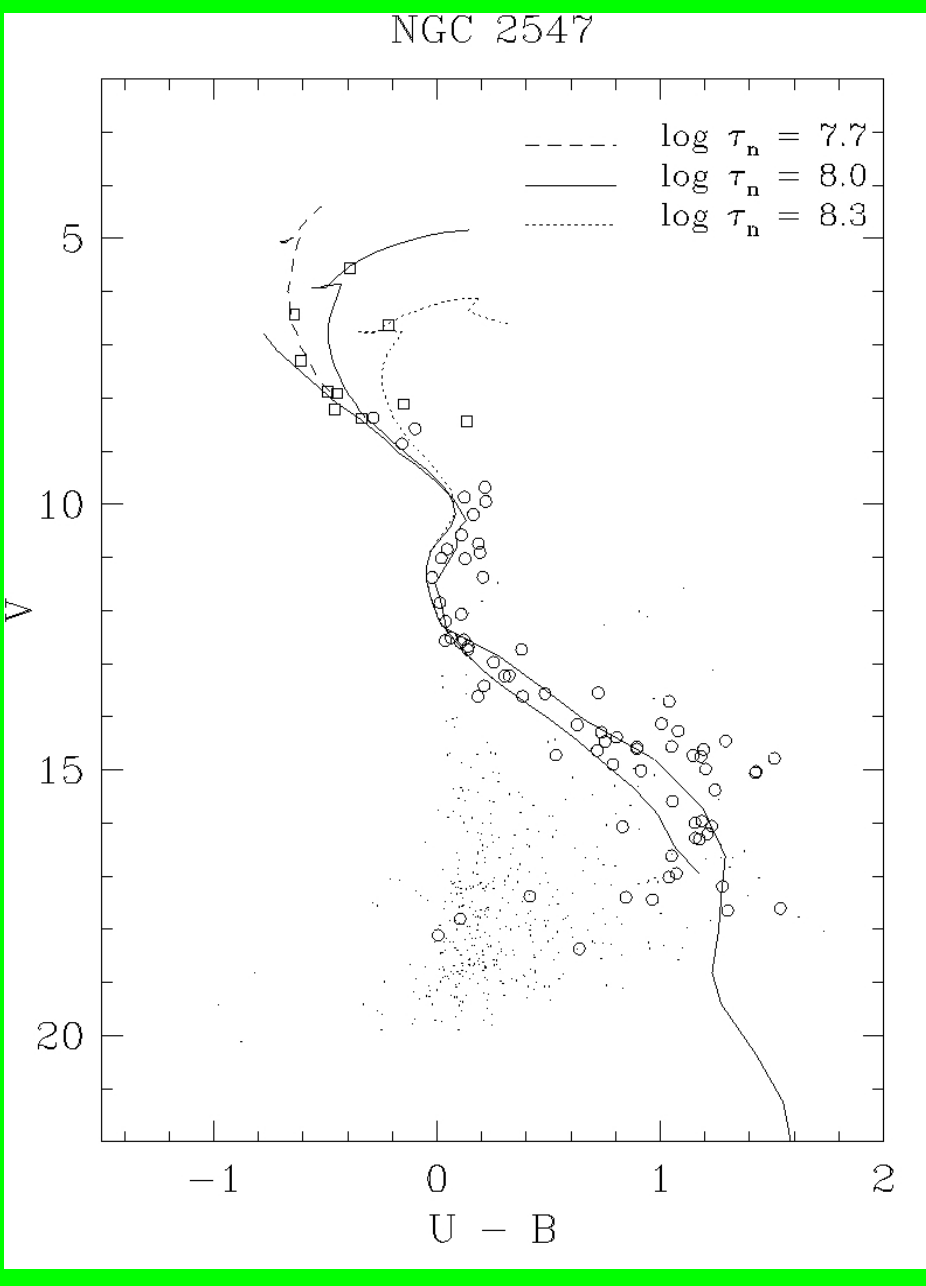

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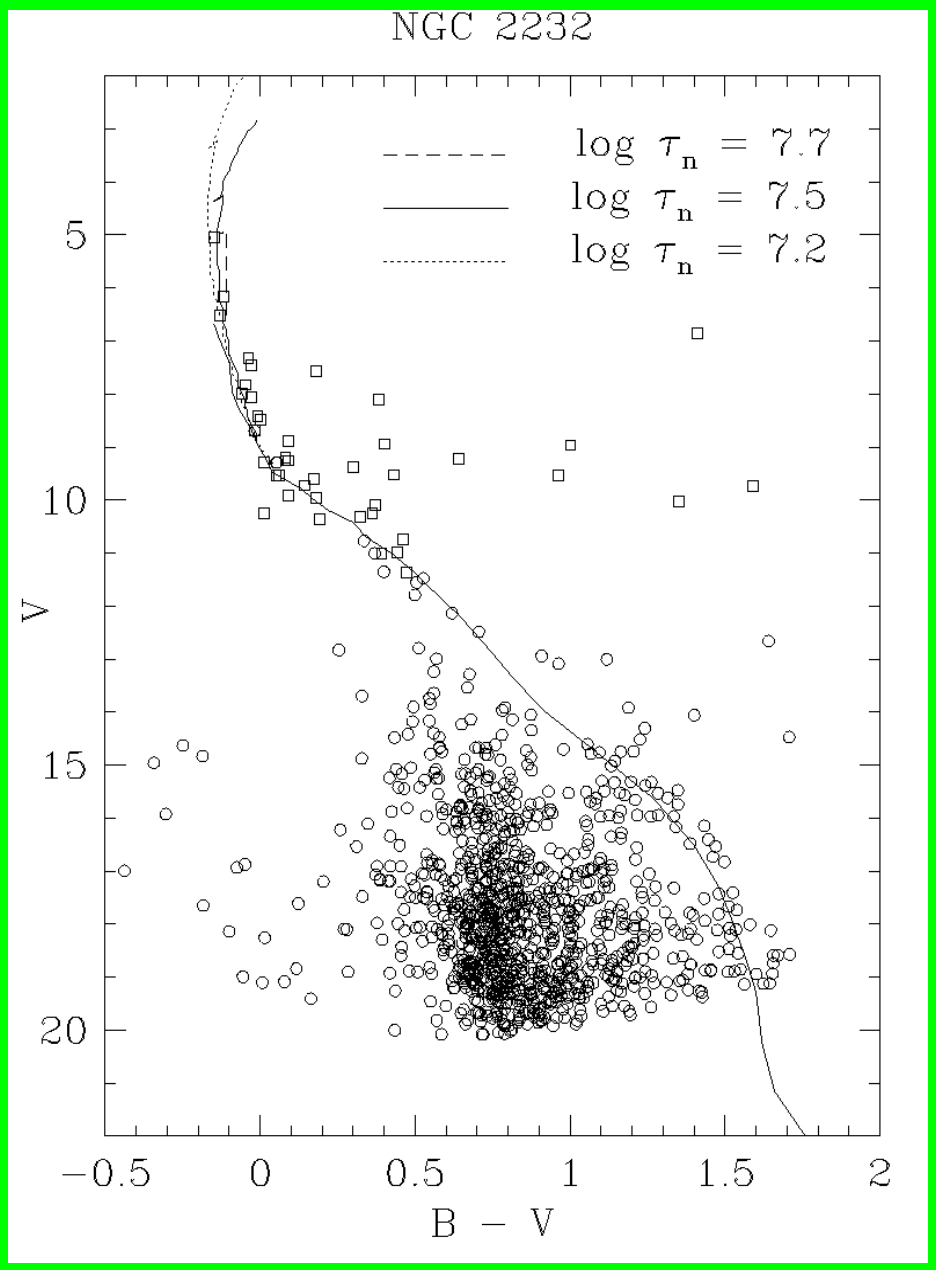

