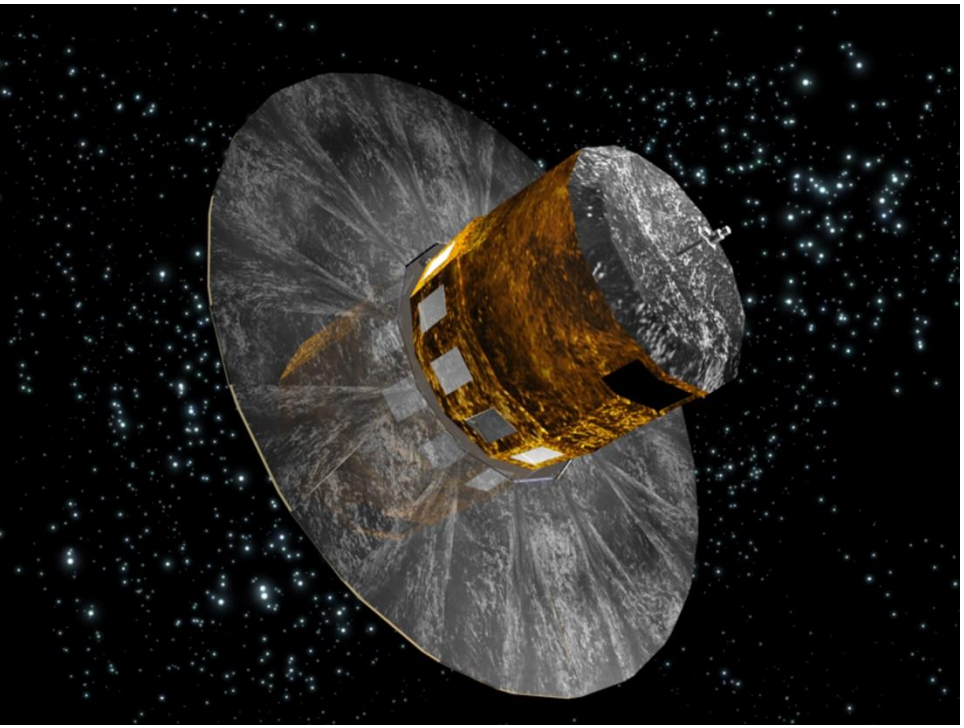
Introduction – Star Clusters I

The Gaia Satellite Mission

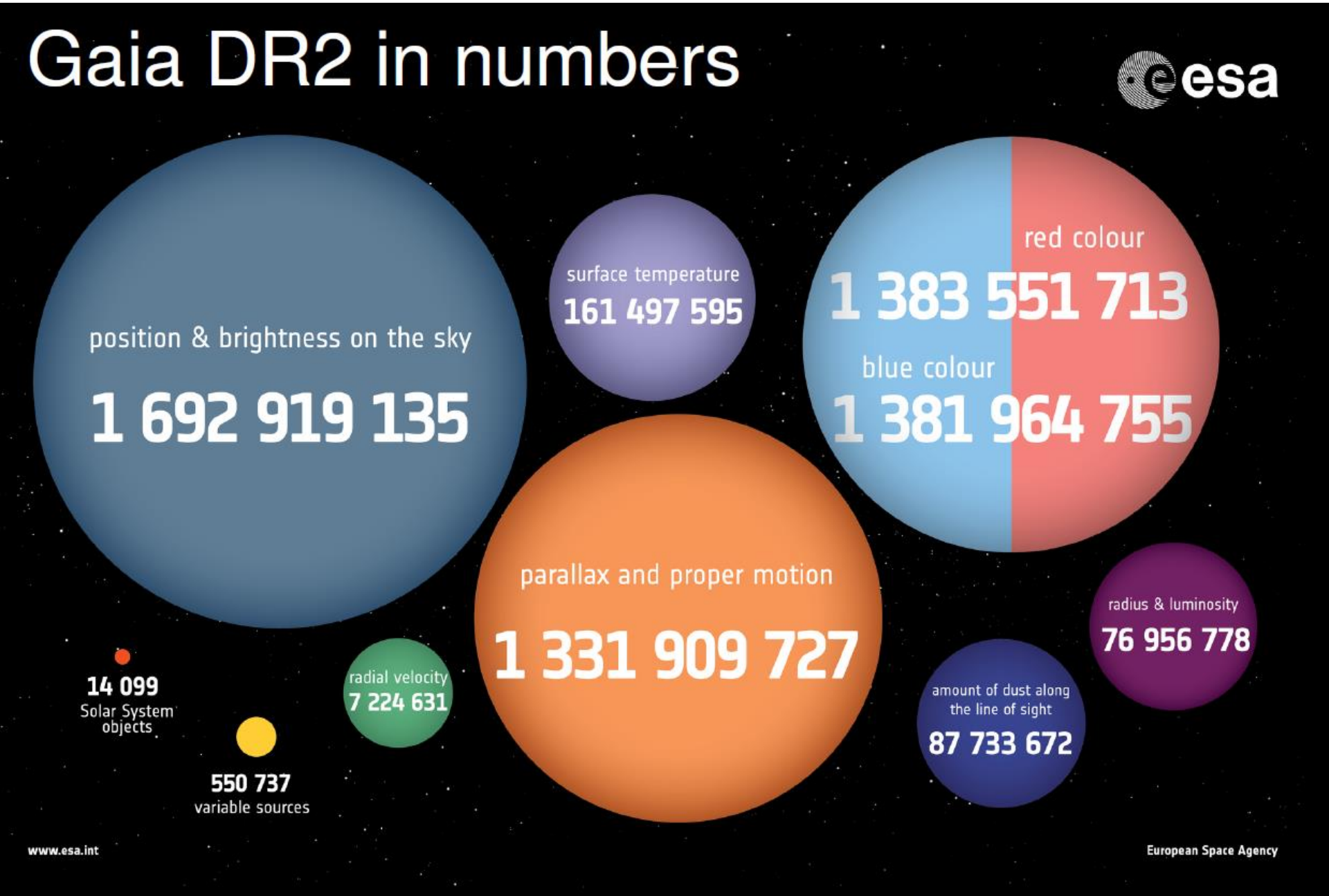


Launched in 2013

At Sun–Earth Lagrange point L2 located approximately 1.5 million kilometres from Earth

- Positions and proper motions of objects
- Spectrophotometry of objects
- Spectra of objects

The Gaia Satellite Mission



Open Clusters

Textbook

Open Clusters

Reality

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?

