# Definition of Star Clusters

Star clusters are physically related groups of stars held together by mutual gravitational attraction.

The number of all star clusters in the Milky Way is about 10 000 but only 3000 in catalogues. From these, about 170 Globular Clusters (“old”, Population II).

# Working Hypothesis

All members of an individual Star Cluster are born within one Giant Molecular Cloud (GMC) over a time scale of some few Myrs.

What are the immediate conclusions?

# All members of an individual star cluster have:

- ***Identical distance from the Sun:*** +- The volume expansion of the cluster (diameters < 25 pc)
- ***Identical age:*** +- Time scale of star formation (a few Myrs)
- ***Identical metallicity:*** +- Inhomogeneities of the initial GMC and the chemical evolution of the giant branch
- ***Identical kinematical characteristics:*** +- Intrinsic spread
  - Radial velocity
  - Proper motion

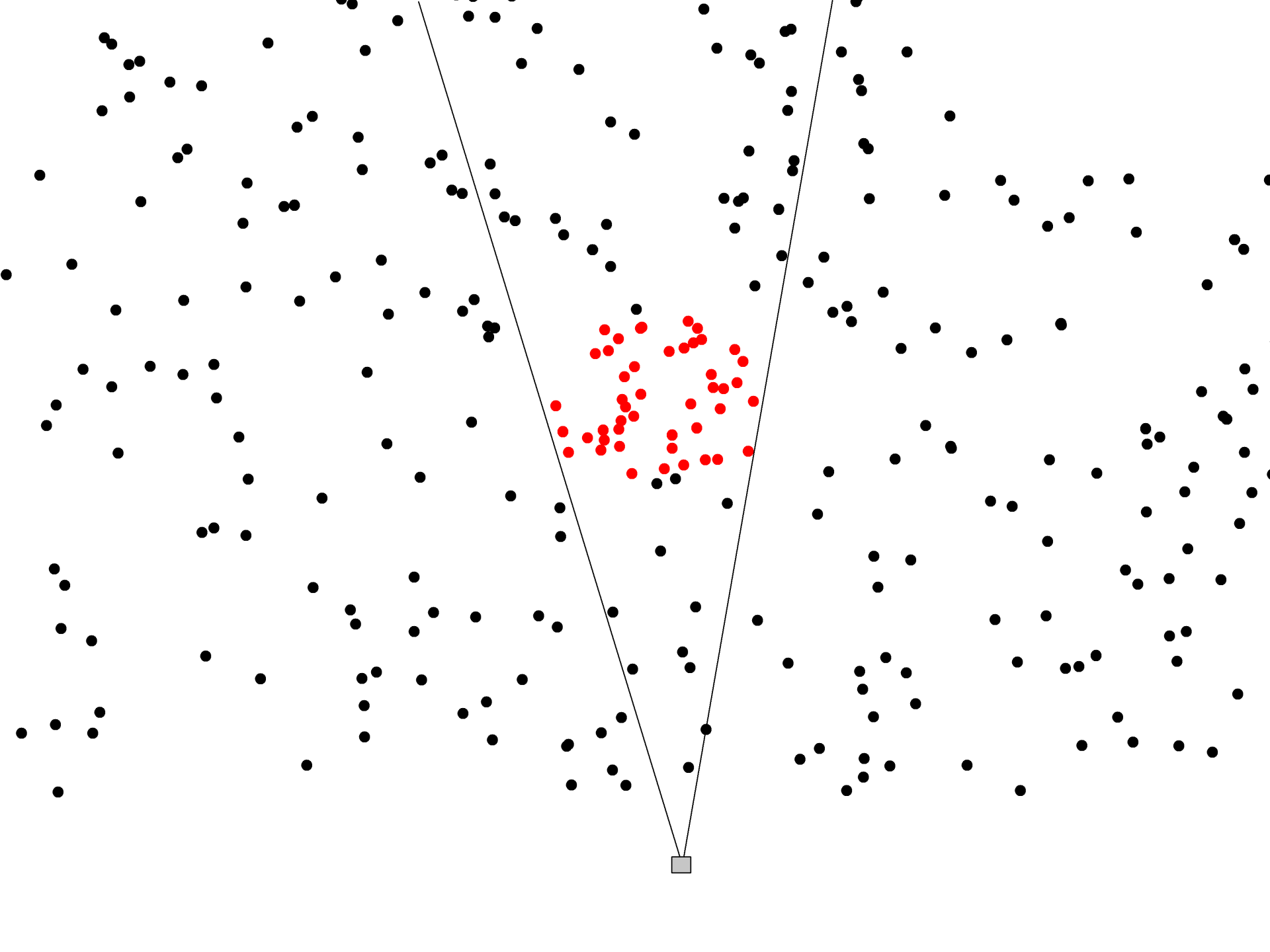
# Characteristics – Open Clusters

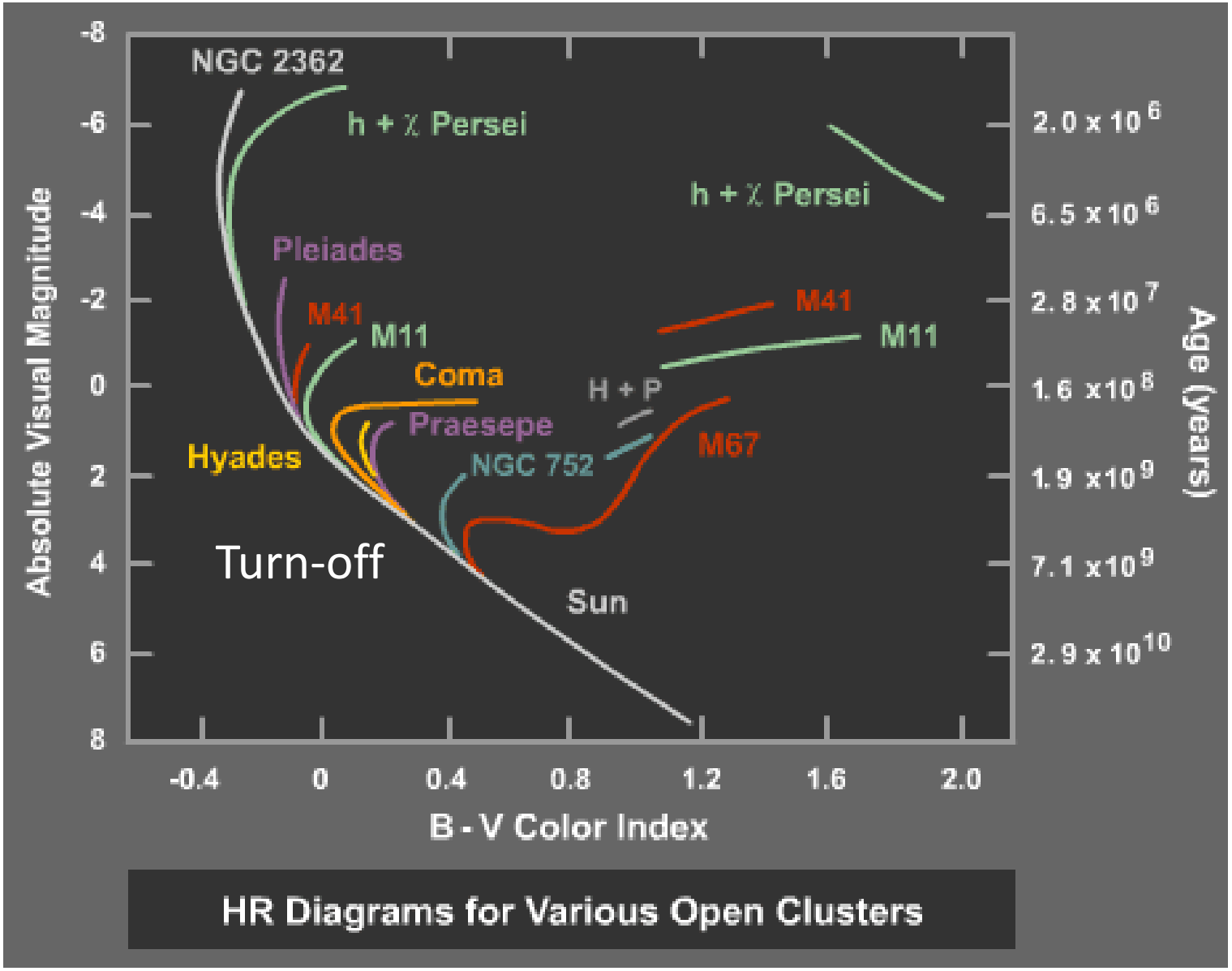
- **Age:** 1 Myr – 5 Gyr (Population I)
- **Metallicity:** -1.0 to +0.6 dex (factor 10 to 4) compared to the Sun
- **Distance from the Sun:** > 45 pc
- **Mass range of the members:** 0.08 to 100 M(sun)
- **Total masses:** up to 40000 M(sun)
- **Absolute linear diameter:** 2 to 25 pc