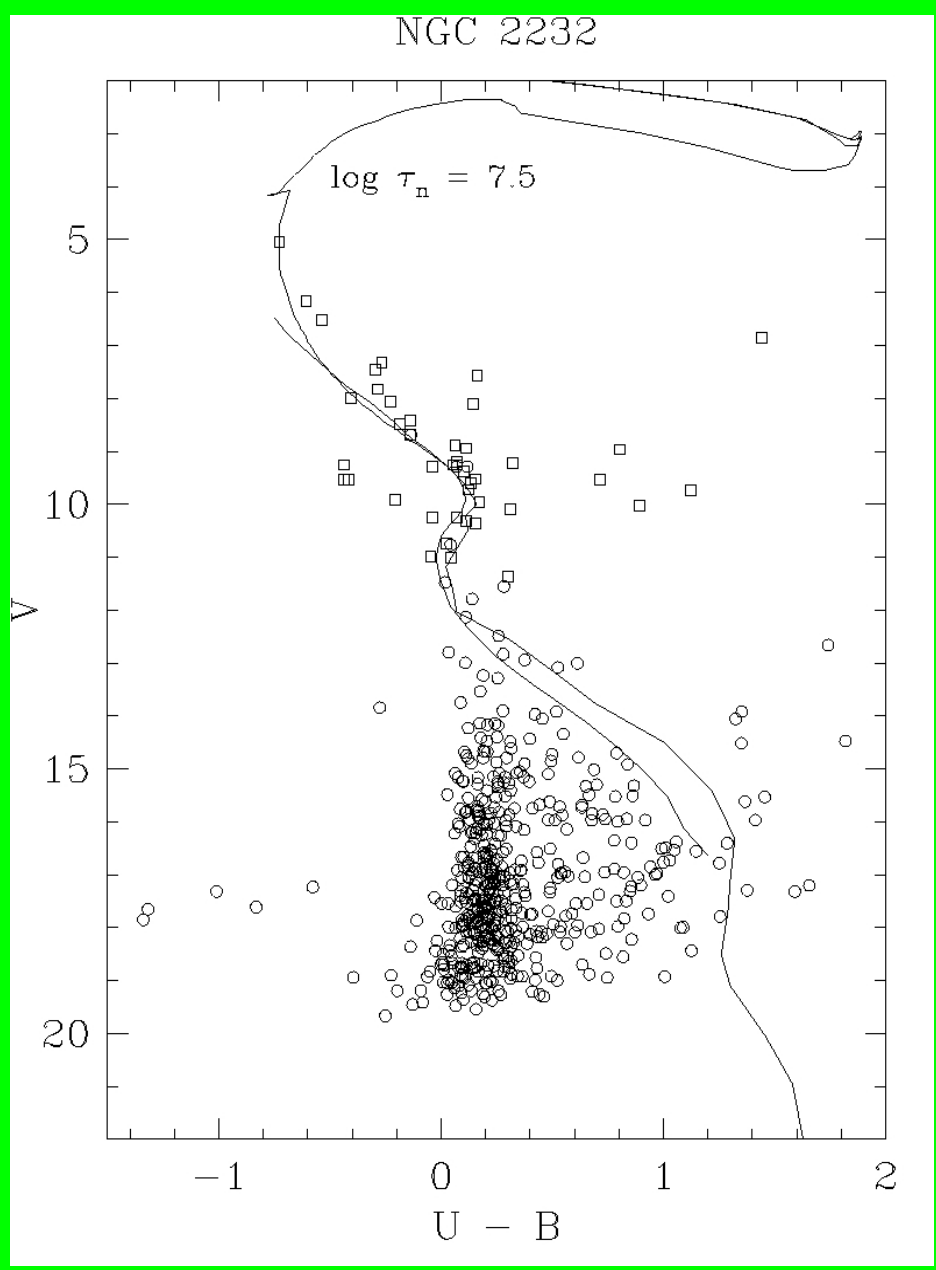

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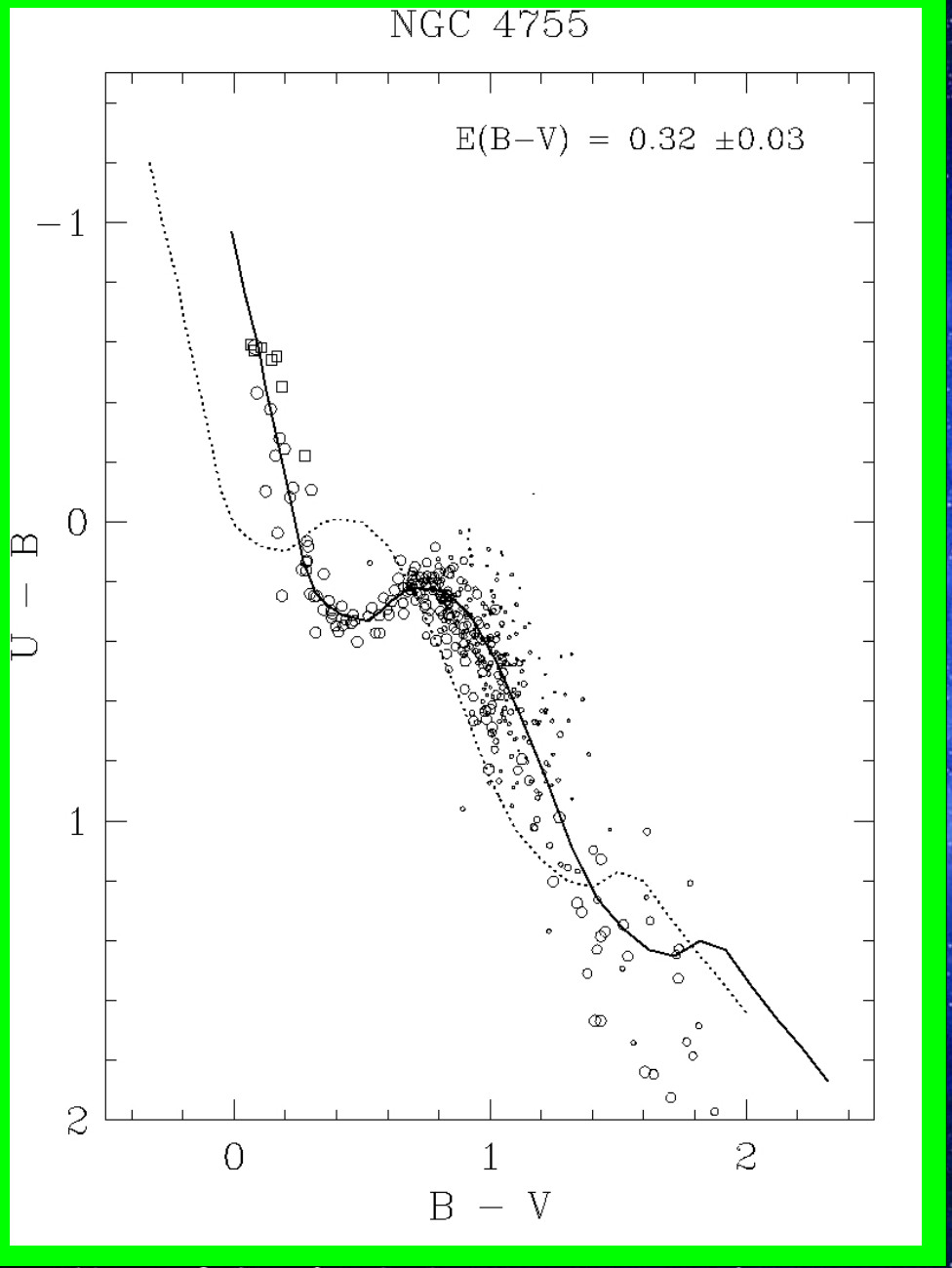