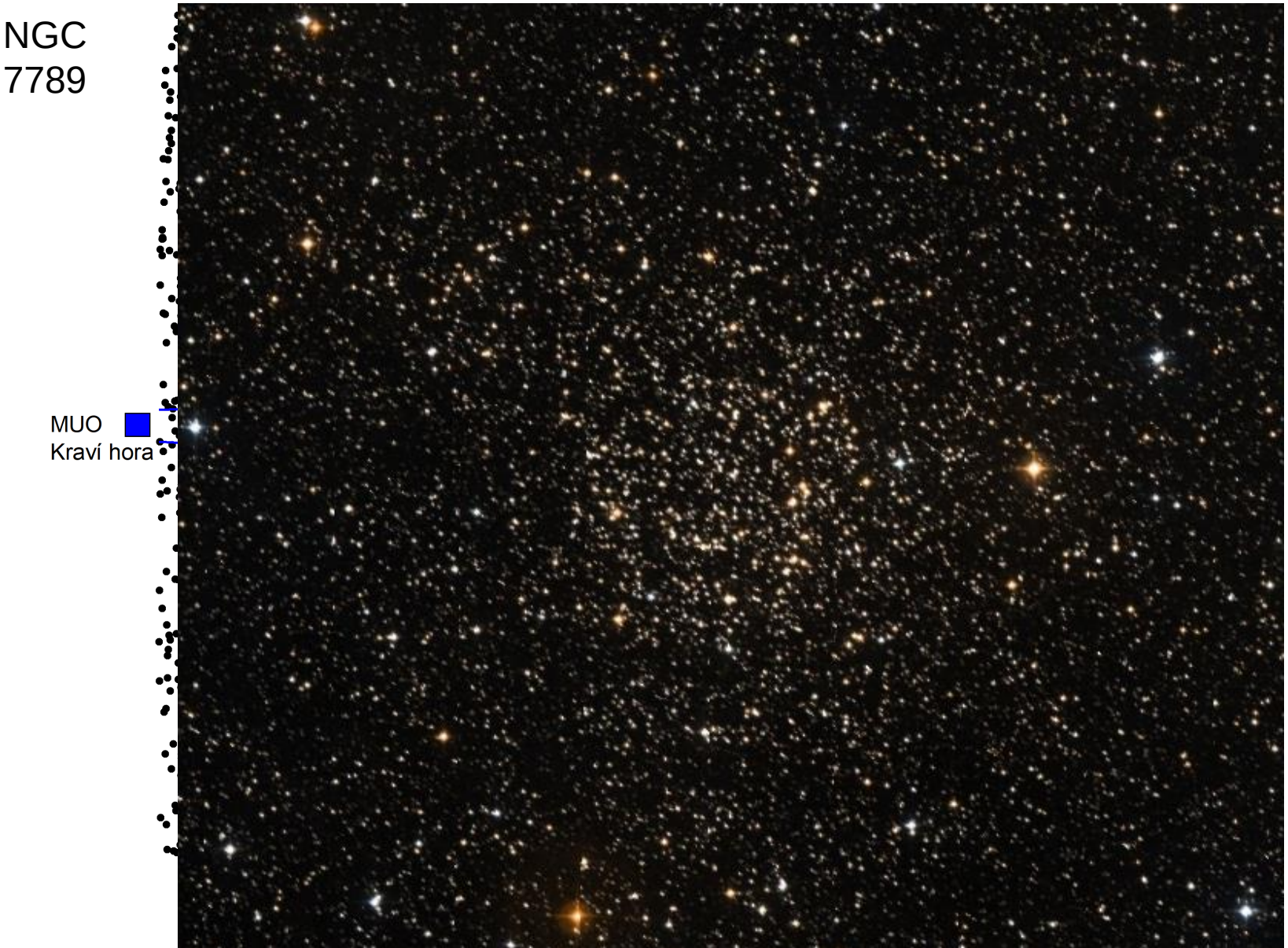
All members of an individual star cluster have:

- ***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

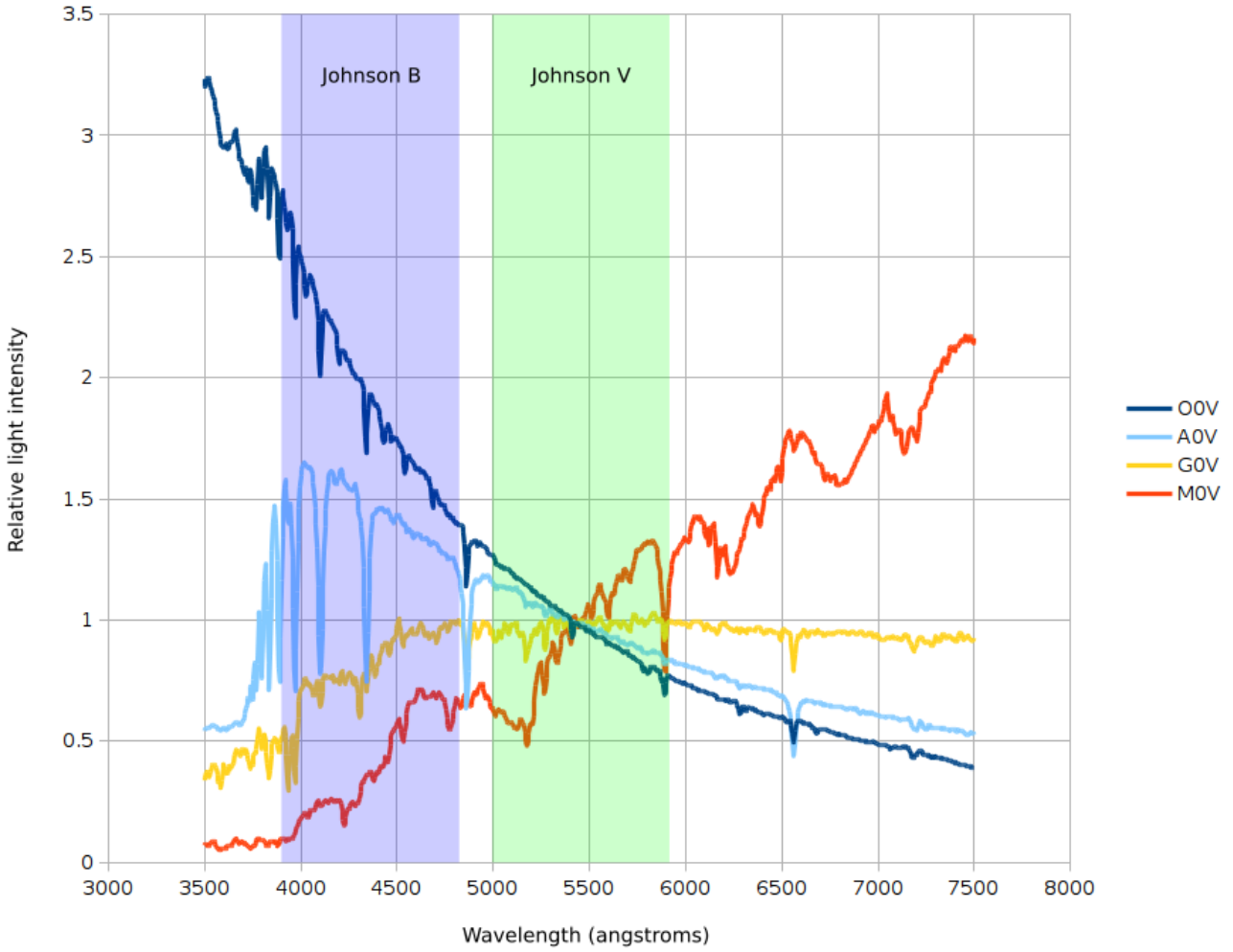
Characteristics – Star Clusters in the Milky Way

