Dark Matter

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M T 4:00-5:15pm
Sears 552

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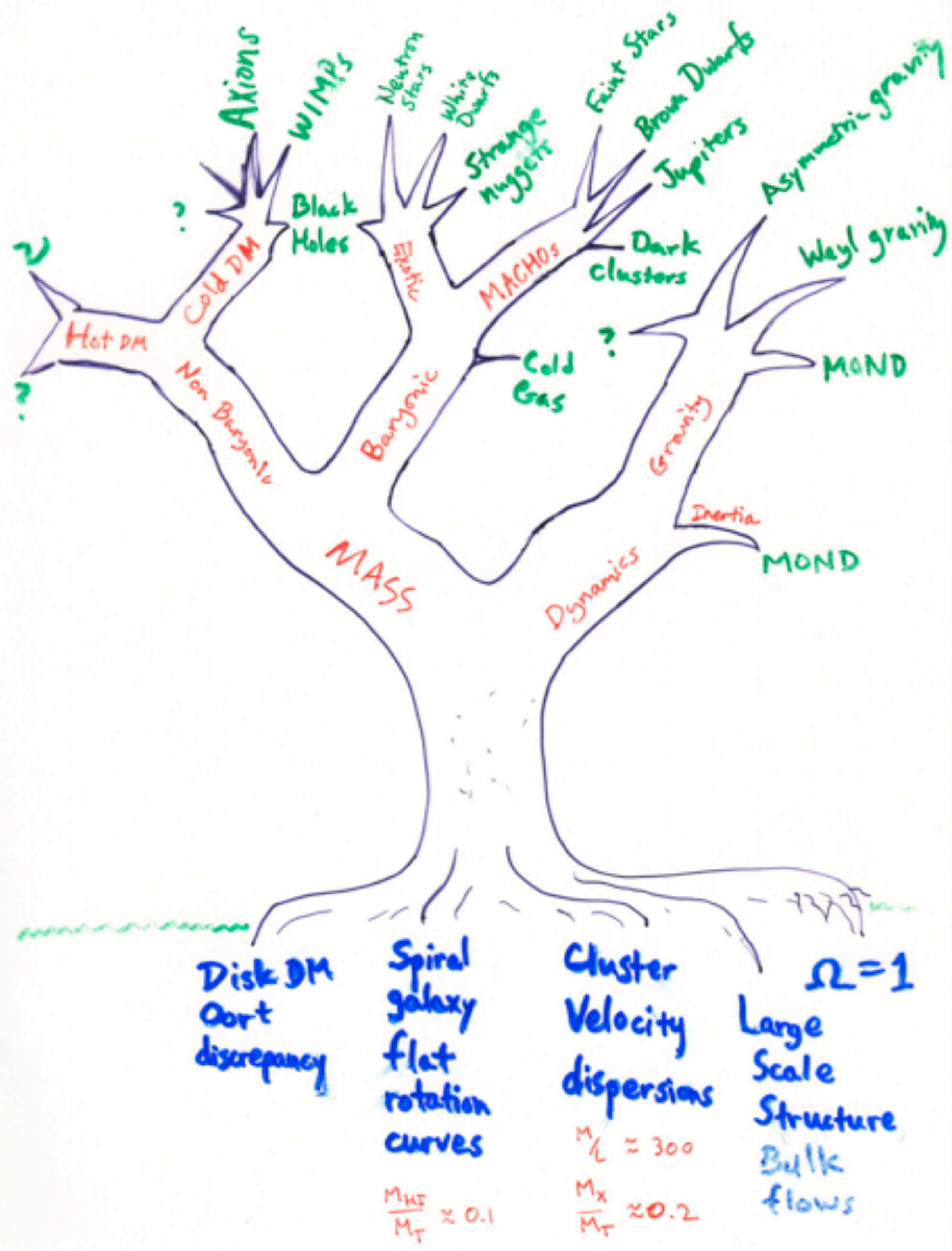