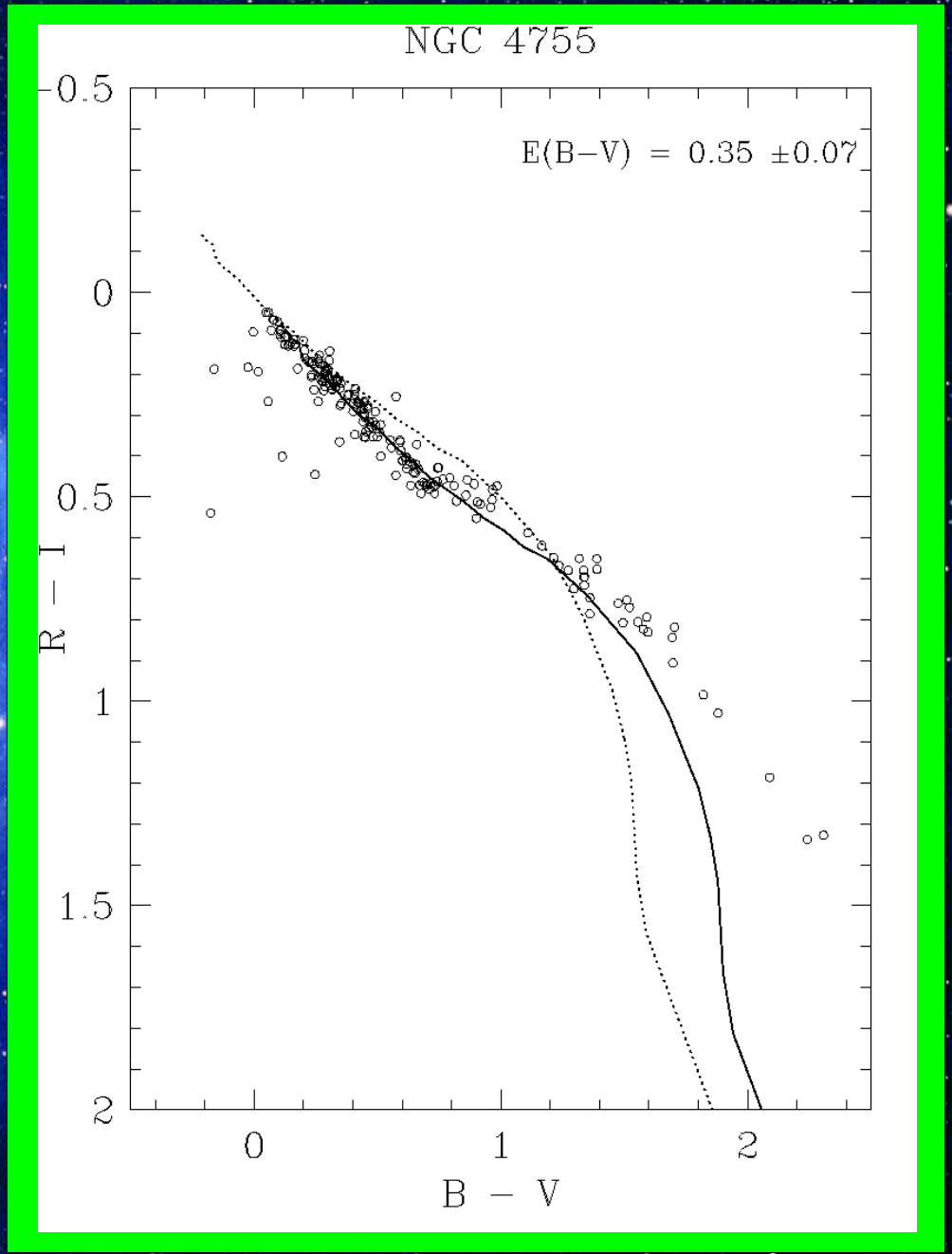

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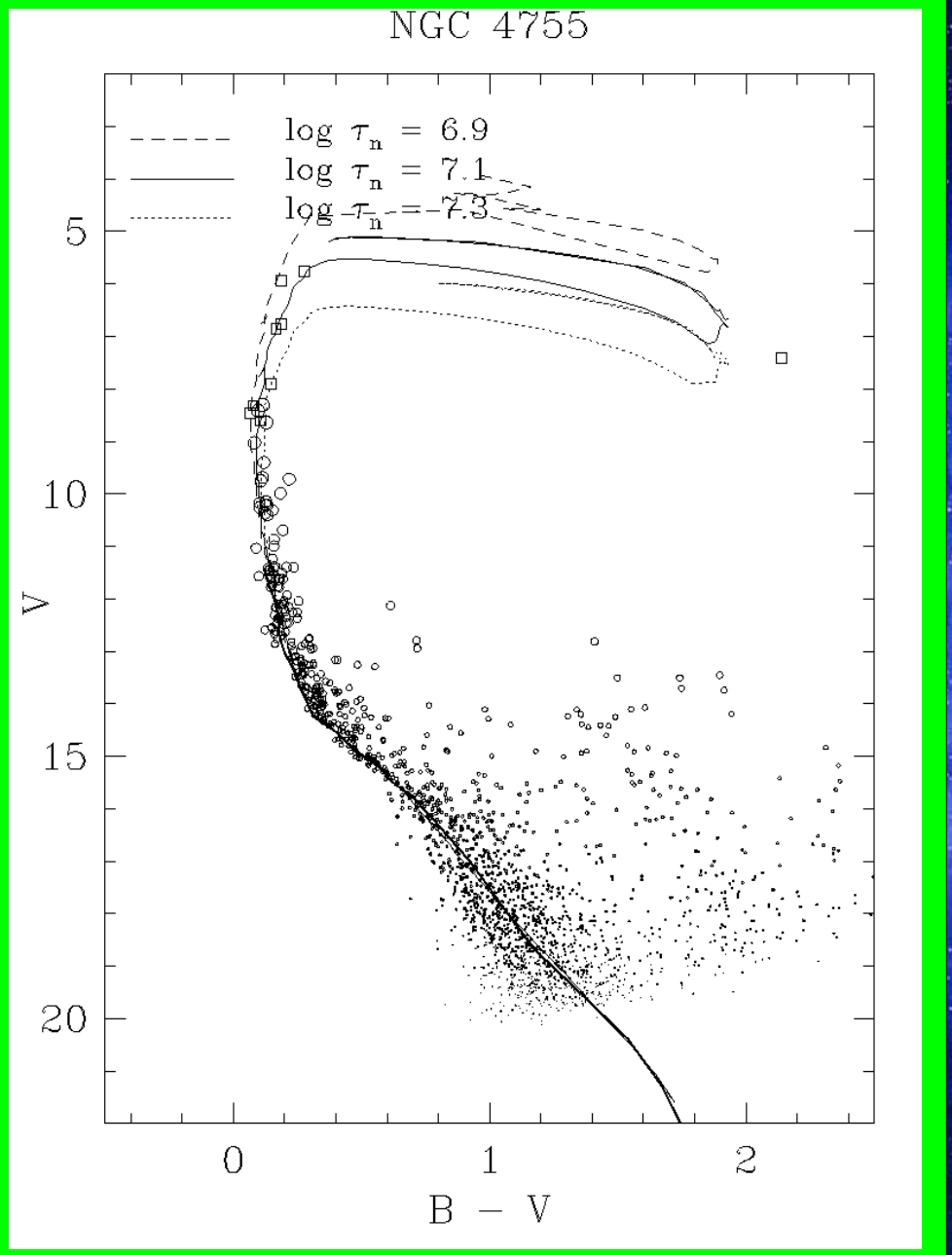

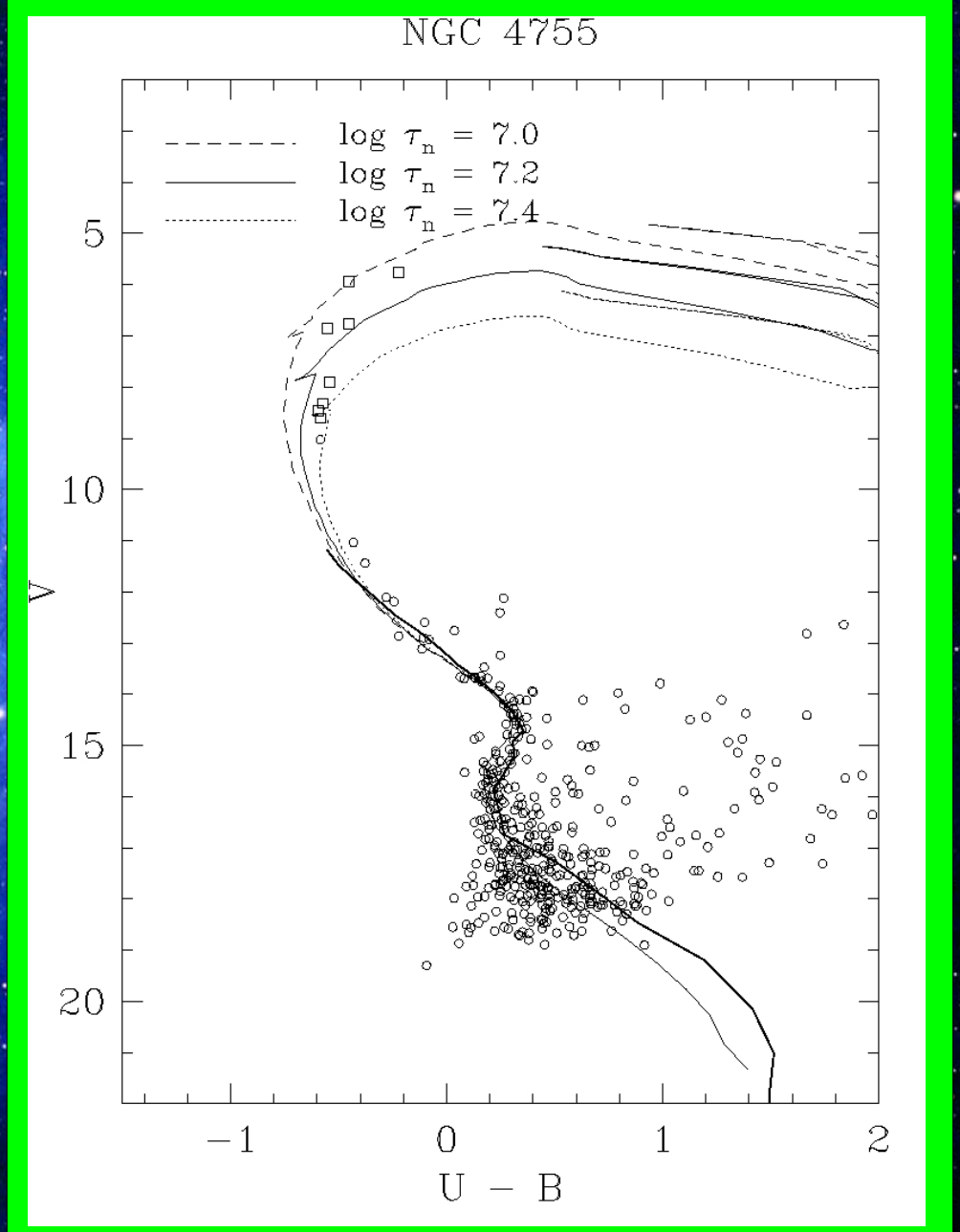

PMS Models

Palla & Stahler (PS99)

Orion Nebula properties
as initial condition

D'Antona & Mazzitelli 1997 (DM97)

Convection treated with FST
(Full Spectrum of Turbulence)
instead of mixing length

Siess et al. 2000 (SDF00)

non-grey atmosphere

Baraffe et al. 1998 (BCAH98)

sophisticated non-grey atmosphere
of Allard et al. 1998

self consistent colors,
fully integrated with the models

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Color-Temperature transformations