	Open Clusters	Globular Clusters
Age	< 5 Gyr	≤ age of the Milky Way
Distance from the Sun	> 45 pc	> 2000 pc
Mass range of the members	Complete range depending on the age of the cluster	< 20 $M_\odot$
Total mass	< 60 000 $M_\odot$	< 1 000 000 $M_\odot$
Absolute diameter	< 25 pc	< 100 pc
Metallicity	-1.0 to +0.6 dex compared to the Sun	-2.5 to -0.5 dex compared to the Sun

Star Clusters – tricky to analyze

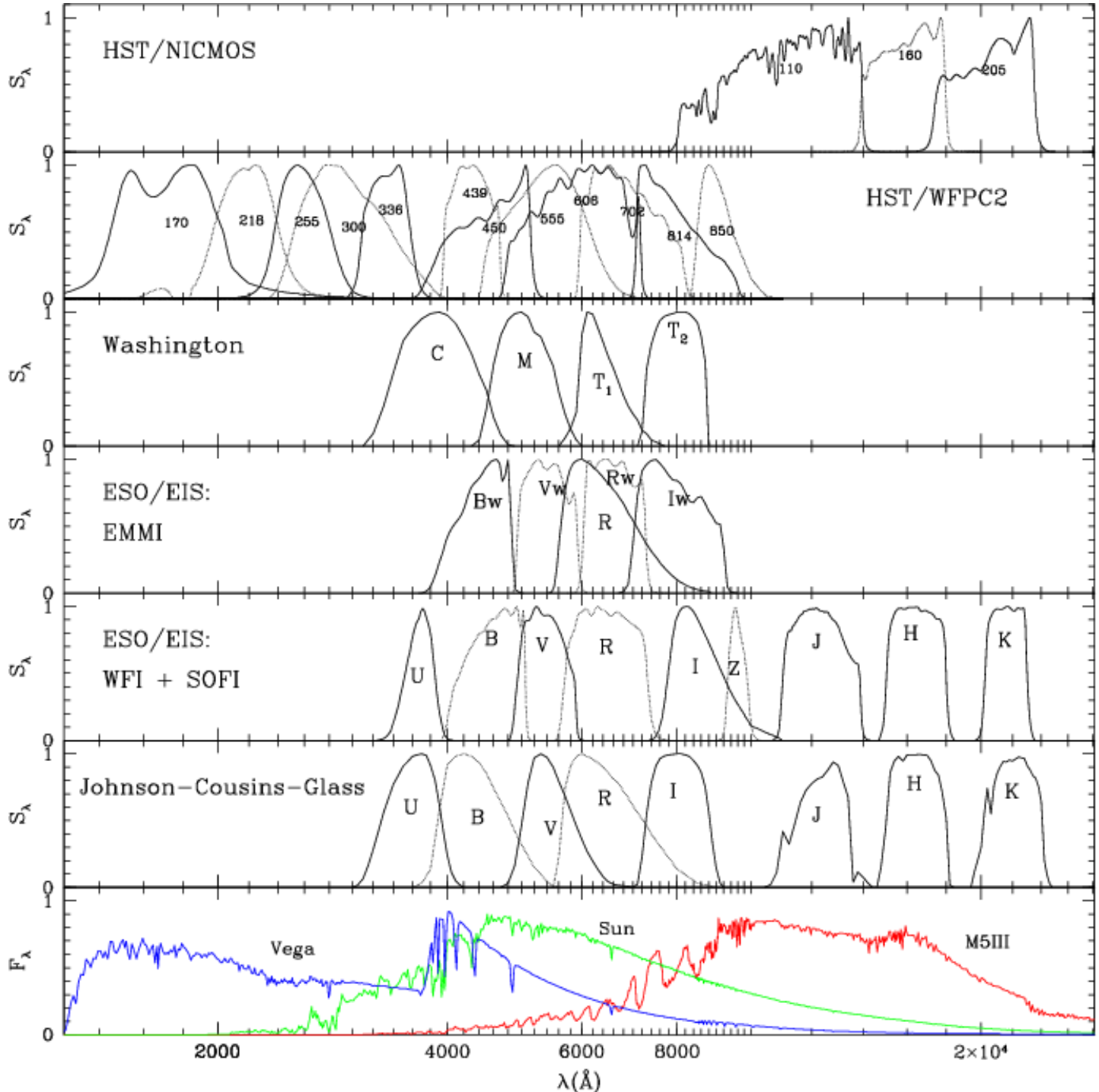


Photometry



We measure astrophysical properties in different filters

The Asiago Database on Photometric Systems: http://ulisse.pd.astro.it/Astro/ADPS/enter.html


HST/NICMOS
110
160
205
HST/WFPC2
170
218
255
300
336
439
450
555
606
702
814
850
Washington
C
M
T1
T2
ESO/EIS:
EMMI
Bw
Vw
Rw
R
Iw
ESO/EIS:
WFI + SOFI
U
B
V
R
I
Z
J
H
K
Johnson−Cousins−Glass
U
B
V
R
I
J
H
K
Vega
Sun
M5III
Sλ
Fλ
2000
4000
6000
8000
2×10⁴
λ(Å)

The cluster parameters

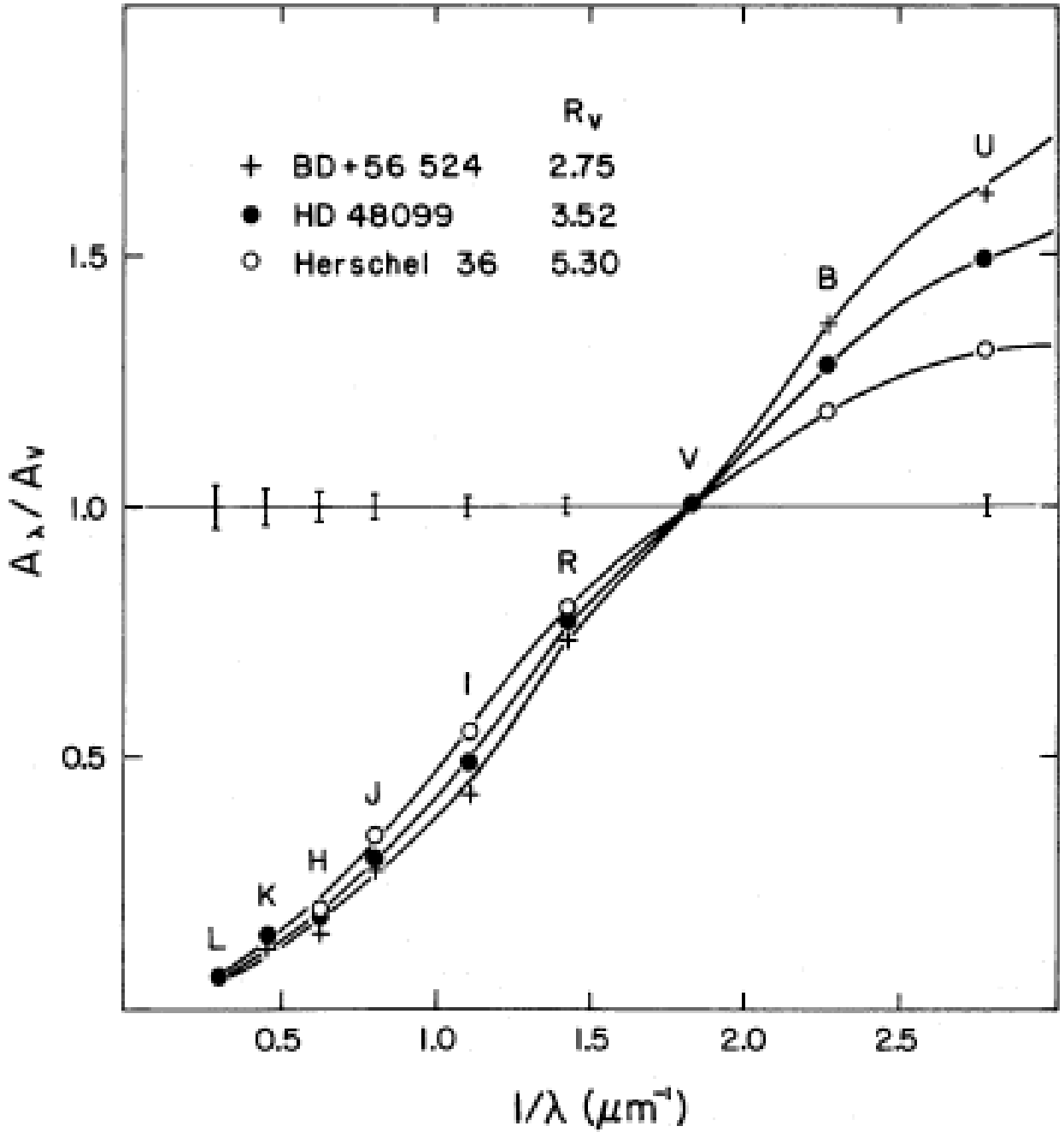
1. Reddening
2. Distance modulus
3. Age
4. Metallicity

