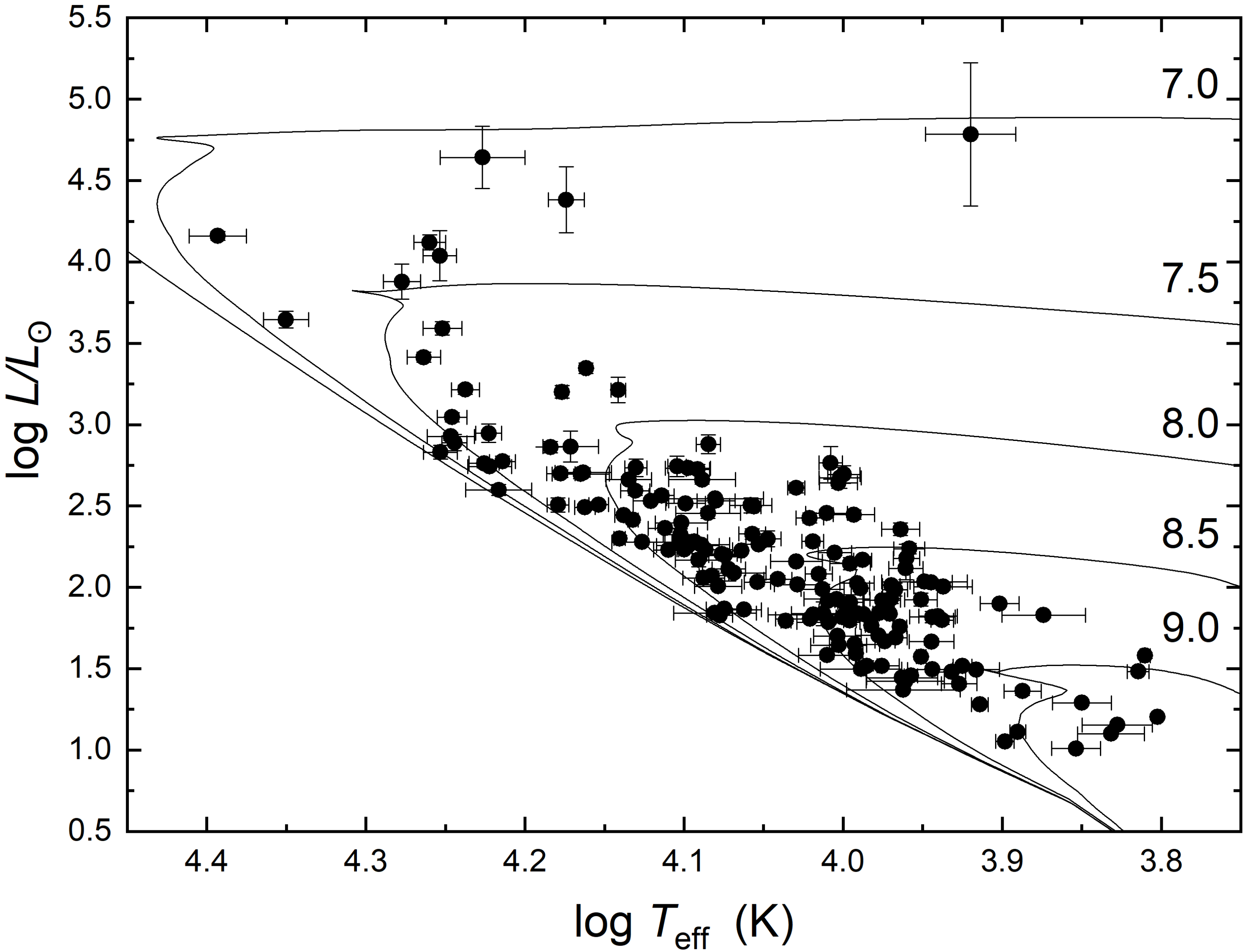
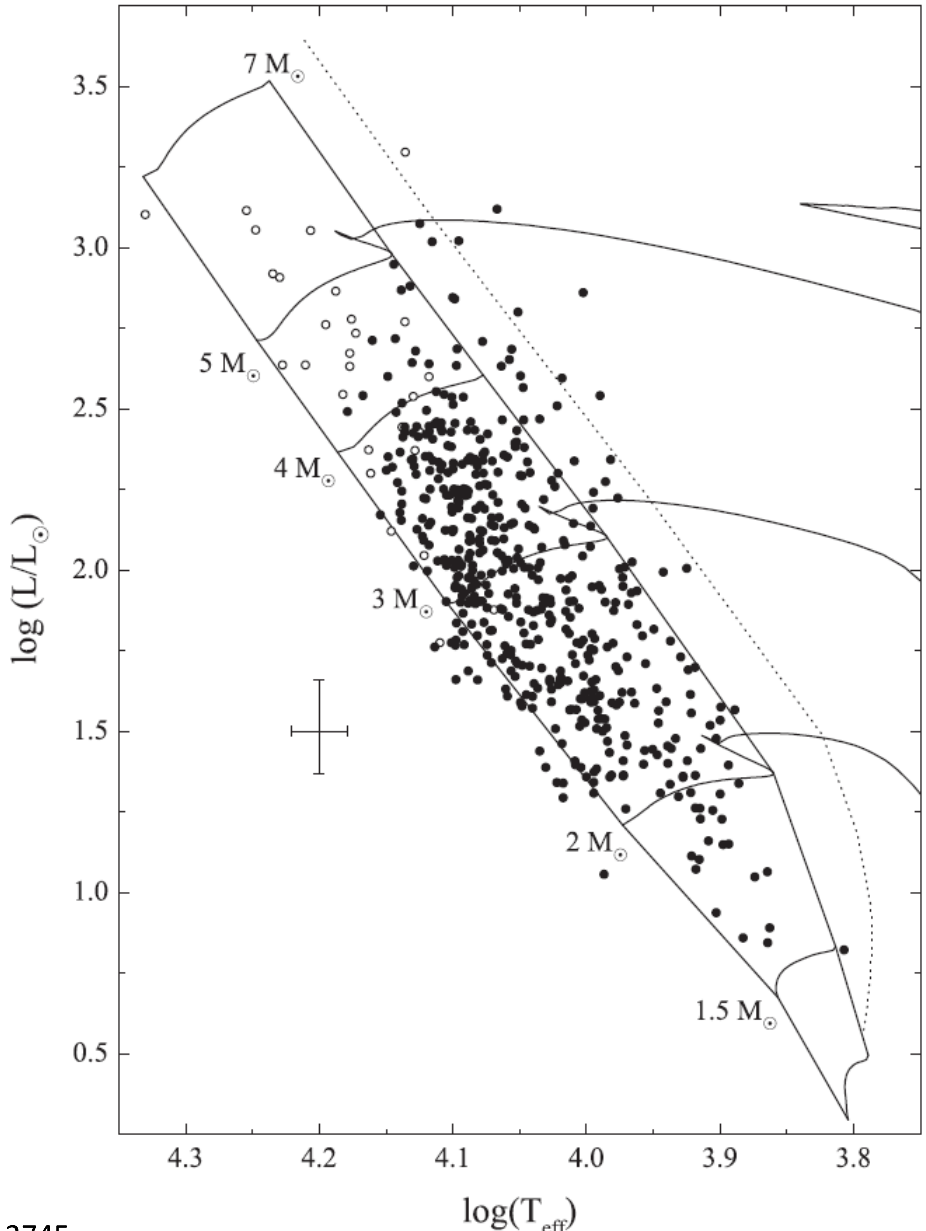
Hertzsprung-Russell Diagram