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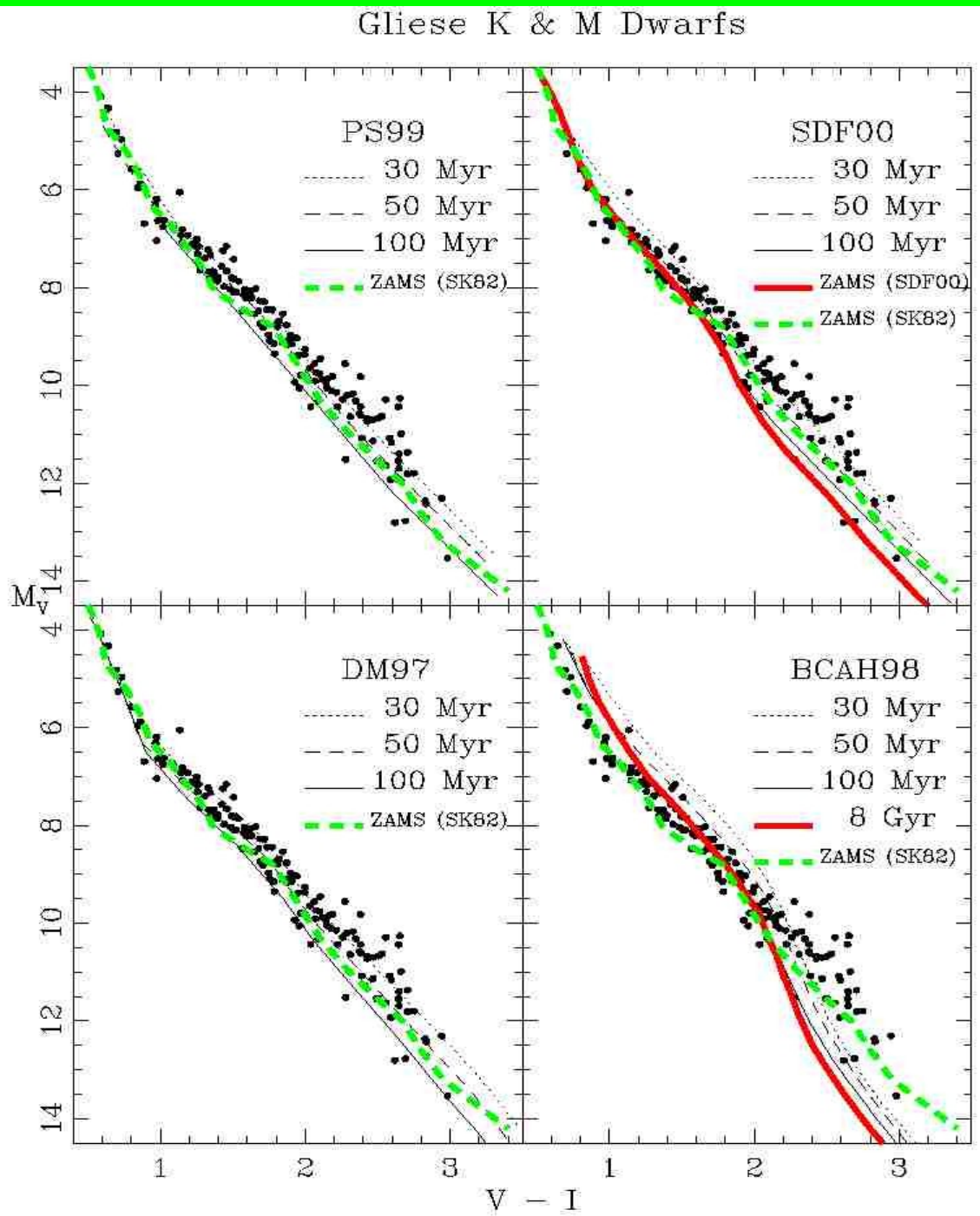
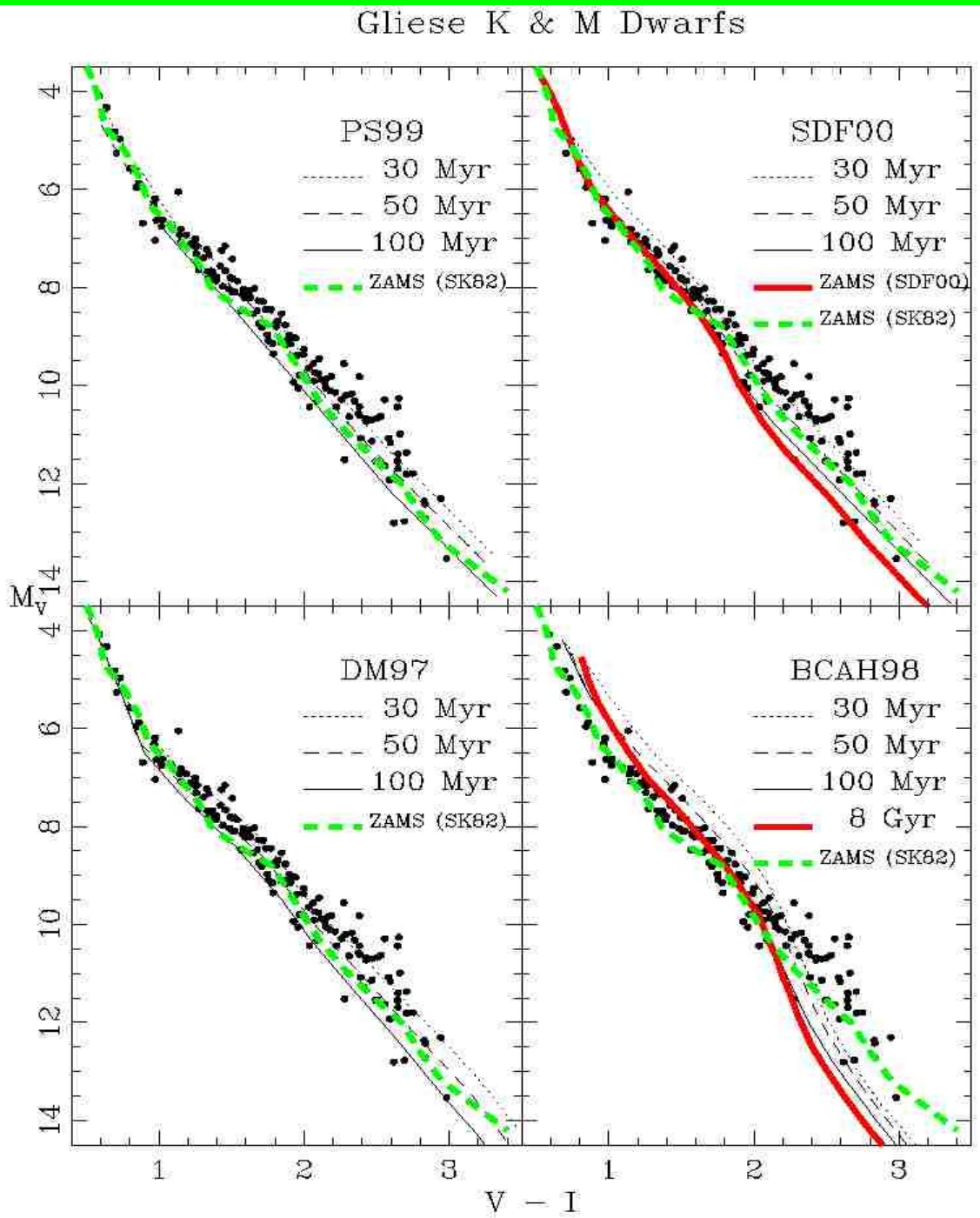


Testing against old field dwarfs.

How good are our models of low mass stars?



Testing against old field dwarfs.