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

Absorption = Extinction = Reddening

- $A_V = k_1\ E(B\text{-}V) = k_2\ E(V\text{-}R) = \ldots$
- *General extinction* because of the ISM characteristics between the observer and the object
- *Differential extinction* within one star cluster because of local environment
- Both types are, in general *wavelength dependent*
- *Extinction* of the earth's atmosphere

Cardelli et al., 1989, ApJ, 345, 245



Important parameter:

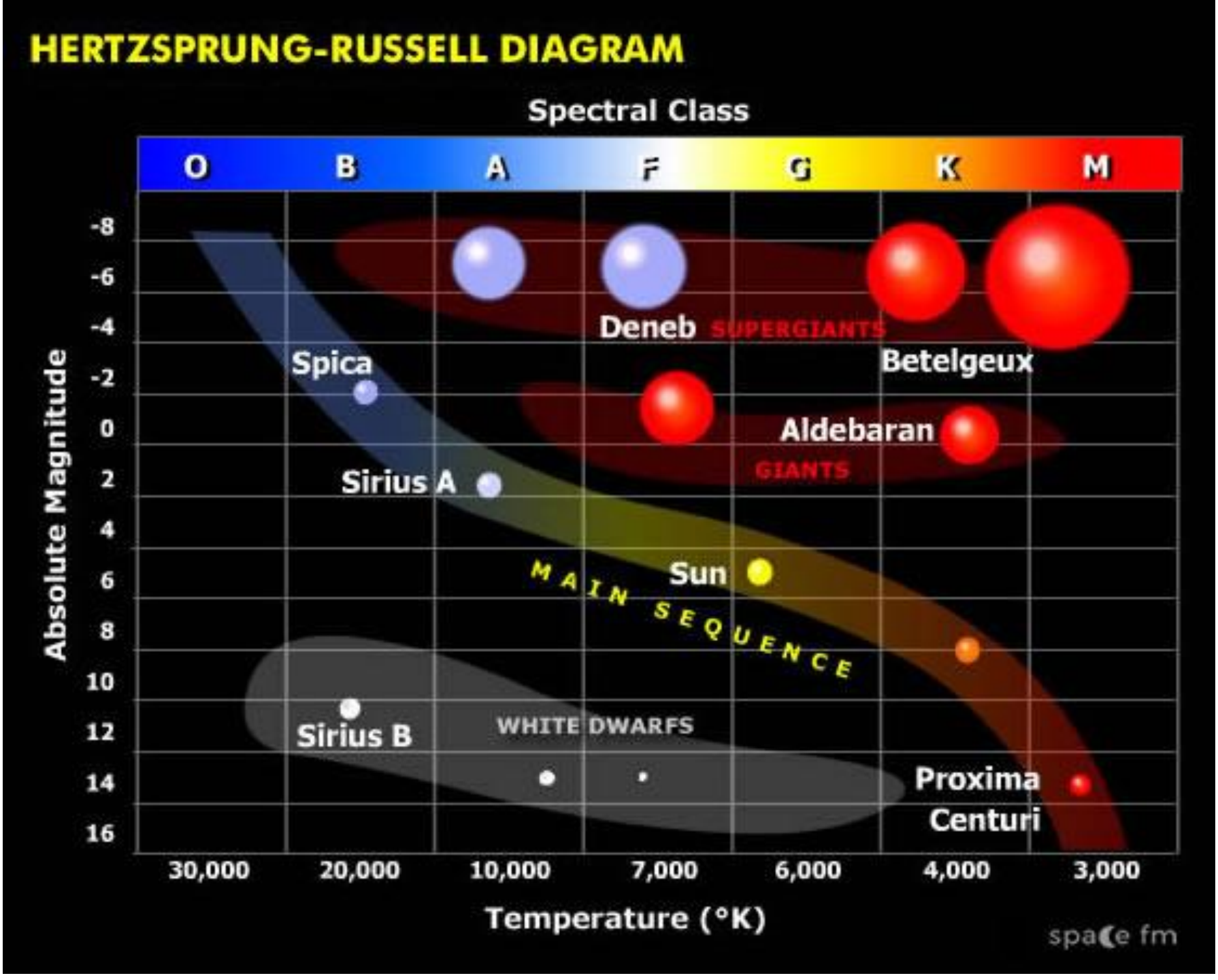
$R_V = A_V/E(B - V)$

Normalization factor

Standard value used is 3.1

Be careful, different values used!