# The cluster parameters

1. Reddening
2. Distance modulus
3. Age
4. Metallicity

Determination in the order: Reddening, age, distance modulus simultaneously, metallicity with possible iterations






Distance: $V_0 - M_V$

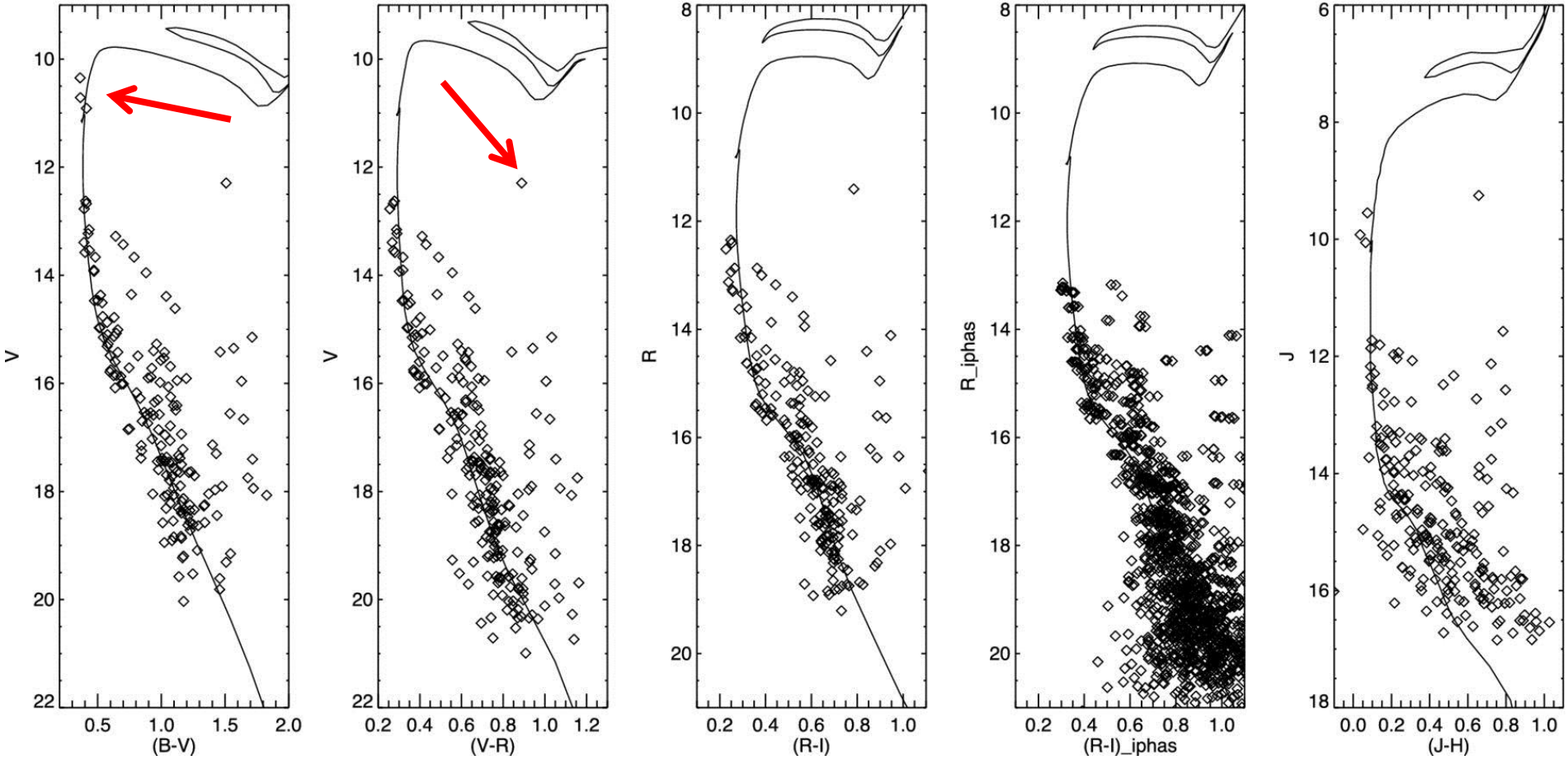
$k \cdot A_V$

$A_V$

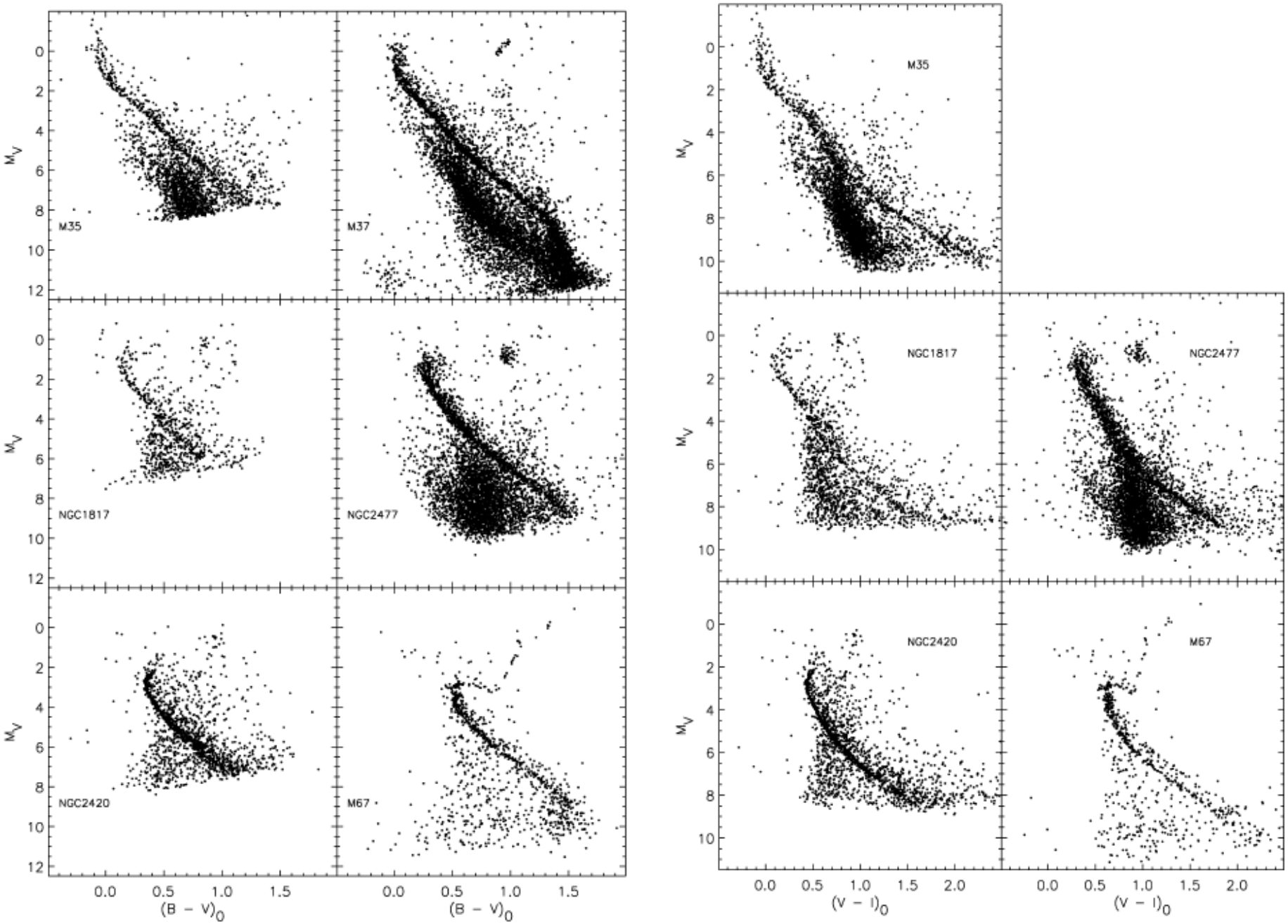
*Reddening*

# Color – Magnitude - Diagram

Different CMDs for one open cluster

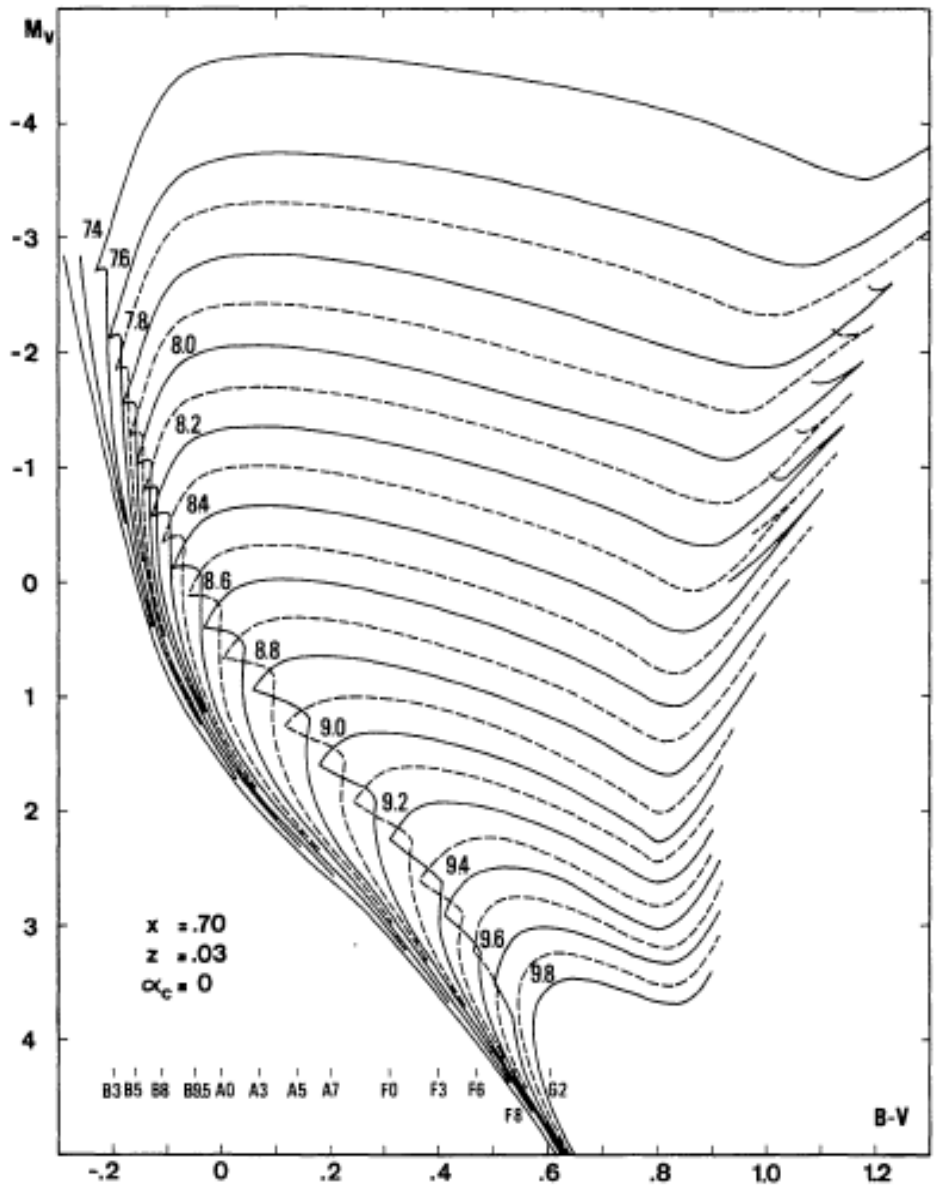


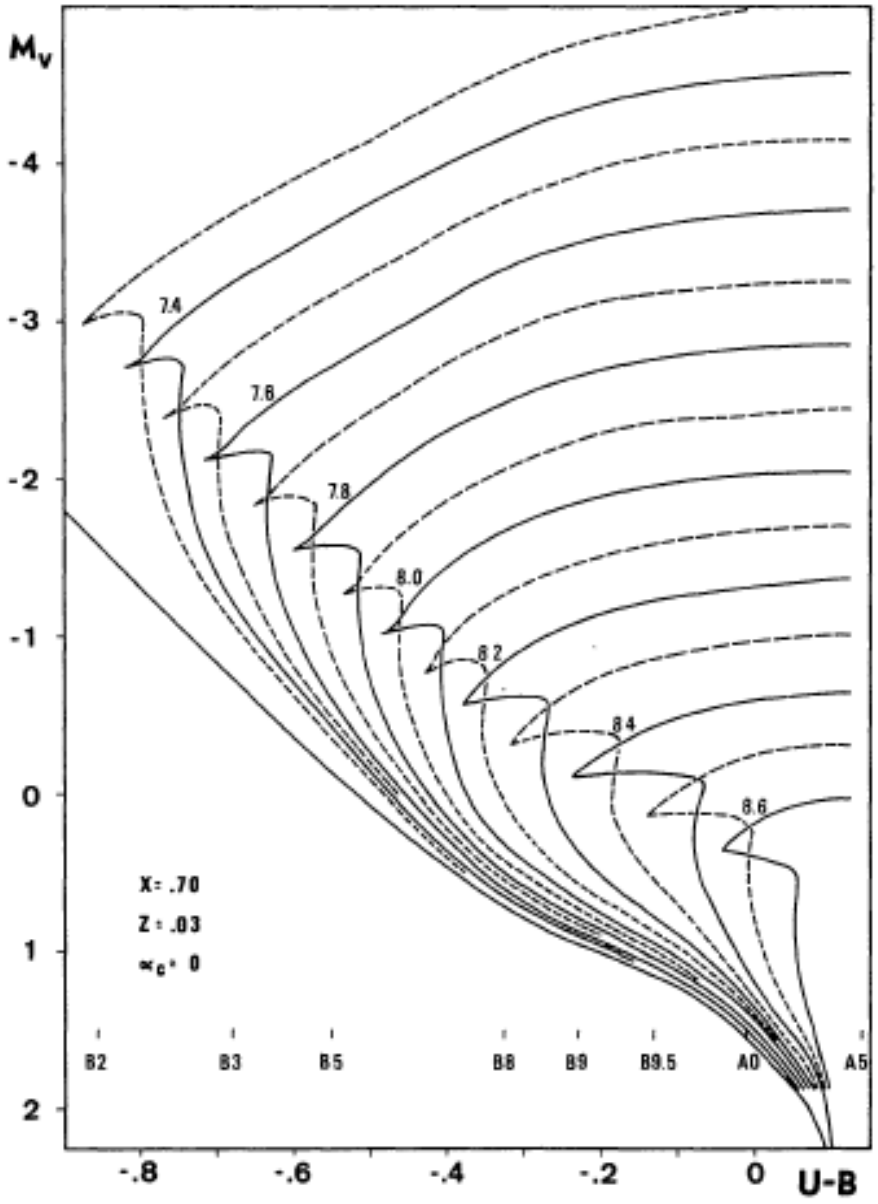

Glushkova et al., 2013, MNRAS, 429, 1102




Grocholski & Sarajedini, 2003, MNRAS, 345, 1015