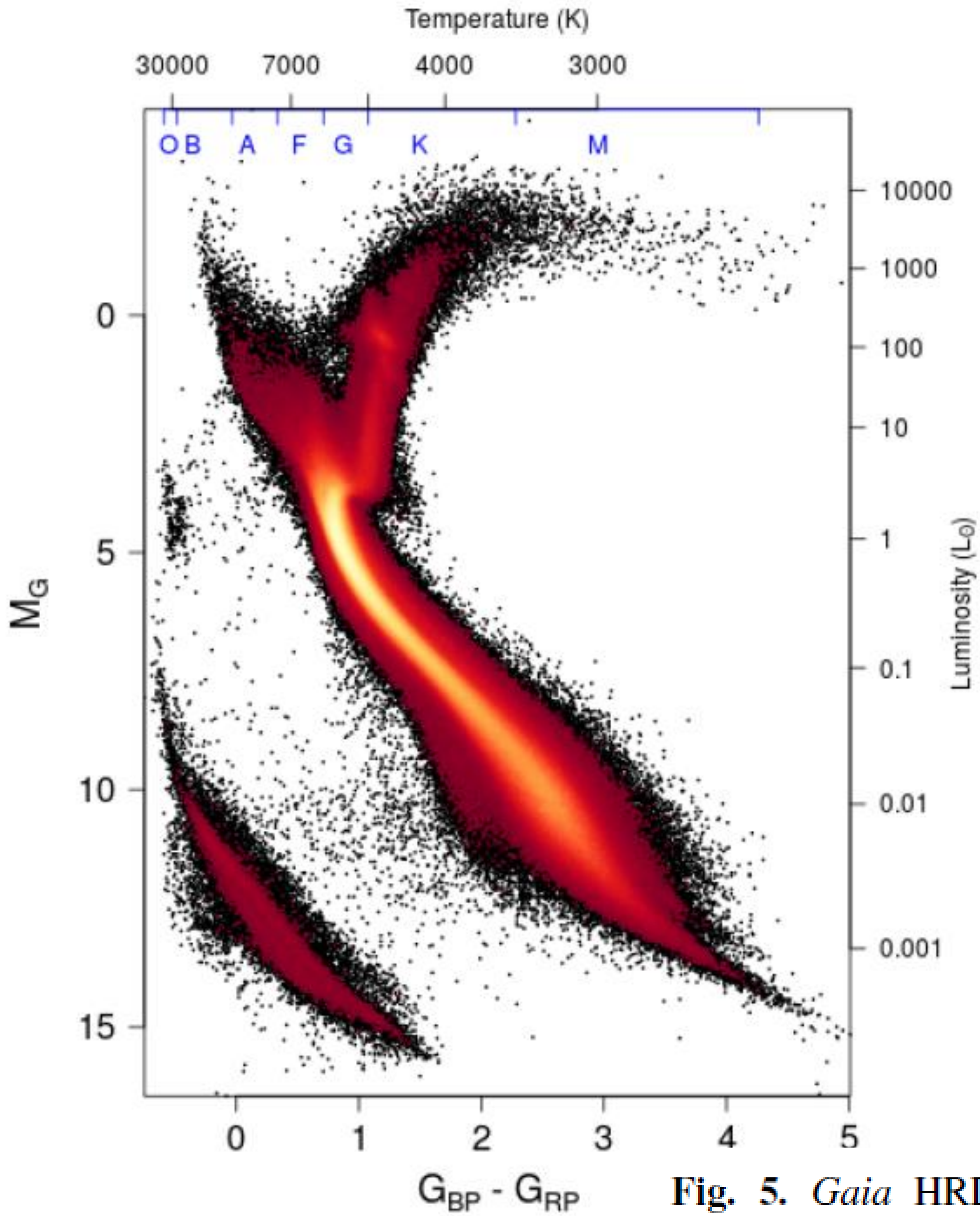


Hertzsprung-Russell Diagram



Netopil et al., 2017, MNRAS, 468, 2745

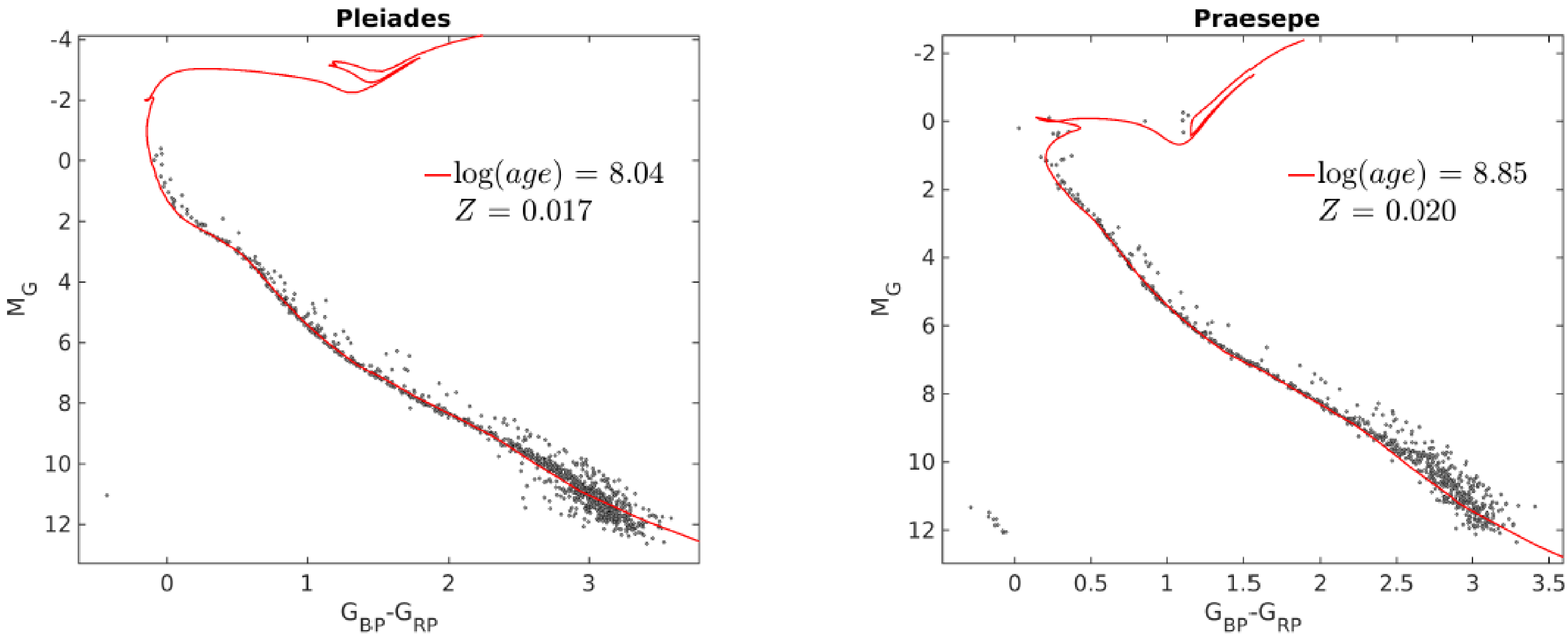
Color-Magnitude Diagram