Depending on the line of sight


HERTZSPRUNG-RUSSELL DIAGRAM
Spectral Class
O
B
A
F
G
K
M
Absolute Magnitude
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
Deneb
SUPERGIANTS
Betelgeux
Spica
Aldebaran
GIANTS
Sirius A
Sun
MAIN SEQUENCE
WHITE DWARFS
Sirius B
Proxima
Centuri
30,000
20,000
10,000
7,000
6,000
4,000
3,000
Temperature (°K)
space fm

Formation of Star Clusters

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

The „Initial Mass Function“ (IMF) describes the mass distribution for a population of stars when they are formed together:

$$IMF(m) \approx m^{-\Gamma}$$ Salpeter law (1955)

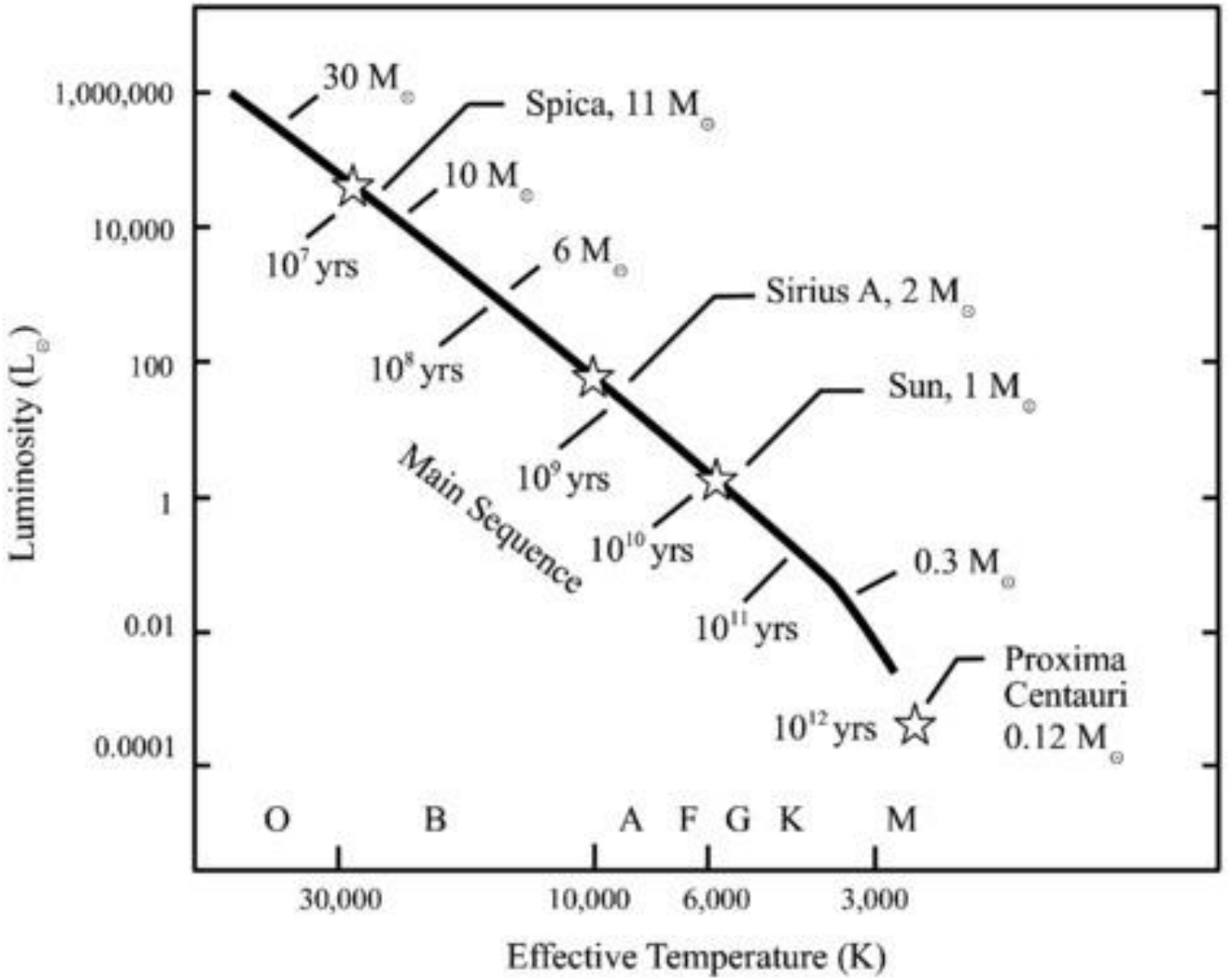
$$\Gamma = \begin{array}{ll} -0.2 \pm 0.3 & \text{for } 0.1 \text{ to } 1\ M_\odot \\ -1.7 \pm 0.5 & \text{for } 1\text{–}10\ M_\odot \\ -1.3 \pm 0.5 & \text{for } 10\text{–}100\ M_\odot \end{array}$$

Formation and Evolution of Star Clusters

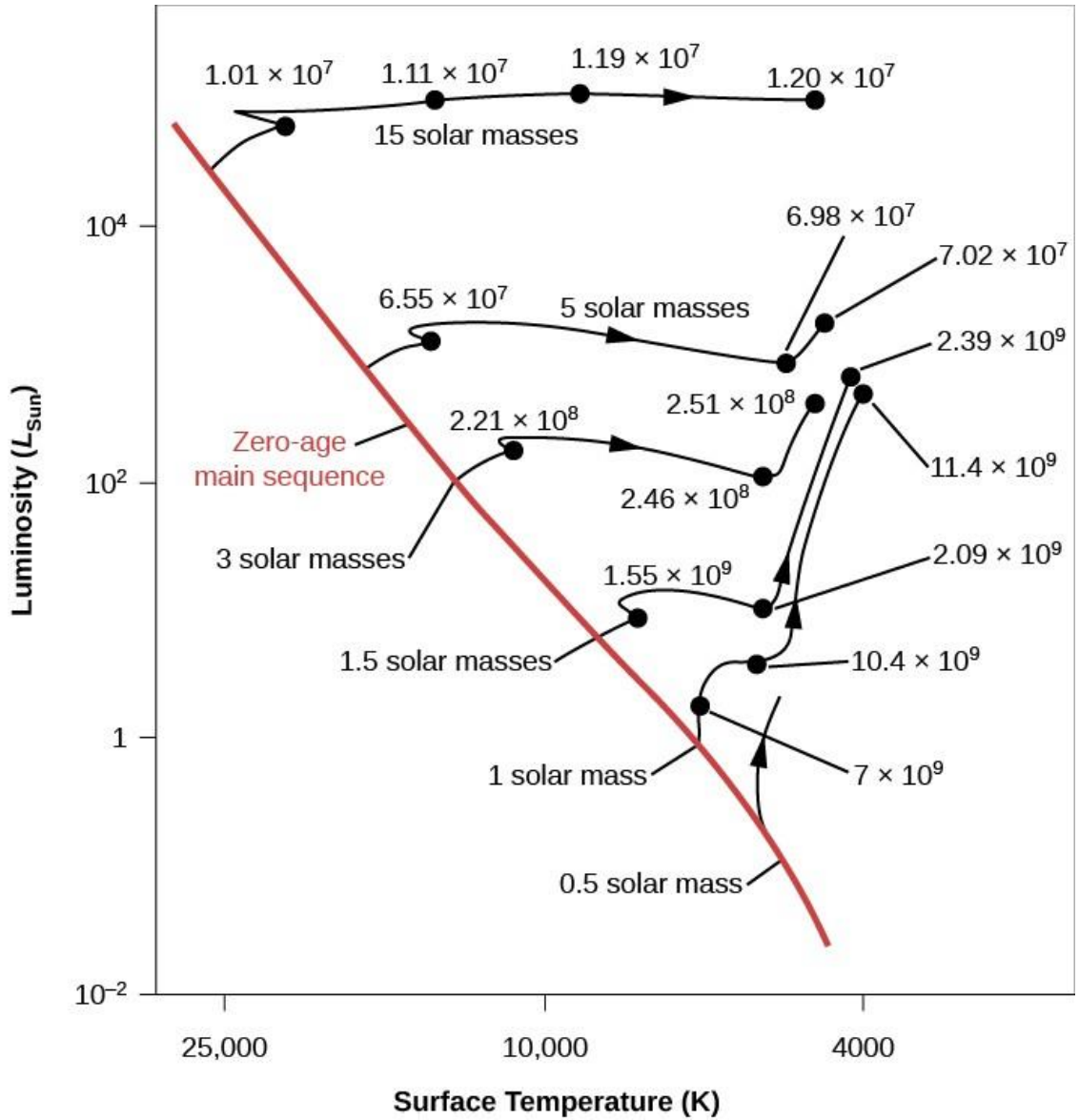
- Stars with all masses form in a star clusters
- Much more low mass that high mass stars
- How is such a star cluster evolving?
- High mass evolve much faster than low mass stars
- Luminosity: $L \propto M^{3.5}$
- Life time on the main sequence