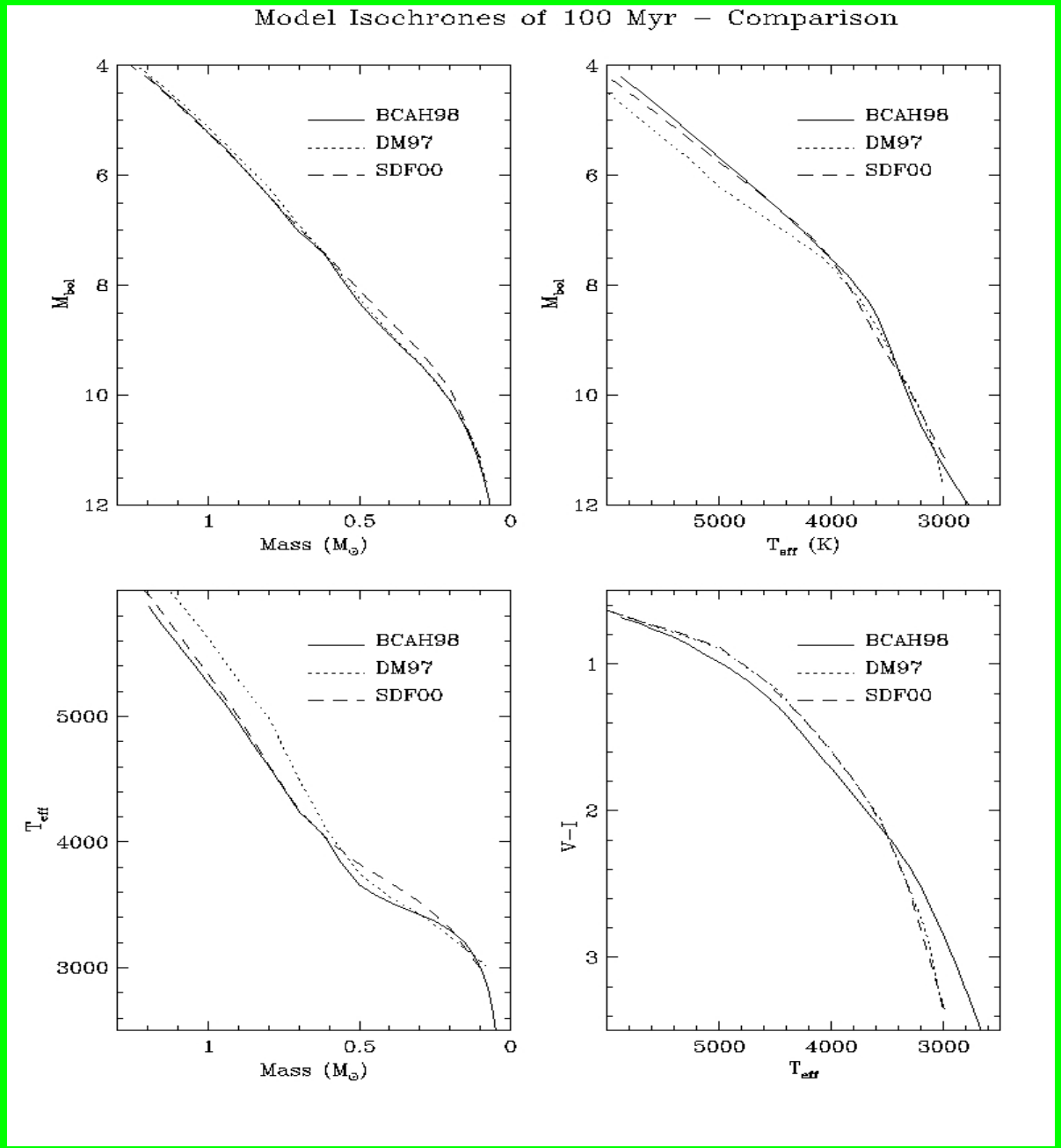
How good are our models of low mass stars?

No good

Ages given by PS99, SDF00 and DM97 are ***unreliable***

BCAH98 good match only in a 0.4 mag range

How do the models differ?



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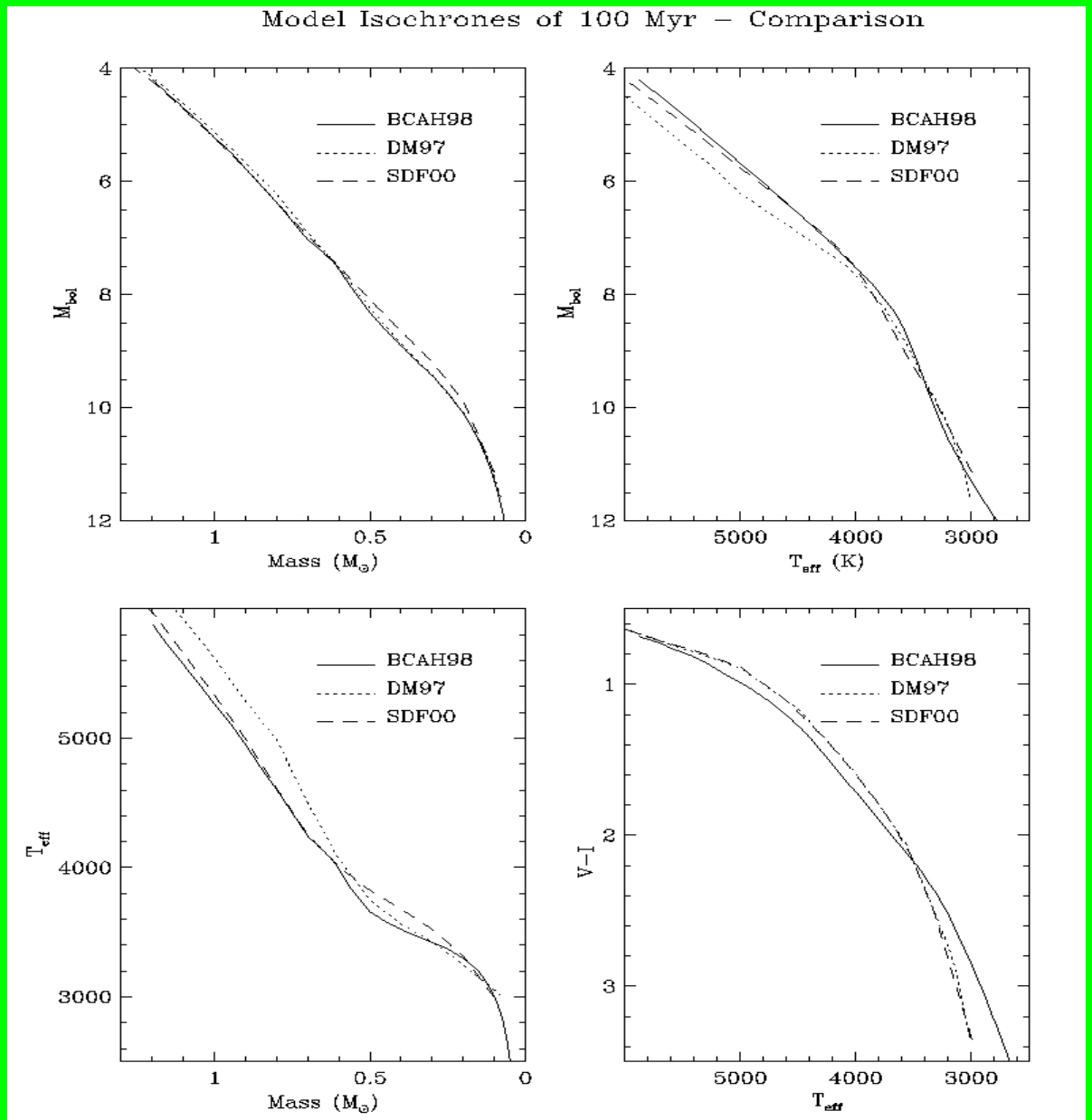

Mass-luminosity is consistent

DM97 deviates by ~400 K for intermediate mass

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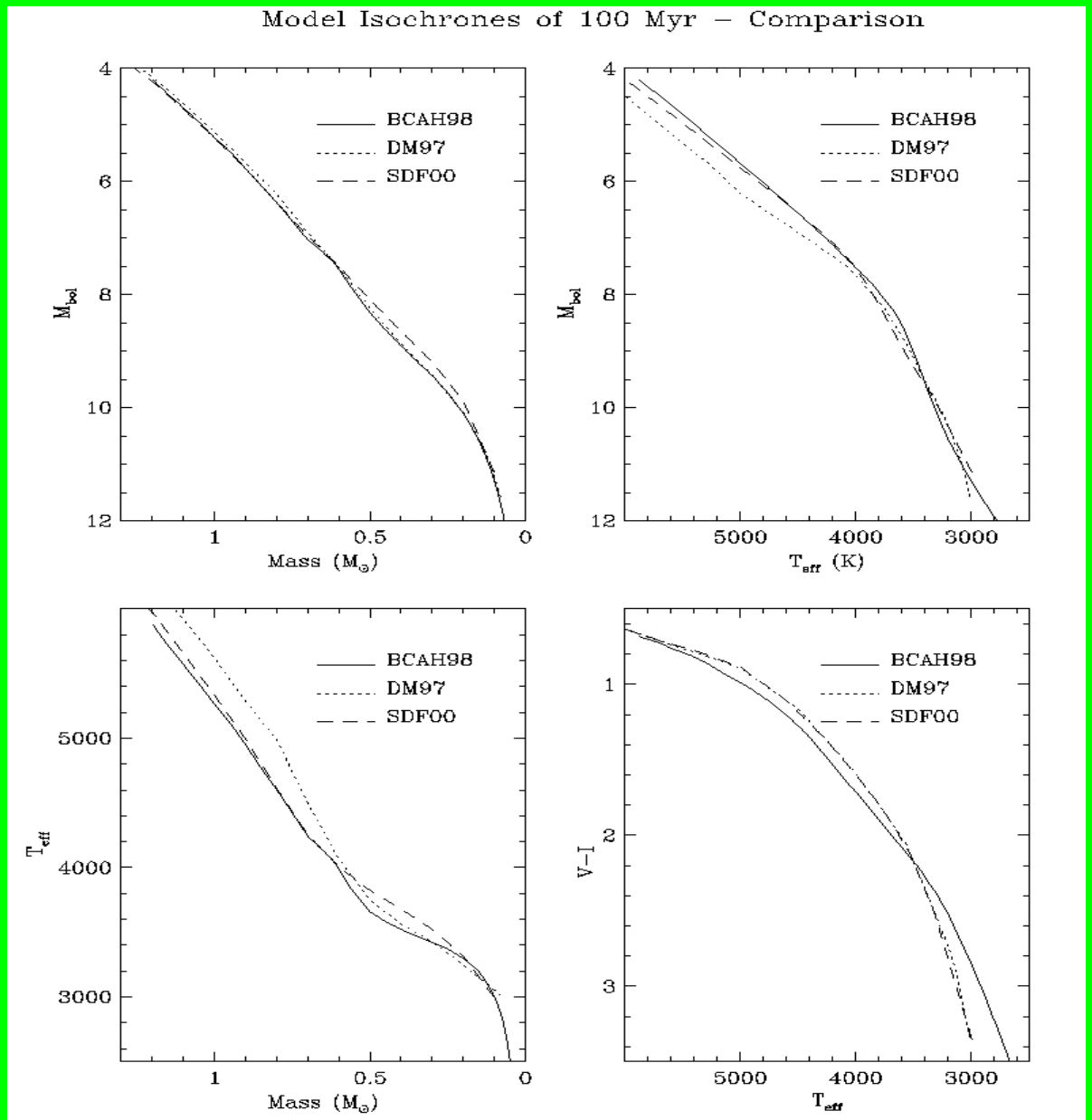