Gaia Collaboration, 2018, A&A, 616, A10

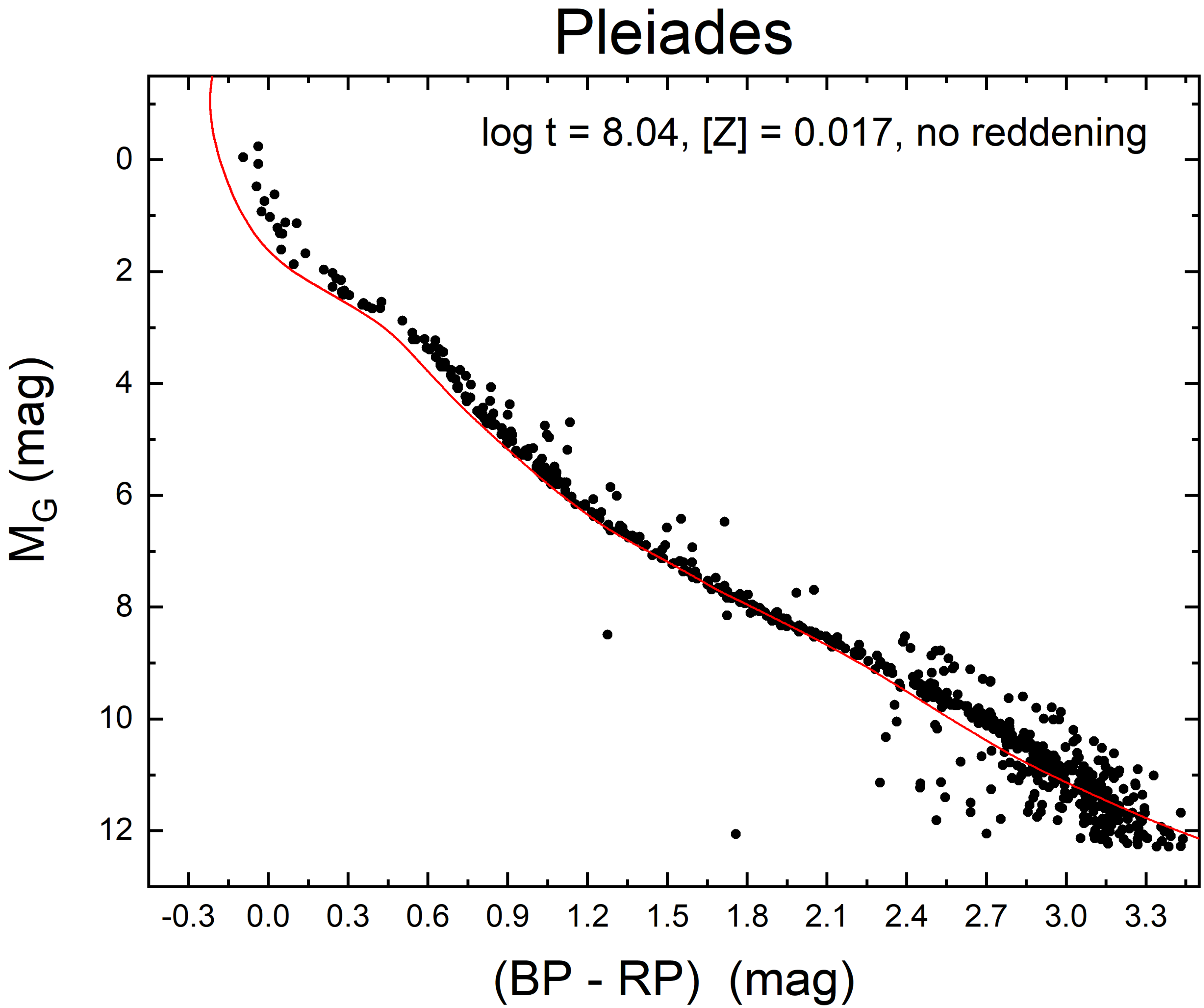
Fig. 5. *Gaia* HRD of sources with low extinction ($E(B - V) < 0.015$ mag) satisfying the filters described in Sect. 2.1 (4,276,690 stars).