$$\tau_{\rm MS} \approx 10^{10}{\rm years}\left[\frac{M}{M_\odot}\right]\left[\frac{L_\odot}{L}\right] = 10^{10}{\rm years}\left[\frac{M}{M_\odot}\right]^{-2.5}$$

Evolution of Star Clusters

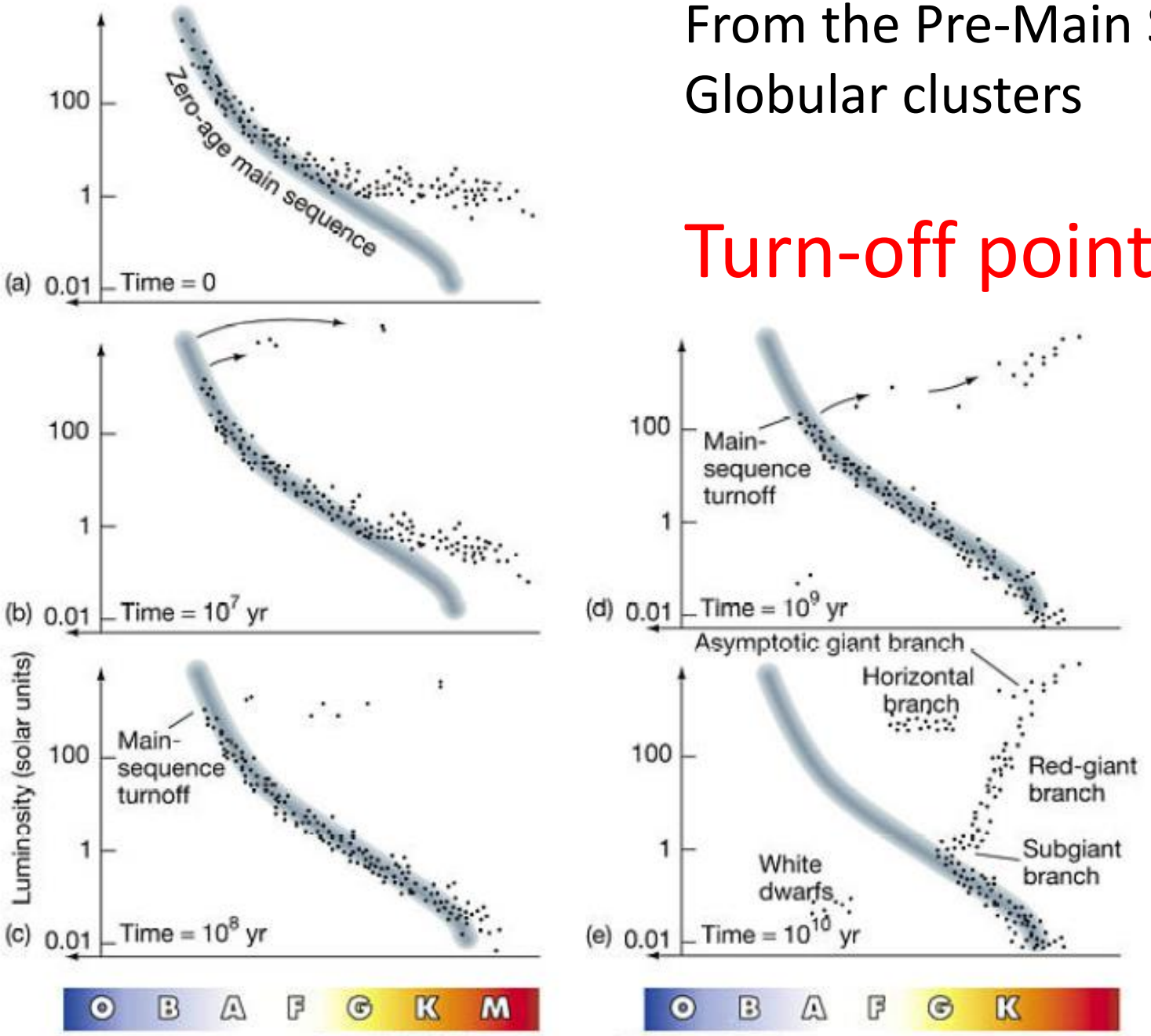


Evolution of Star Clusters



From the Pre-Main Sequence to Globular clusters