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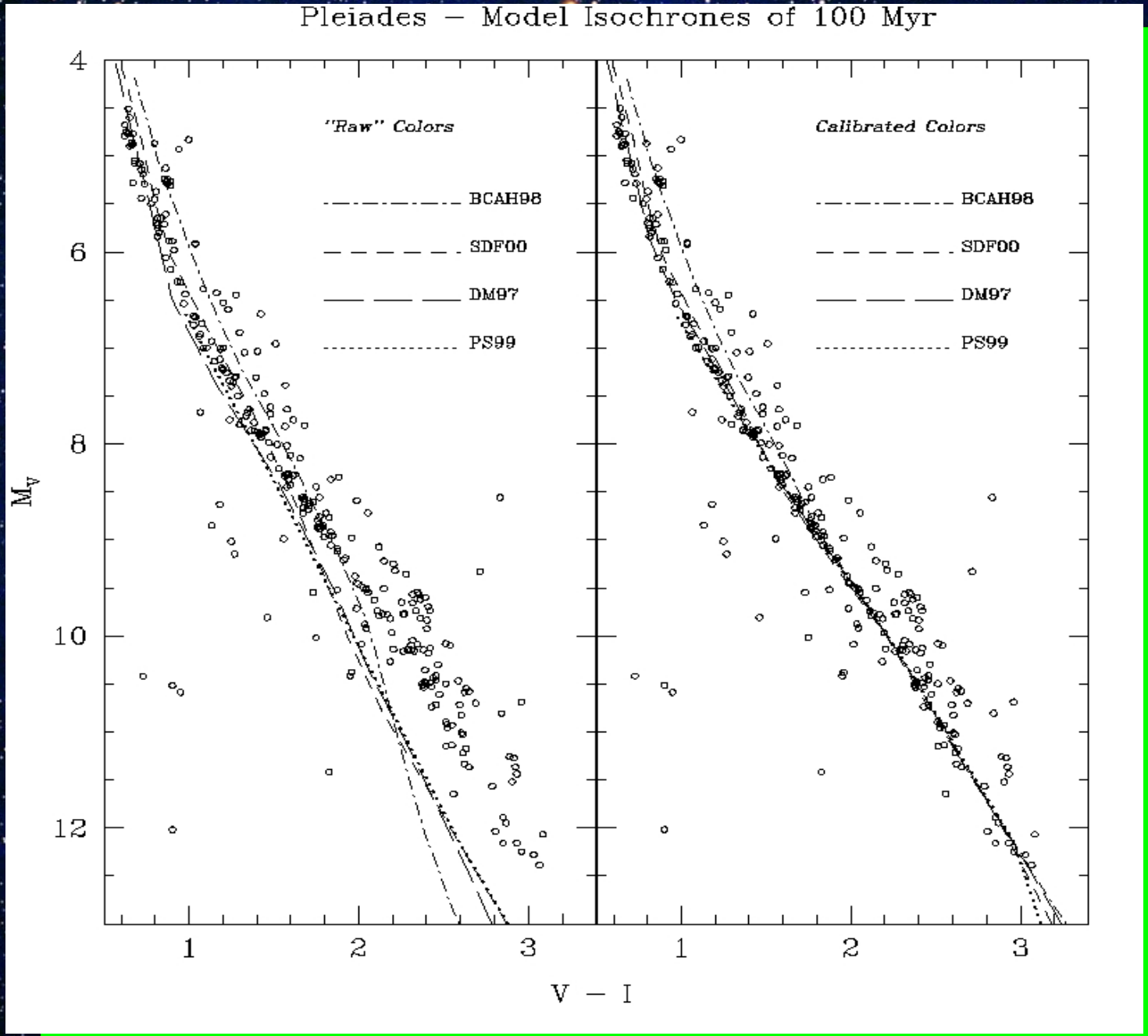
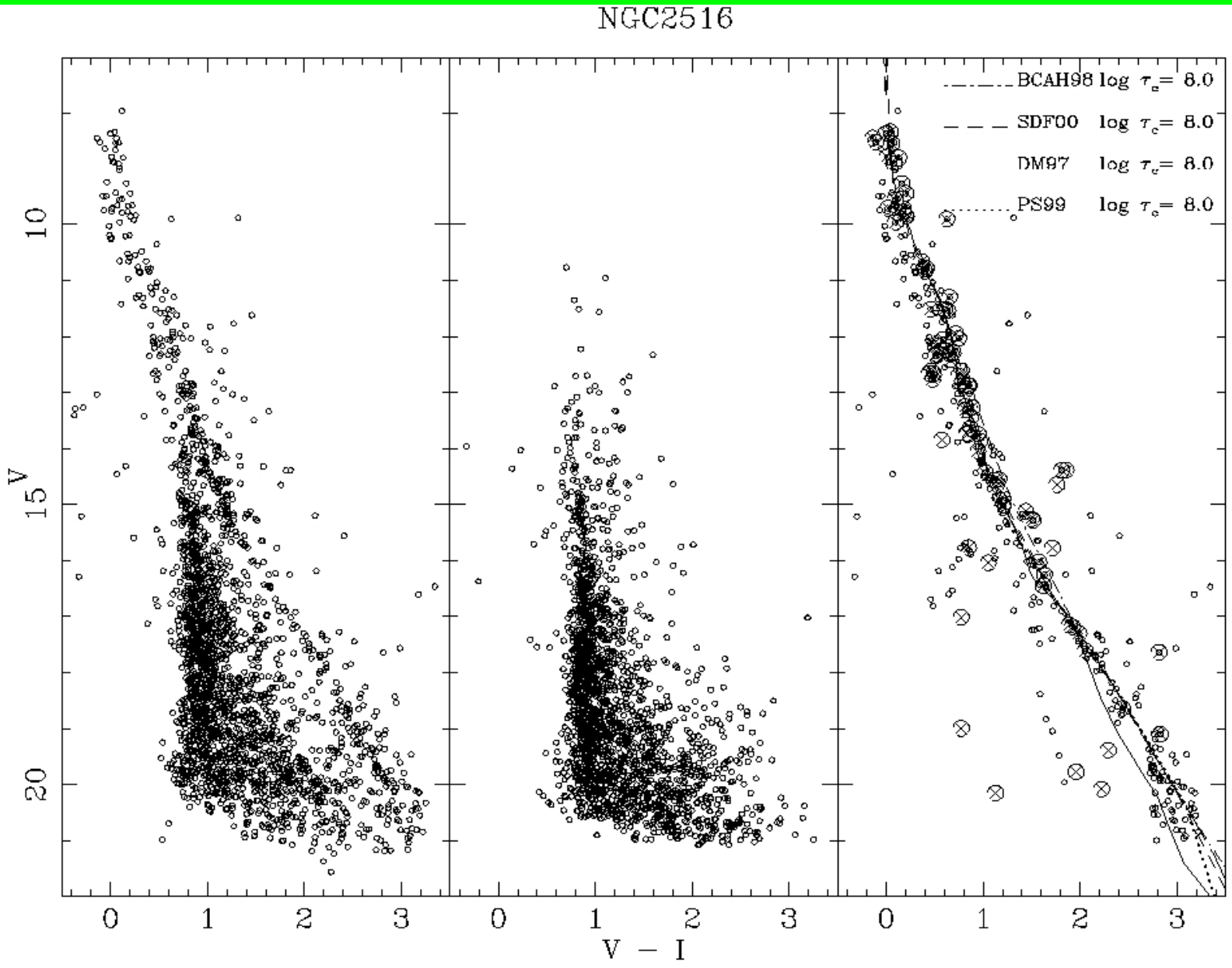
Color-Temperature conversion is the dominant difference