Color-Magnitude Diagram

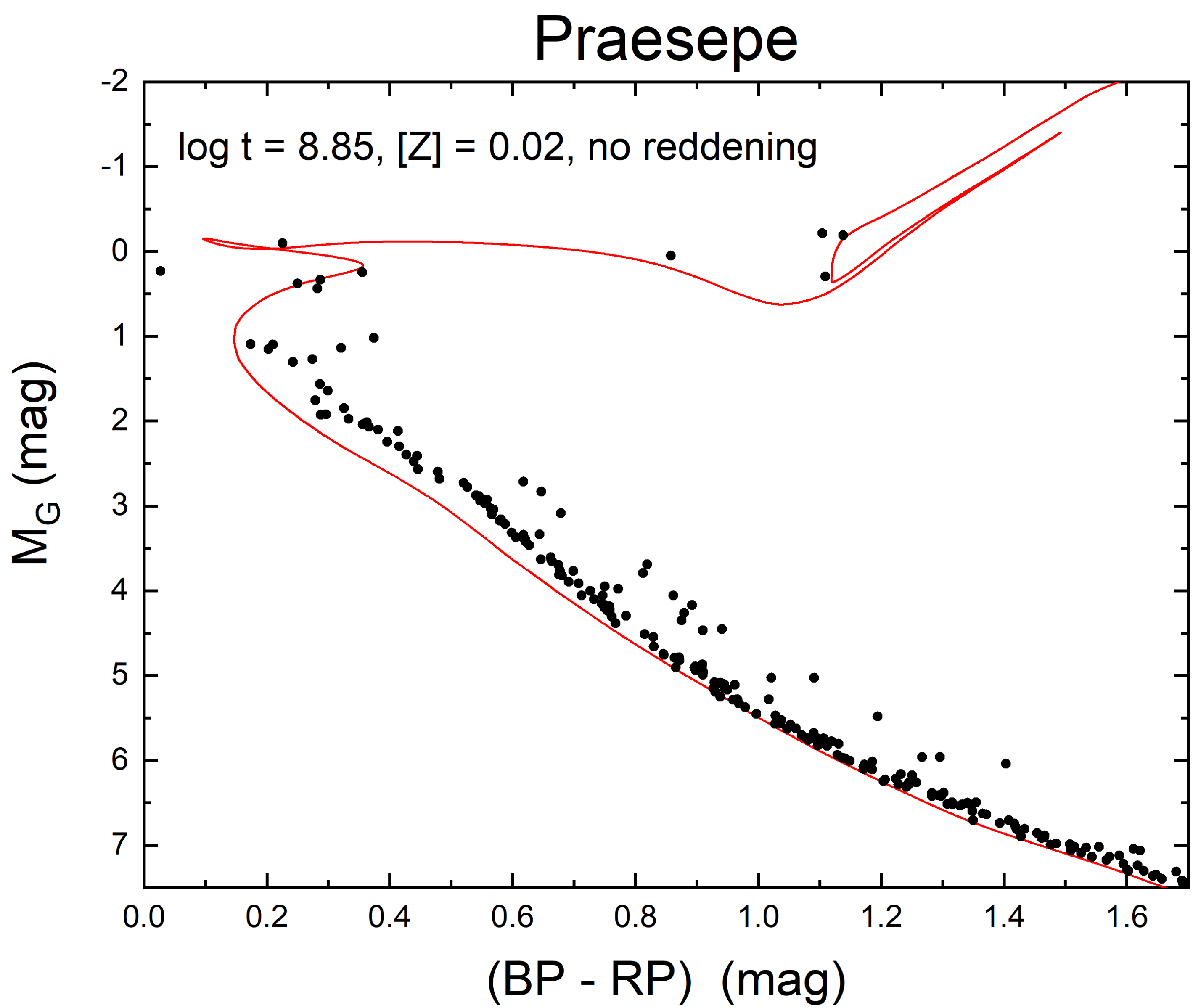


Gaia Collaboration, 2018, A&A, 616, A10

Color-Magnitude Diagram

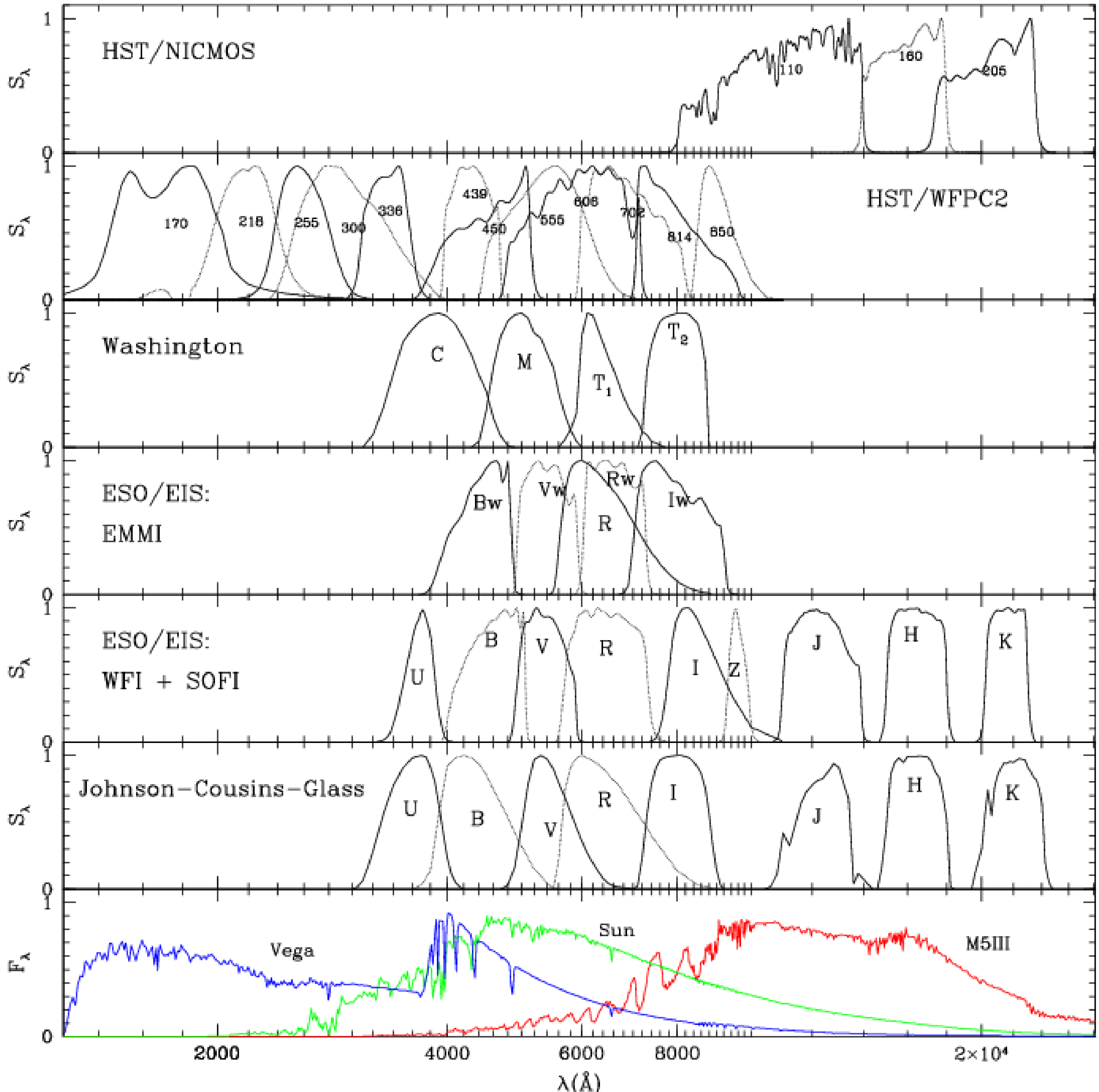


Color-Magnitude Diagram

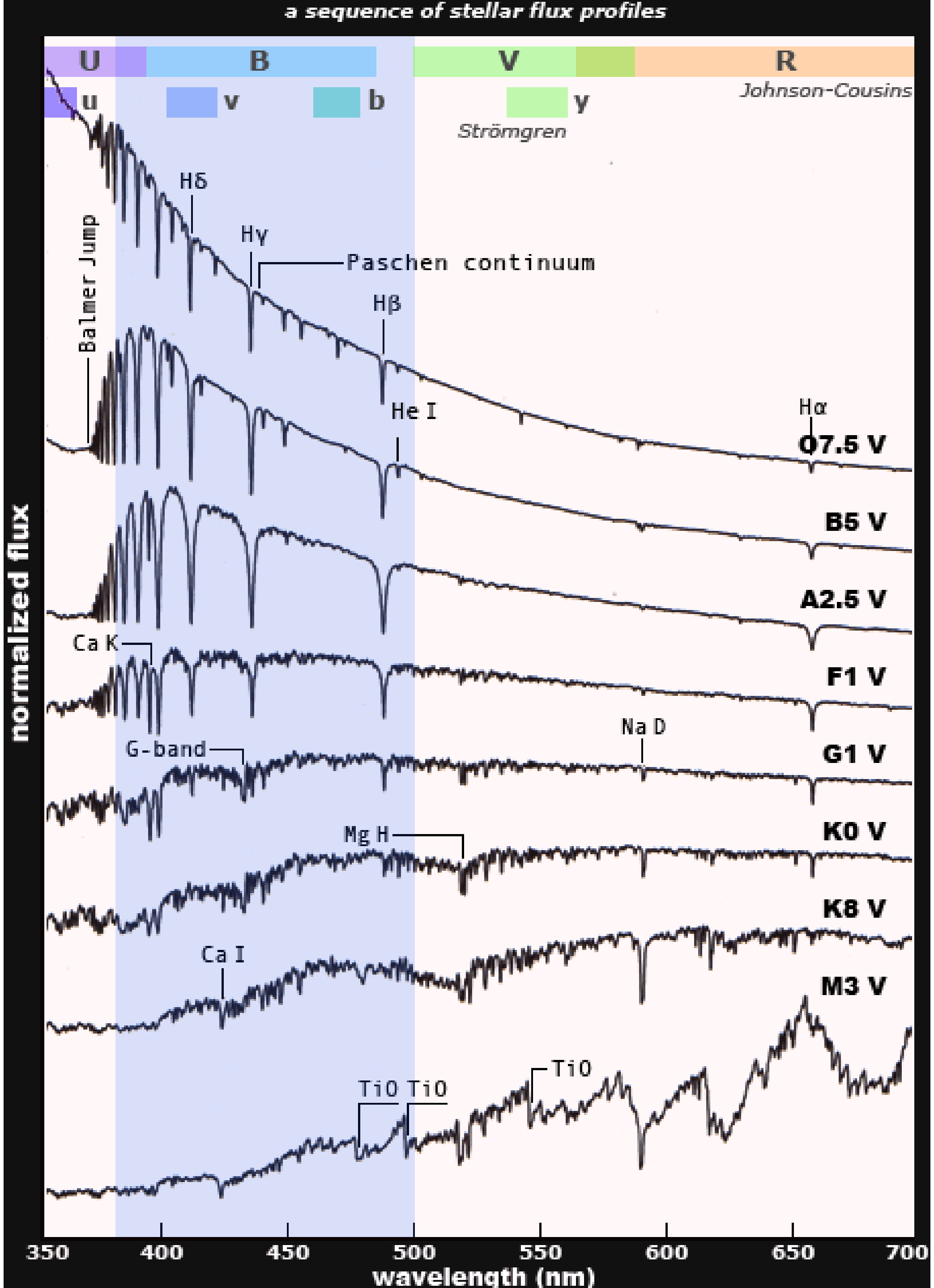


Colour and T_{eff}

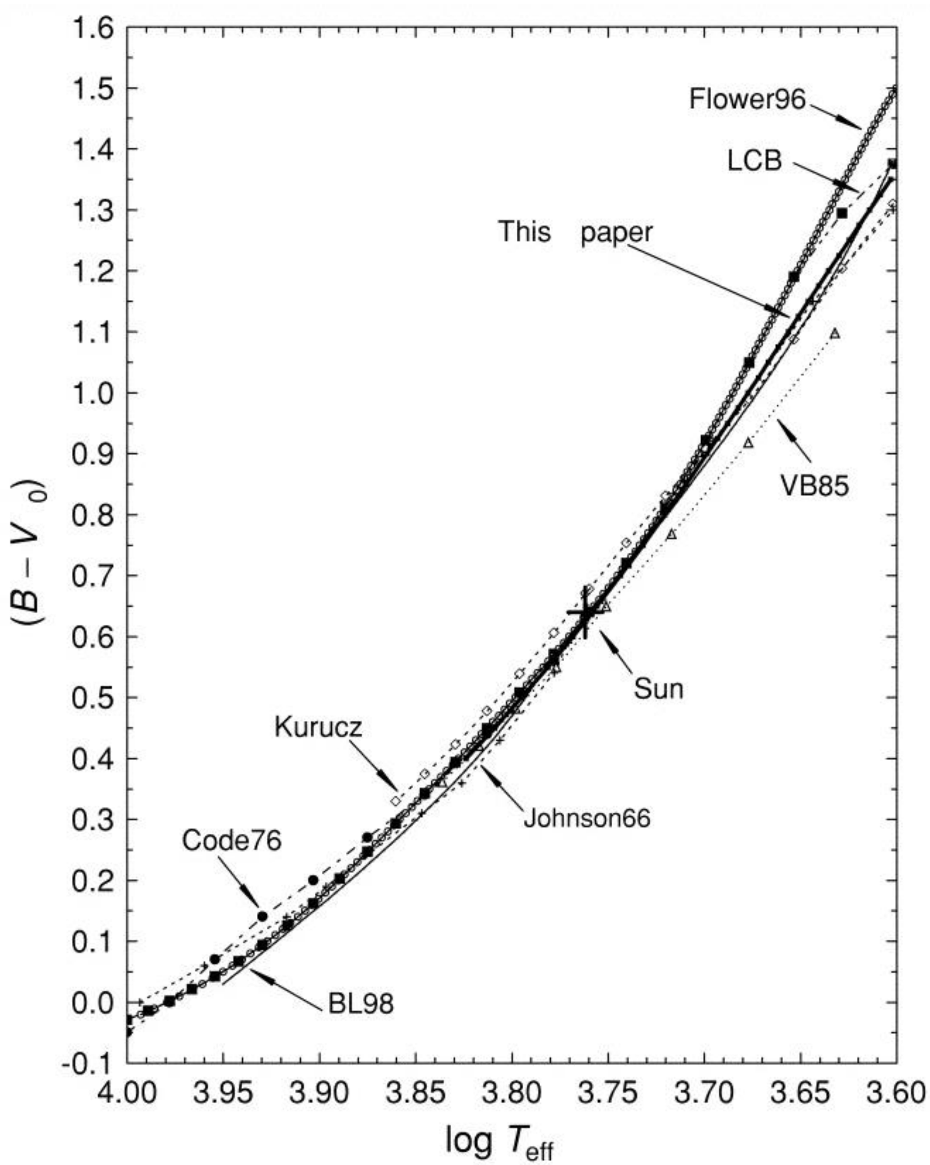
- Measuring accurate T_{eff} for stars is an intensive task – spectra needed and model atmospheres
- Spectral Energy Distribution (SED) fitting, only useful if measurements in the UV are available
- Magnitudes of stars are measured at different wavelengths
- Colours => Calibrations => T_{eff}
- The Asiago Database on Photometric Systems (ADPS) lists about 200 different systems



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
0
1
2000
4000
6000
8000
2×10⁴
λ(Å)


a sequence of stellar flux profiles
U
B
V
R
Johnson-Cousins
u
v
b
y
Strömgren
Hδ
Hγ
Paschen continuum
Hβ
Balmer Jump
He I
Hα
O7.5 V
B5 V
A2.5 V
Ca K
F1 V
G-band
Na D
G1 V
Mg H
K0 V
K8 V
Ca I
M3 V
TiO
TiO TiO
normalized flux
350
400
450
500
550
600
650
700
wavelength (nm)

Colour and T_{eff}



Various calibrations can be used to provide the colour relation:

$(B - V) = f(T_{eff})$

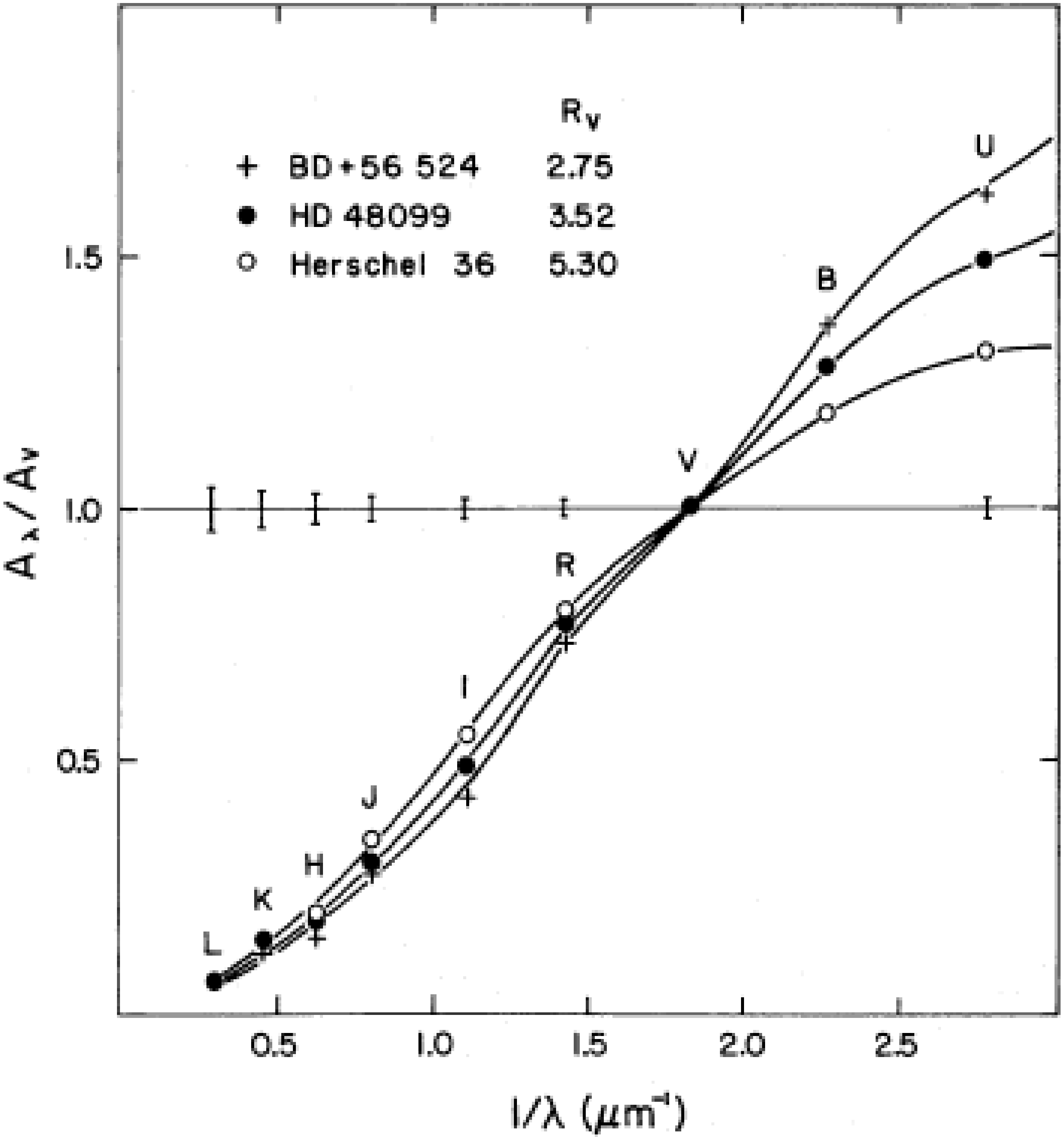
Remember that observed (B - V) must be corrected for interstellar extinction to $(B - V)_0$

Most of the calibrations are for cool type stars

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*

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

Fitzpatrick, 1999, PASP, 111, 63

TABLE 2

OPTICAL/IR EXTINCTION RATIOS FOR $R = 3.1$

Extinction Ratio (1)	Observed Value (2)	References (3)	Model Curve Value (4)
$A(M)/E(B-V)$	0.08–0.12	1, 2	0.12
$A(L)/E(B-V)$	0.09–0.20	1,2,3,4	0.19
$A(K)/E(B-V)$	0.33–0.38	2, 3, 4	0.36
$A(H)/E(B-V)$	0.52–0.55	1, 2	0.53
$A(J)/E(B-V)$	0.85–0.91	1, 2, 3	0.86
$A(I)/E(B-V)$	1.50	3	1.57
$A(R)/E(B-V)$	2.32	3	2.32
$A(V)/E(B-V)$	3.10		3.10
$E(U-B)/E(B-V)$	$0.70 + 0.05 \times E(B-V)$	5	$0.69 + 0.04 \times E(B-V)$
$E(b-y)/E(B-V)$	0.74	6	0.74
$E(m1)/E(b-y)$	−0.32	6	−0.32
$E(c1)/E(b-y)$	0.20	6	0.17
$E(u-b)/E(b-y)$	1.5	6	1.54

REFERENCES.—(1) Rieke & Lebofsky 1985; (2) Whittet 1988; (3) Schultz & Wiemer 1975; (4) Savage & Mathis 1979; (5) FitzGerald 1970; (6) Crawford 1975.

Table 3. Multiband Relative Extinction Values

Band (λ)	$\lambda_{\rm eff,0}$ (μm)	$A_\lambda/A_{G_{\rm RP}}$	$A_\lambda/A_{G_{\rm RP}}$ (from Chen18)	A_λ/A_V	$A_\lambda/E(G_{\rm BP}-G_{\rm RP})$
GAIA $G_{\rm BP}$	0.5387	1.700 ± 0.007		1.002 ± 0.007	2.429 ± 0.015
GAIA $G_{\rm RP}$	0.7667	1		0.589 ± 0.004	1.429 ± 0.015
Johnson B	0.4525	2.206 ± 0.023		1.317 ± 0.016	3.151 ± 0.027
Johnson V	0.5525	1.675 ± 0.010		1	2.394 ± 0.018
SDSS u	0.3602	2.653 ± 0.024		1.584 ± 0.017	3.791 ± 0.028
SDSS g	0.4784	2.018 ± 0.012		1.205 ± 0.010	2.883 ± 0.019
SDSS r	0.6166	1.421 ± 0.006		0.848 ± 0.006	2.030 ± 0.016
SDSS i	0.7483	1.056 ± 0.002		0.630 ± 0.004	1.509 ± 0.015
SDSS z	0.8915	0.767 ± 0.004		0.458 ± 0.003	1.096 ± 0.012
Pan-STARRS g	0.4957	1.934 ± 0.010		1.155 ± 0.009	2.764 ± 0.018
Pan-STARRS r	0.6211	1.413 ± 0.005		0.843 ± 0.006	2.019 ± 0.015
Pan-STARRS i	0.7522	1.052 ± 0.001		0.628 ± 0.004	1.503 ± 0.015
Pan-STARRS z	0.8671	0.815 ± 0.002		0.487 ± 0.003	1.165 ± 0.012
Pan-STARRS y	0.9707	0.662 ± 0.004		0.395 ± 0.003	0.947 ± 0.011
2MASS J	1.2345	0.407 ± 0.007		0.243 ± 0.004	0.582 ± 0.011
2MASS H	1.6393	0.219 ± 0.010	0.222 ± 0.012	0.131 ± 0.006	0.313 ± 0.014
2MASS $K_{\rm S}$	2.1757	0.125 ± 0.010	0.130 ± 0.006	0.078 ± 0.004	0.186 ± 0.009
WISE $W1$	3.3172	0.055 ± 0.011	0.066 ± 0.006	0.039 ± 0.004	0.094 ± 0.009
WISE $W2$	4.5501	0.029 ± 0.011	0.044 ± 0.006	0.026 ± 0.004	0.063 ± 0.009
WISE $W3$	11.7281	0.066 ± 0.016		0.040 ± 0.009	0.095 ± 0.021
GAIA G	0.6419	1.323 ± 0.003		0.789 ± 0.005	1.890 ± 0.015
Spitzer [3.6]			0.062 ± 0.005	0.037 ± 0.003	0.089 ± 0.007
Spitzer [4.5]			0.044 ± 0.005	0.026 ± 0.003	0.063 ± 0.007
Spitzer [5.8]			0.031 ± 0.005	0.019 ± 0.003	0.044 ± 0.007
Spitzer [8.0]			0.042 ± 0.005	0.025 ± 0.003	0.060 ± 0.007