Turn-off point



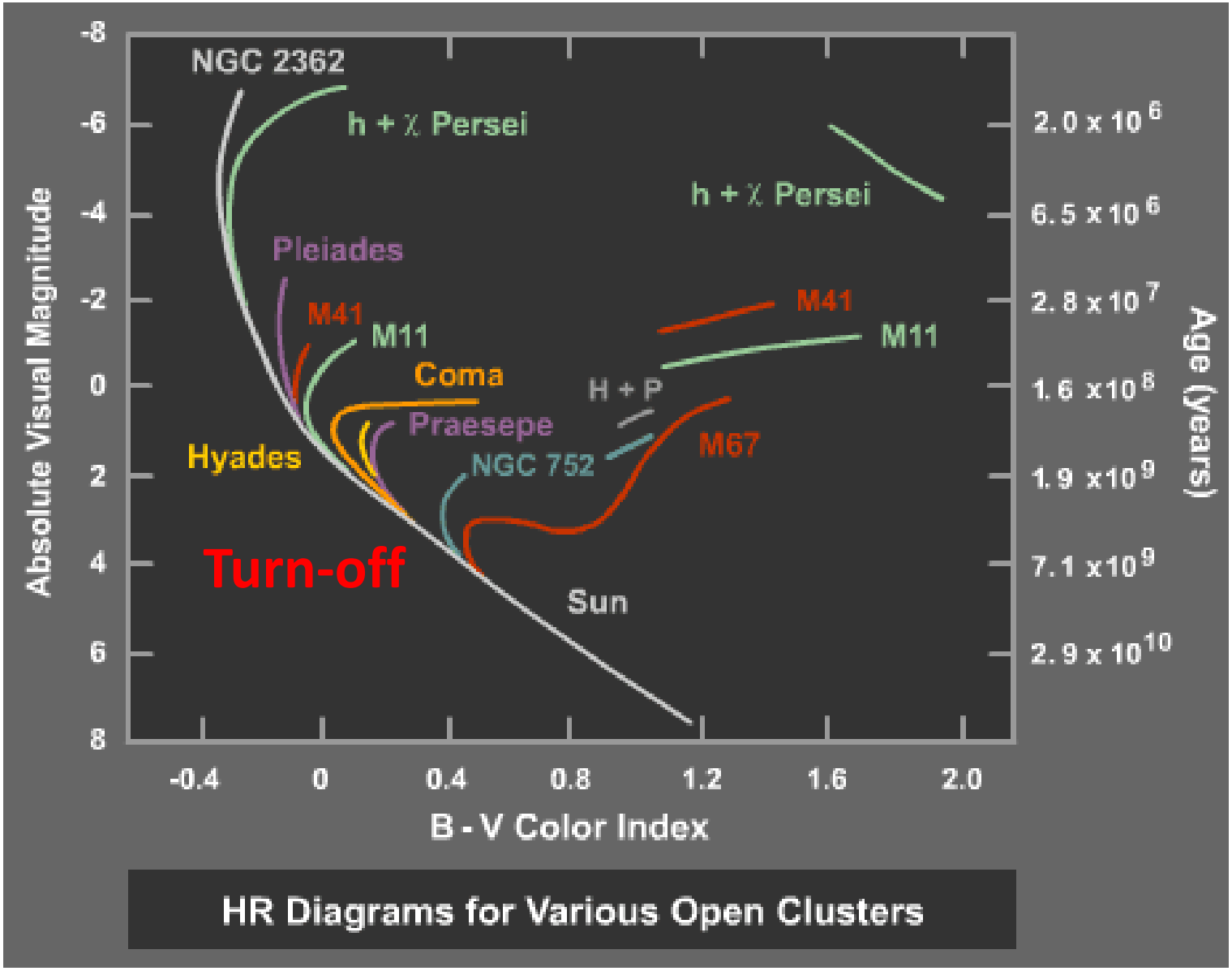
(a) $t = 0$

(b) $t = 10^7$yr

(c) $t = 10^8$yr

(d) $t = 10^9$yr

(e) $t = 10^{10}$yr



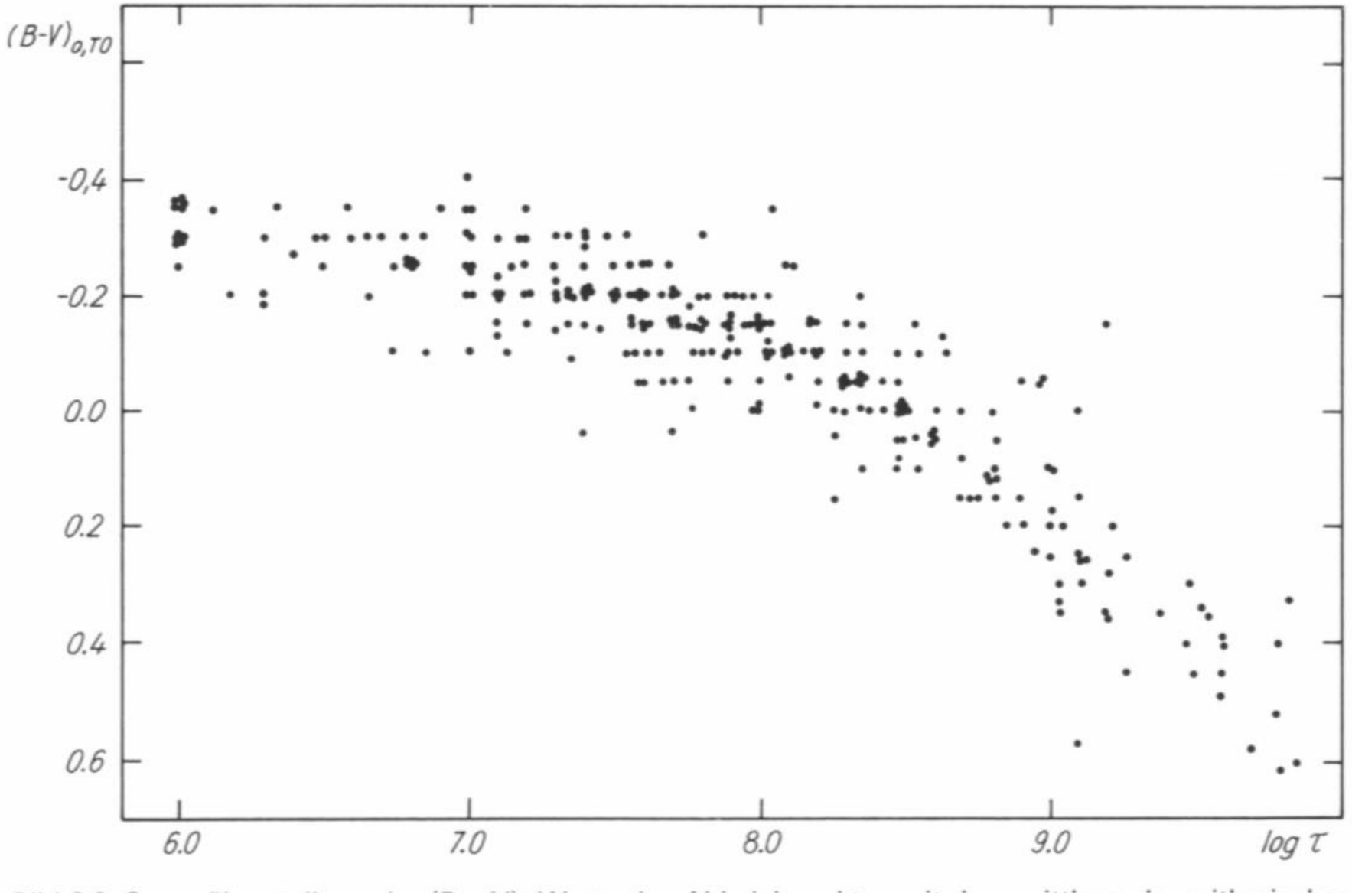
Distance: $V_0 - M_V$

$k \cdot A_V$

A_V

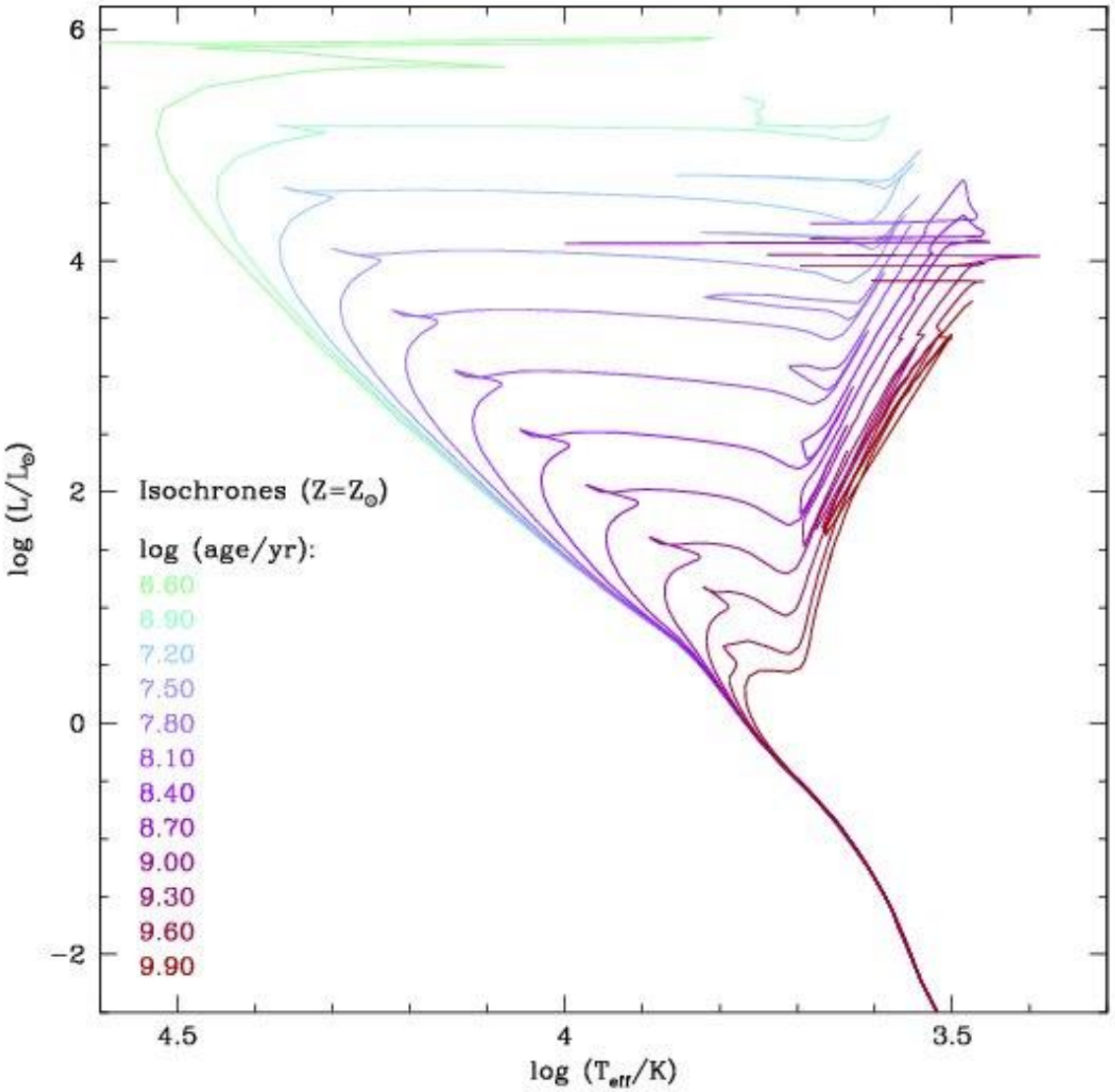
Reddening

Götz, 1989, Die offenen Sternhaufen unserer Galaxis