An empirical Color-Teff calibration for young low mass stars



Fitting Contraction Ages



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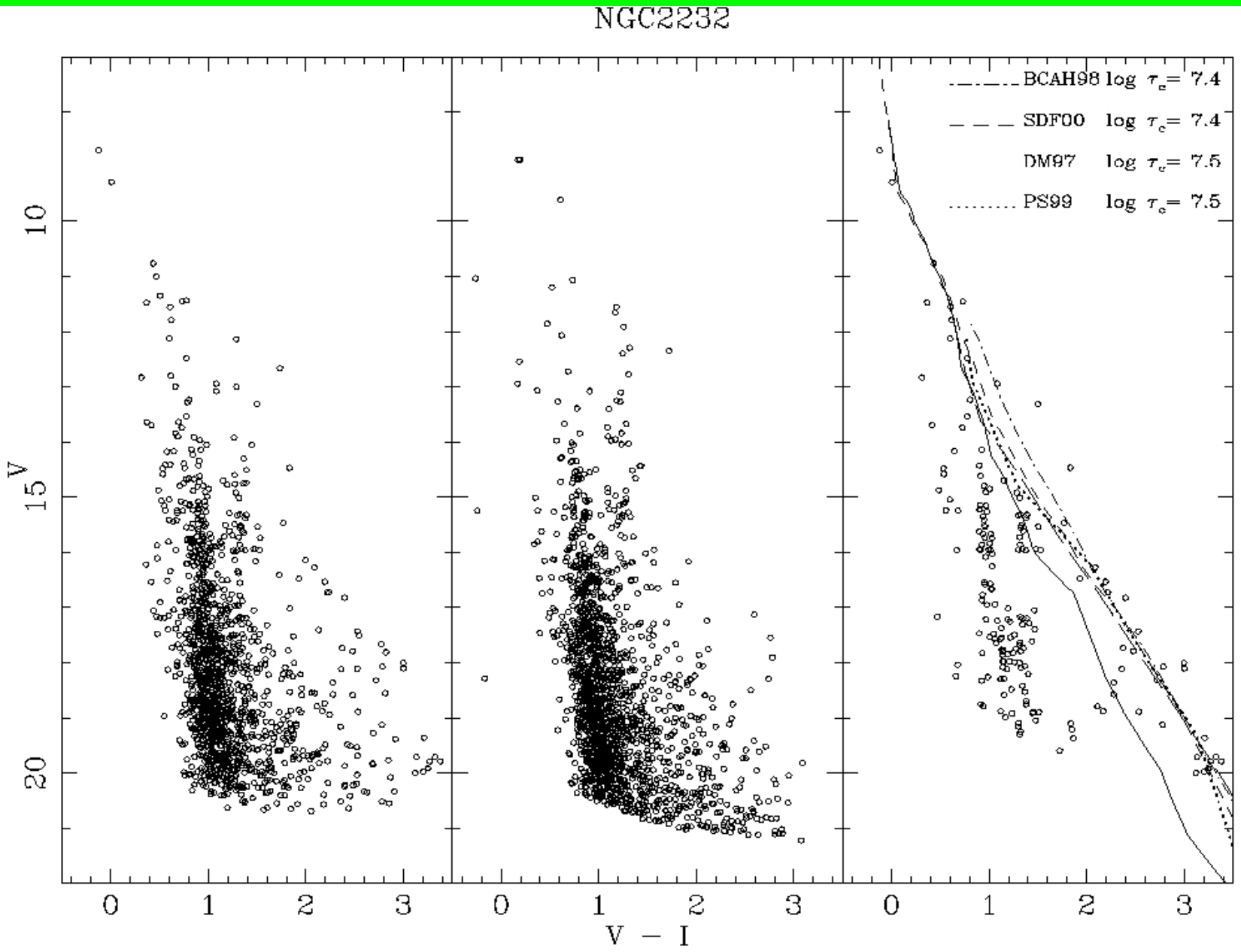

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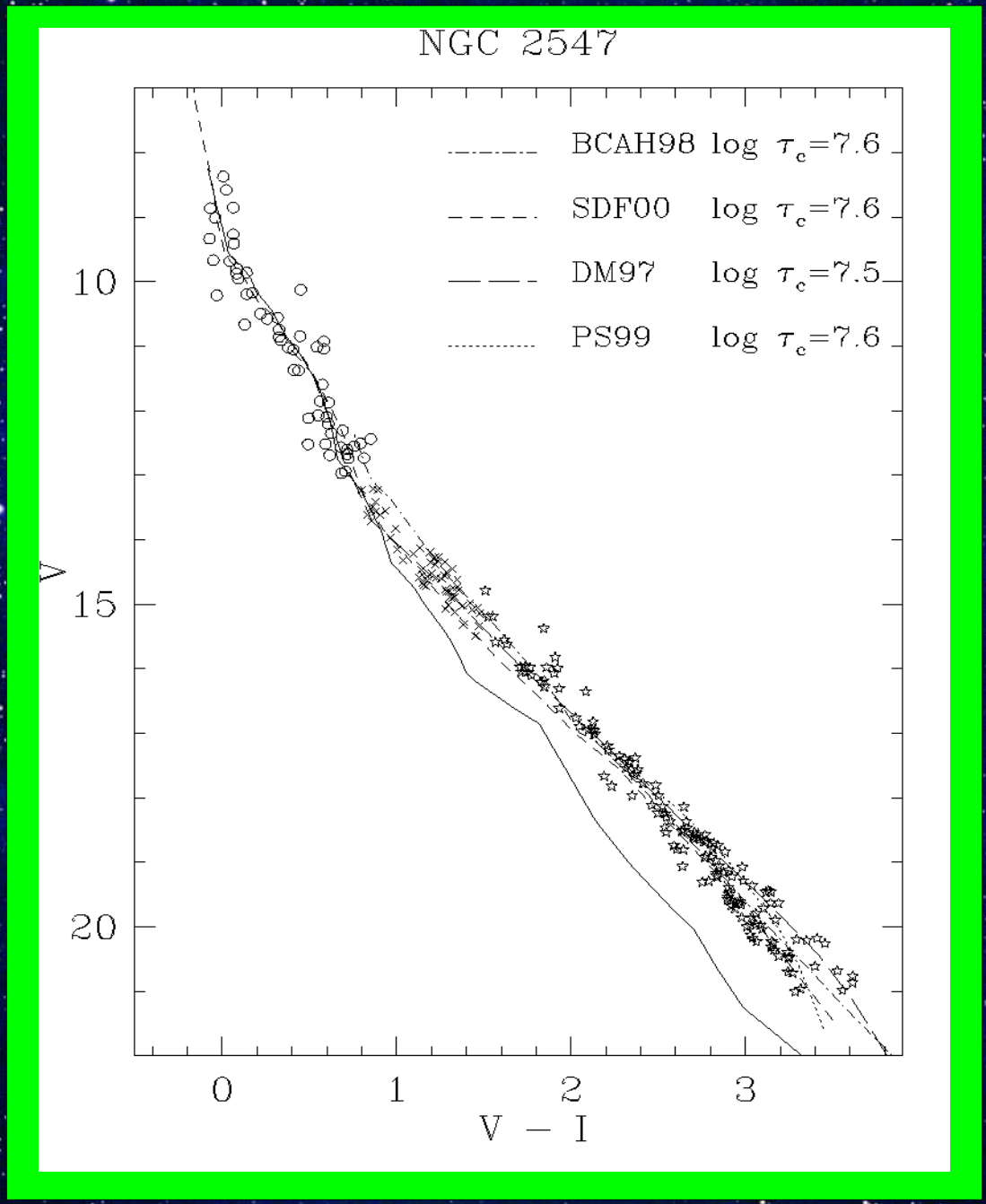