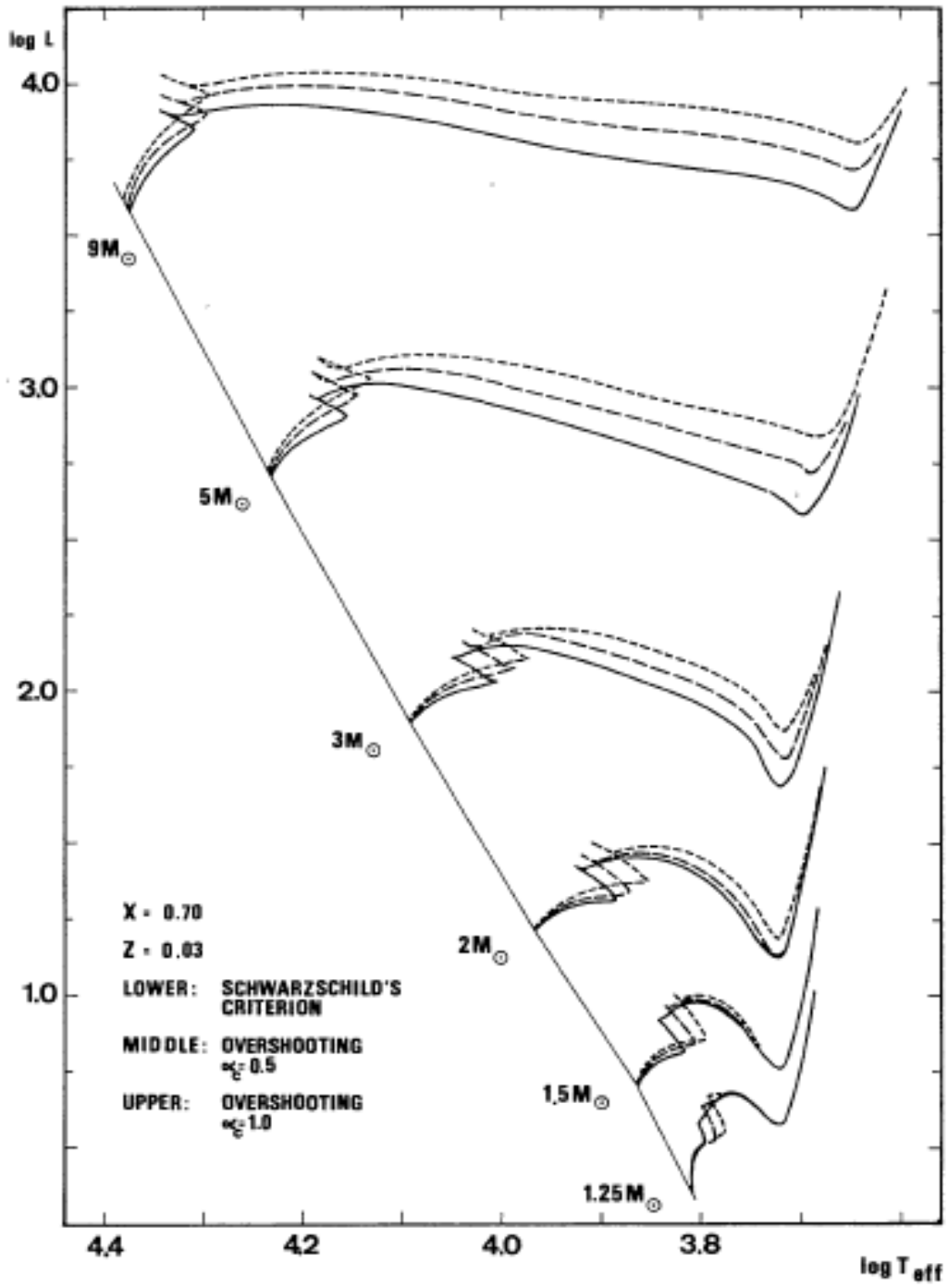
Maeder & Mermilliod, 1981, A&A, 93, 136



Maeder & Mermilliod, 1981, A&A, 93, 136

# Different treatment of convection



# von Hippel, 1998, AJ, 115, 1536

WHITE DWARFS IN OPEN CLUSTERS

| Cluster (1) | Alias (2) | $N_s$ (3) | Reference (4) | $N_b$ (5) | Reference (6) | $N_c$ (7) | Mass (8) | Reference (9) | Age (10) | Reference (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| Hyades..... | | 7 | 1, 2 | 3 | 9, 14 | [a] | 410–480 | 16 | 0.63 | 21 |
| Pleiades..... | M45 | 1 | 3, 4, 5 | ... | | 1–2 | 1000–2000 | 17, 18 | 0.07 | 22 |