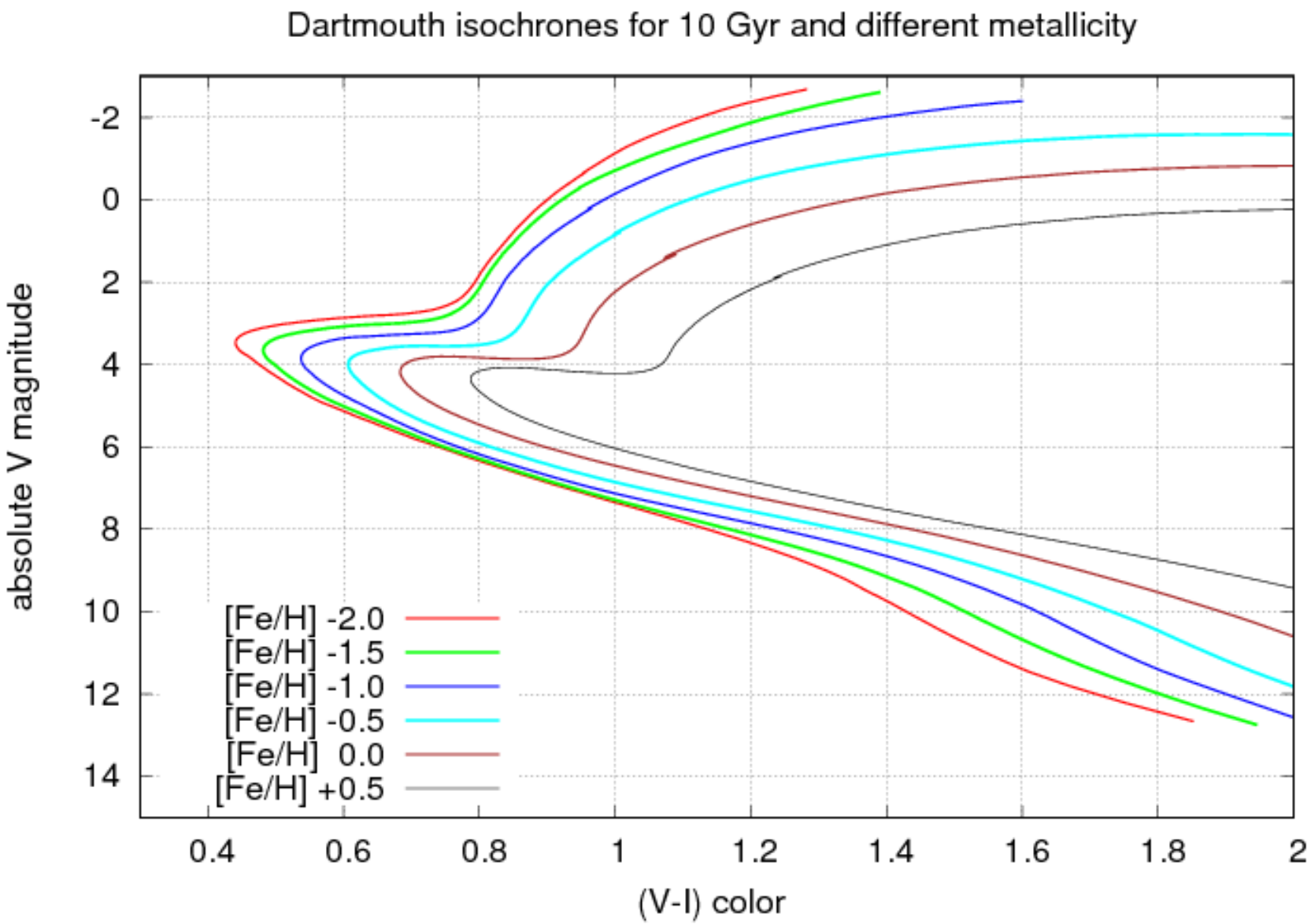


Not very accurate but still useful, never done for 2MASS and NIR

Isochrones


6
4
2
0
−2
log (L/L⊙)
Isochrones (Z=Z⊙)
log (age/yr):
6.60
6.90
7.20
7.50
7.80
8.10
8.40
8.70
9.00
9.30
9.60
9.90
4.5
4
3.5
log (Teff/K)

Isochrones - Metallicity



Gaia – before and after