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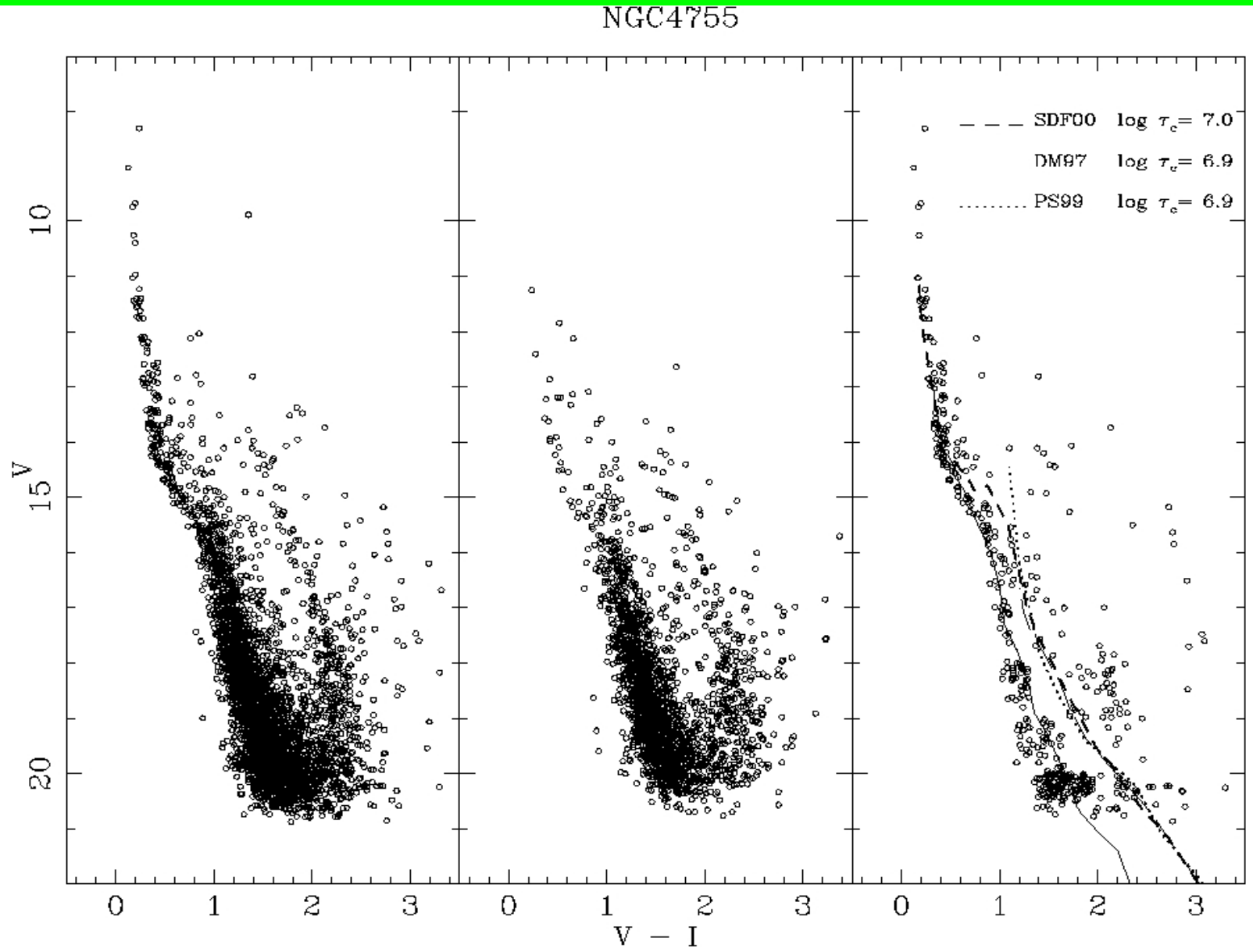
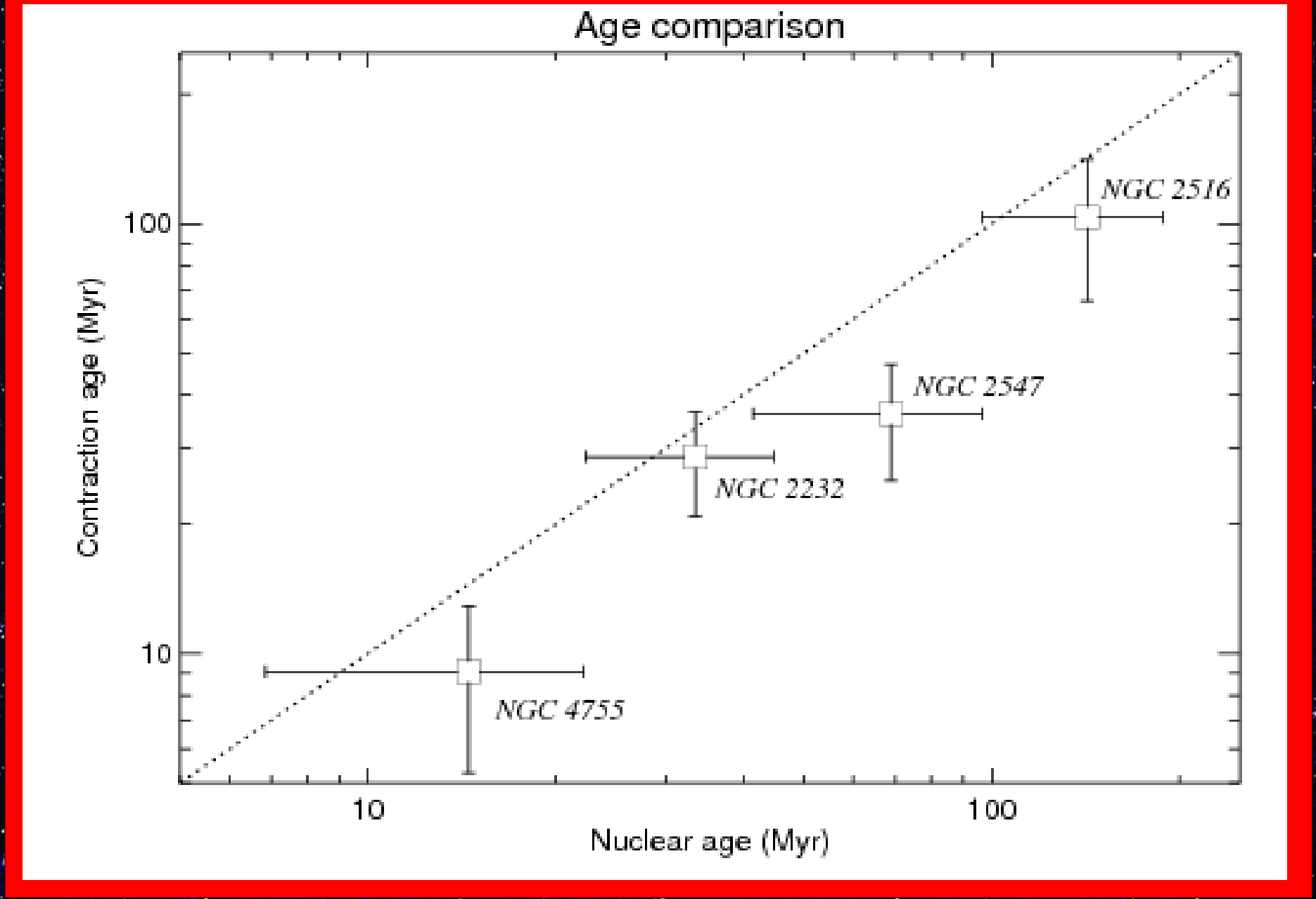
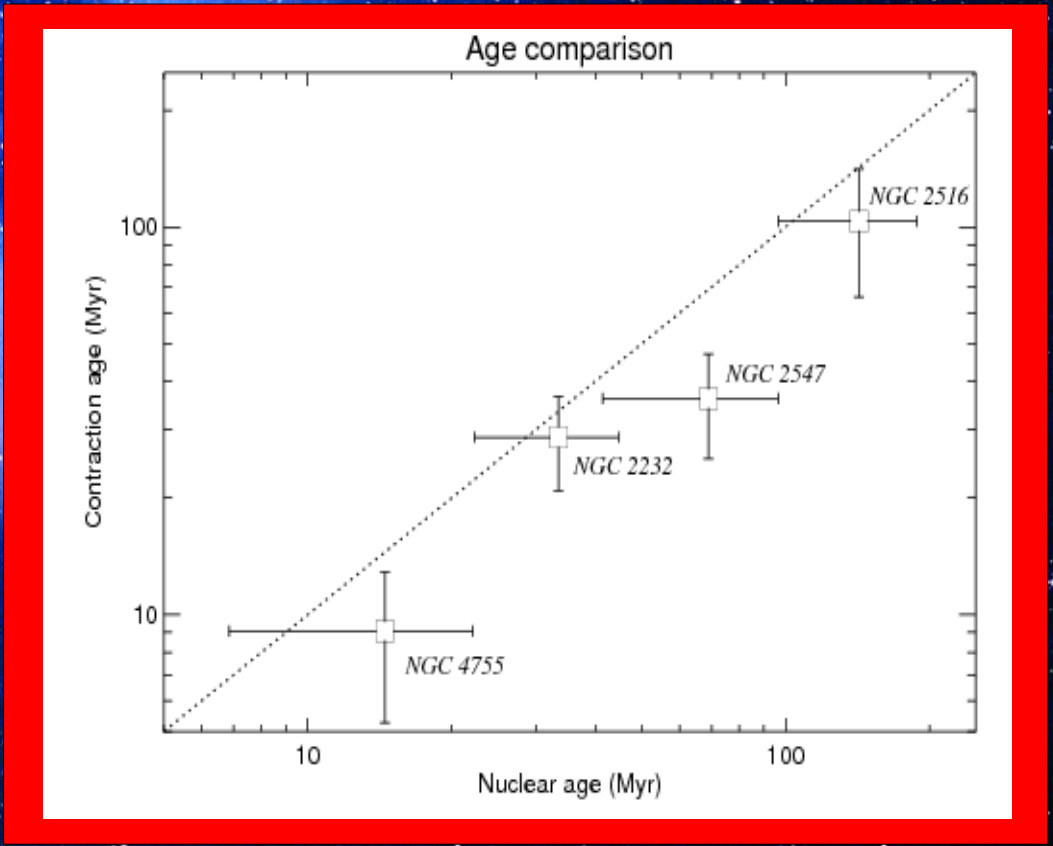


Lyra et al. 2006



Conclusions

-Consistency between the two determinations
-Systematic deviation within 1-sigma



Conclusions

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-Systematic deviation within 1-sigma

-FLAMES follow-up of NGC2232
and NGC2362 for LDB ages