| NGC 2168..... | M35 | 2 | 3, 6 | ... | | ... | ≥1600–3200 | 19 | 0.09 | 3, 6 |
| NGC 2287..... | M41 | 2 | 4 | ... | | ... | ... | | 0.18 | 4 |
| NGC 2420..... | | 4 | 7 | ... | | ... | ≥4000 | 20 | 2.4 | 23 |
| NGC 2451..... | | 1 | 3, 8 | ... | | ... | ... | | 0.07 | 8 |
| NGC 2477..... | | 4 | 7 | ... | | ... | ... | | 1.2 | 7 |
| NGC 2516..... | | 4 | 9 | ... | | ... | ... | | 0.14 | 24 |
| NGC 2632..... | M44 | 4 | 10 | ... | | ... | ... | | 0.7 | 25 |
| NGC 2682..... | M67 | 1 | 11 | 2 | 11, 15 | ... | ... | | 4.0 | 24 |
| NGC 3532..... | | 6 | 3, 12, 13 | ... | | ... | ≥600 | 13 | 0.17 | 13 |
| Total ..... | | 36 | | 5 | | ... | | | | |

NOTE.—NGC 2632 = Praesepe.

Single Multiple

In total, 41 WDs until 1998 found, no firm improvement after that

# **Fellhauer et al., 2003, ApJ, 595, L53**: The White Dwarf Deficit in Open Clusters: Dynamical Processes

PROPERTIES OF THE OPEN CLUSTER MODELS

| Parameter | $N = 2000$ | $N = 10{,}000$ |
|---|---|---|
| Total mass ($M_\odot$) | 1317.1 | 6668.1 |
| Crossing time (Myr) | 6.2 | 2.7 |
| Relaxation time (Myr) | 180.7 | 109.1 |
| Tidal radius (pc) | 15.6 | 26.7 |
| Half-mass radius (pc) | 2.5 | 2.4 |
| Core radius (pc) | 0.9 | 1.0 |