At *Spitzer* bands, the determination of the relative extinction $A_\lambda/A_{\rm V}$ and the extinction coefficient $A_\lambda/E(G_{\rm BP}-G_{\rm RP})$ are based on the relative extinction values from Chen18.

Wang & Chen, 2019, ApJ, 877, 116

Absolute magnitude and bolometric magnitude

- **Absolute Magnitude** *M* defined as apparent magnitude of a star if it were placed at a distance of 10 pc

$$m - M = 5 \log(d) - 5$$

where d is in pc

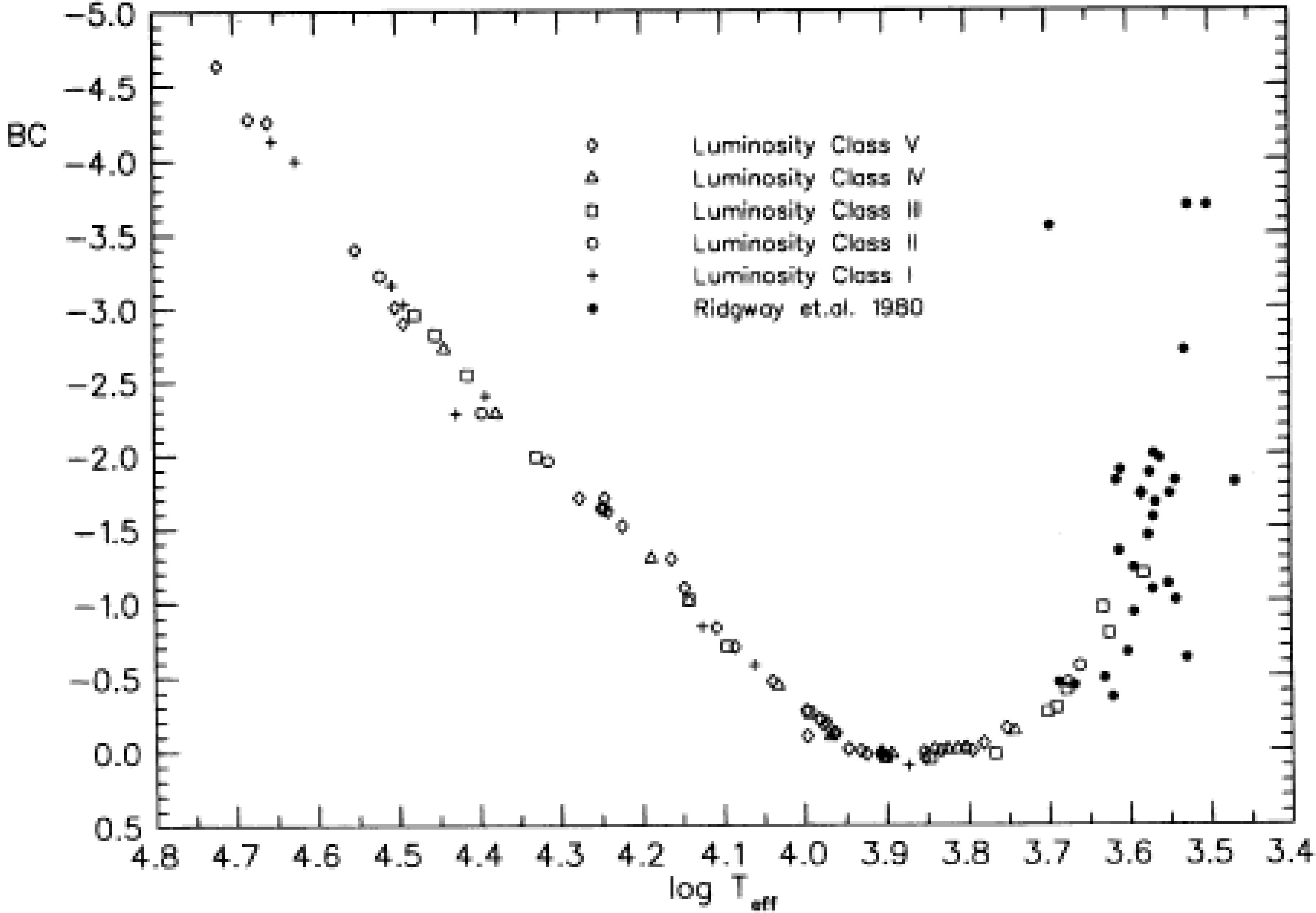
- Magnitudes are measured in some wavelength. To compare with theory it is more useful to determine **bolometric magnitude M_{bol}** – defined as absolute magnitude that would be measured by a bolometer sensitive to all wavelengths. We define the bolometric correction to be

$$BC = M_{bol} - M_V$$

Bolometric luminosity is then

$$M_{bol} - M_{bol,\odot} = -2.5 \log L/L_{\odot};\ M_{bol,\odot} = 4.75 \text{ mag}$$

Bolometric Correction



BC from Flower, 1996, ApJ, 469, 355