| Velocity dispersion (km $s^{-1}$) | 0.8 | 1.8 |

RESULTS OF OUR SIMULATIONS AFTER 100 MYR OF EVOLUTION

| $N$ | $f_b$ | $v_{kick}$ | $WD_{tot}$ | $WD_r$ | $f_{WD}$ | $f_N$ | Run |
|---|---|---|---|---|---|---|---|
| 2000 | 0.0 | 0 | 8 | 8 | 1.00 | 0.99 | 1 |
| | 0.0 | 1 | 8 | 8 | 1.00 | 0.99 | 1 |
| | 0.0 | 2 | 8 | 4 | 0.50 | 0.98 | 1 |
| | 0.0 | 5 | 8 | 1 | 0.13 | 0.98 | 1 |
| | 0.2 | 1 | 6 | 5 | 0.83 | 0.98 | 3 |
| | 0.2 | 2 | 6 | 1 | 0.17 | 0.98 | 1 |
| | 0.2 | 5 | 6 | 1 | 0.09 | 0.98 | 2 |
| | 0.4 | 1 | 5 | 5 | 1.00 | 0.98 | 3 |
| | 0.4 | 2 | 5 | 4 | 0.80 | 0.98 | 3 |
| | 0.4 | 5 | 5 | 1 | 0.20 | 0.98 | 1 |
| | 0.8 | 1 | 3 | 3 | 1.00 | 0.98 | 1 |
| | 0.8 | 2 | 3 | 3 | 1.00 | 0.99 | 1 |
| | 0.8 | 5 | 1 | 0 | 0.00 | 0.97 | 1 |
| 10,000 | 0.0 | 1 | 43 | 43 | 1.00 | 1.00 | 2 |
| | 0.0 | 2 | 43 | 42 | 0.98 | 1.00 | 1 |
| | 0.0 | 5 | 43 | 38 | 0.88 | 0.99 | 2 |
| | 0.2 | 2 | 39 | 38 | 0.97 | 0.99 | 1 |
| | 0.2 | 5 | 39 | 37 | 0.95 | 0.99 | 1 |
| | 0.4 | 2 | 27 | 27 | 1.00 | 0.99 | 1 |

Our models suggest that almost all white dwarfs would be lost from the cluster if the average recoil speed were to exceed twice the velocity dispersion of the cluster.