Stars

Galaxies are made of stars

Spectral Types
Luminosity Classes
Stellar Evolution
IMF

spectral types

Temperature sequence

cool

O B A F G K M

hot

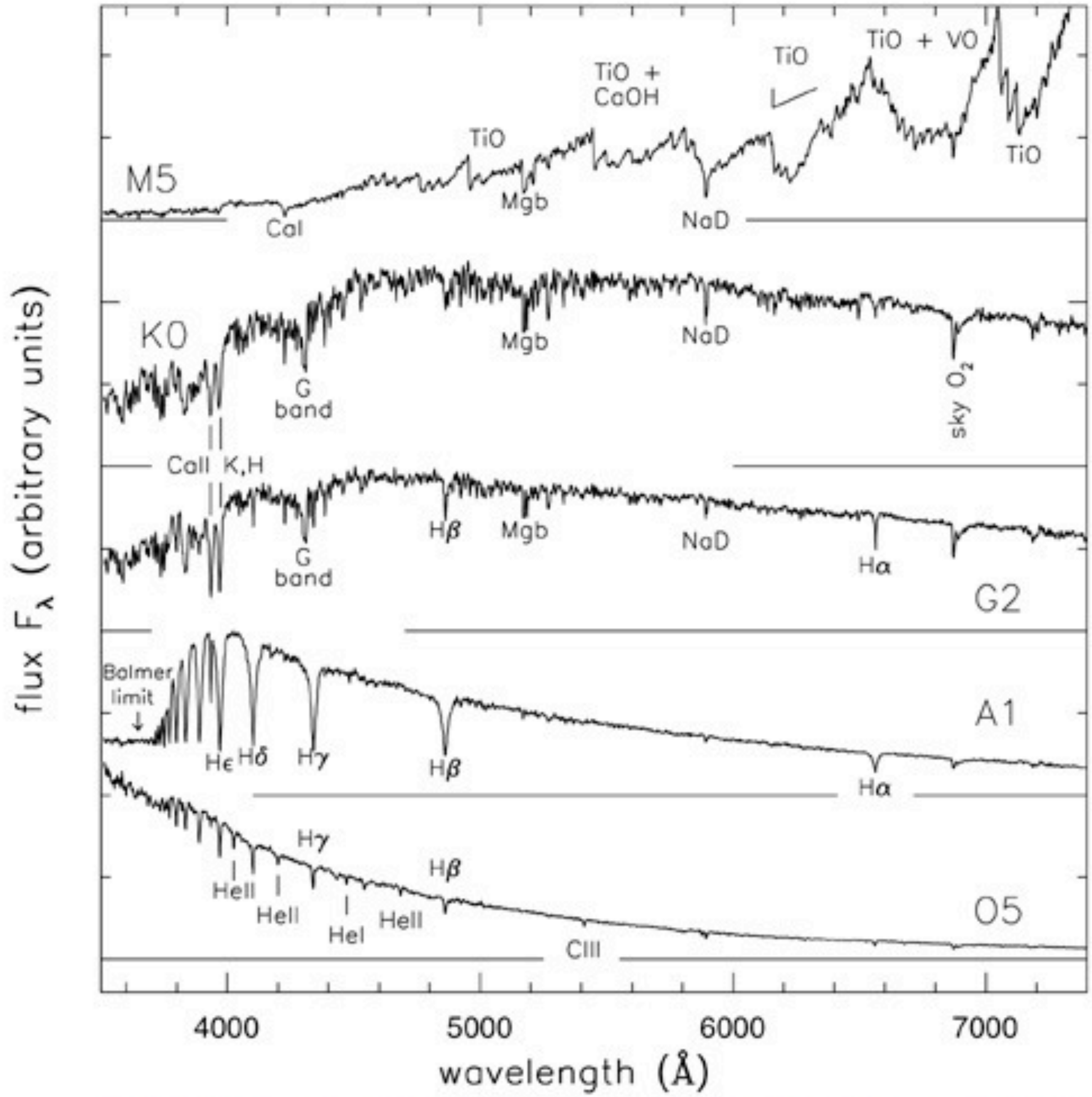


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

M5 ~ 3000 K

K0

G2 (solar) ~ 6000 K

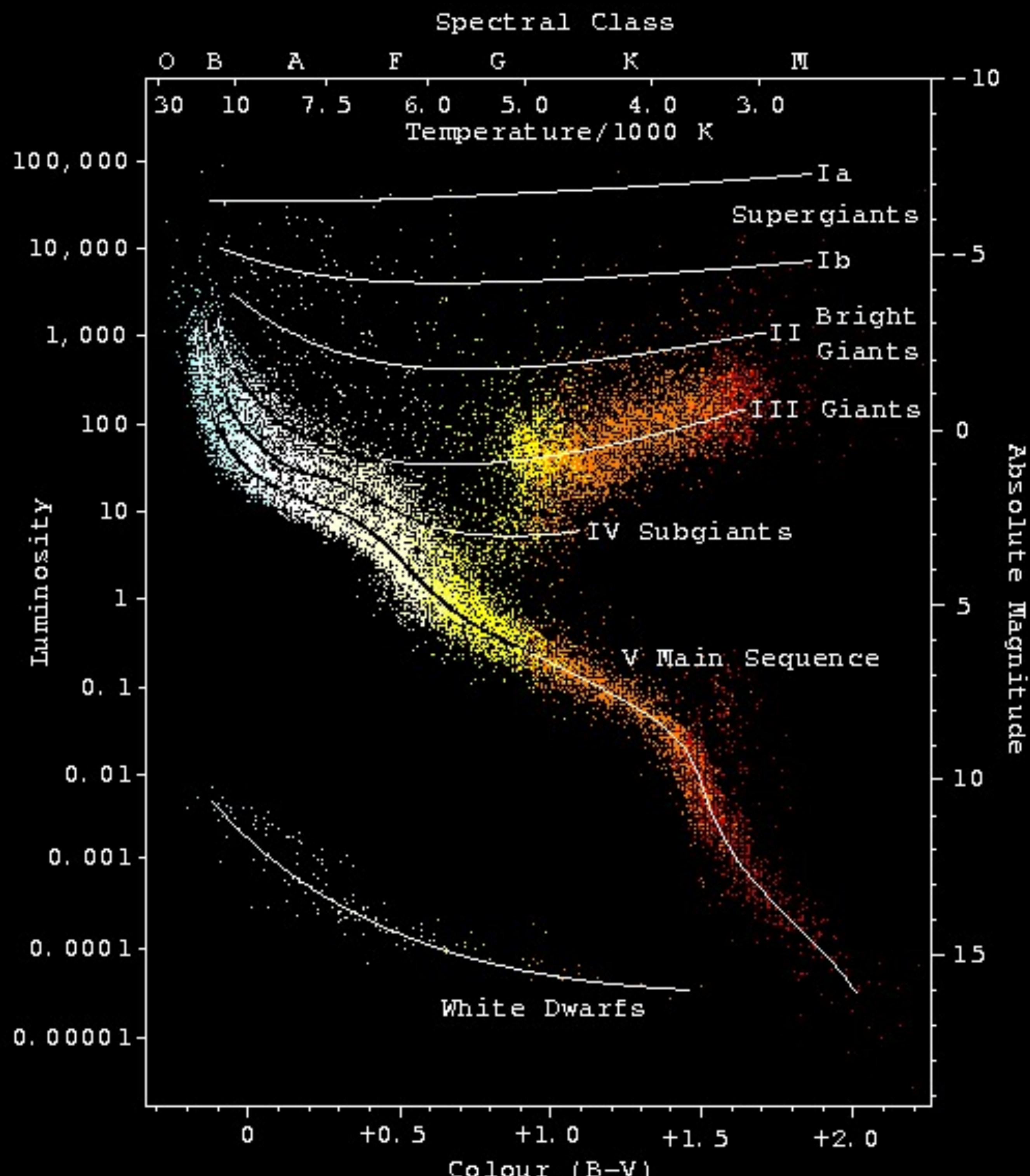
A1 ~ 10000 K

O5 > 30000 K

A star's full classification includes a **spectral type** (**OBAFGKM**) and a **luminosity class** (related to the size & surface gravity of a star - bigger is brighter):

- I — supergiant
- II — bright giant
- III — giant
- IV — subgiant
- V — dwarf (main sequence)

Examples:
- Sun — G2 V
- Sirius — A1 V
- Proxima Centauri — M5.5 V
- Betelgeuse — M2 I


Spectral Class
O B A F G K M
30 10 7.5 6.0 5.0 4.0 3.0
Temperature/1000 K
100,000
10,000
1,000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Luminosity
-10
-5
0
5
10
15
Absolute Magnitude
Ia
Supergiants
Ib
II
Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
0
+0.5
+1.0
+1.5
+2.0
Colour (B-V)

The width of lines varies with surface gravity

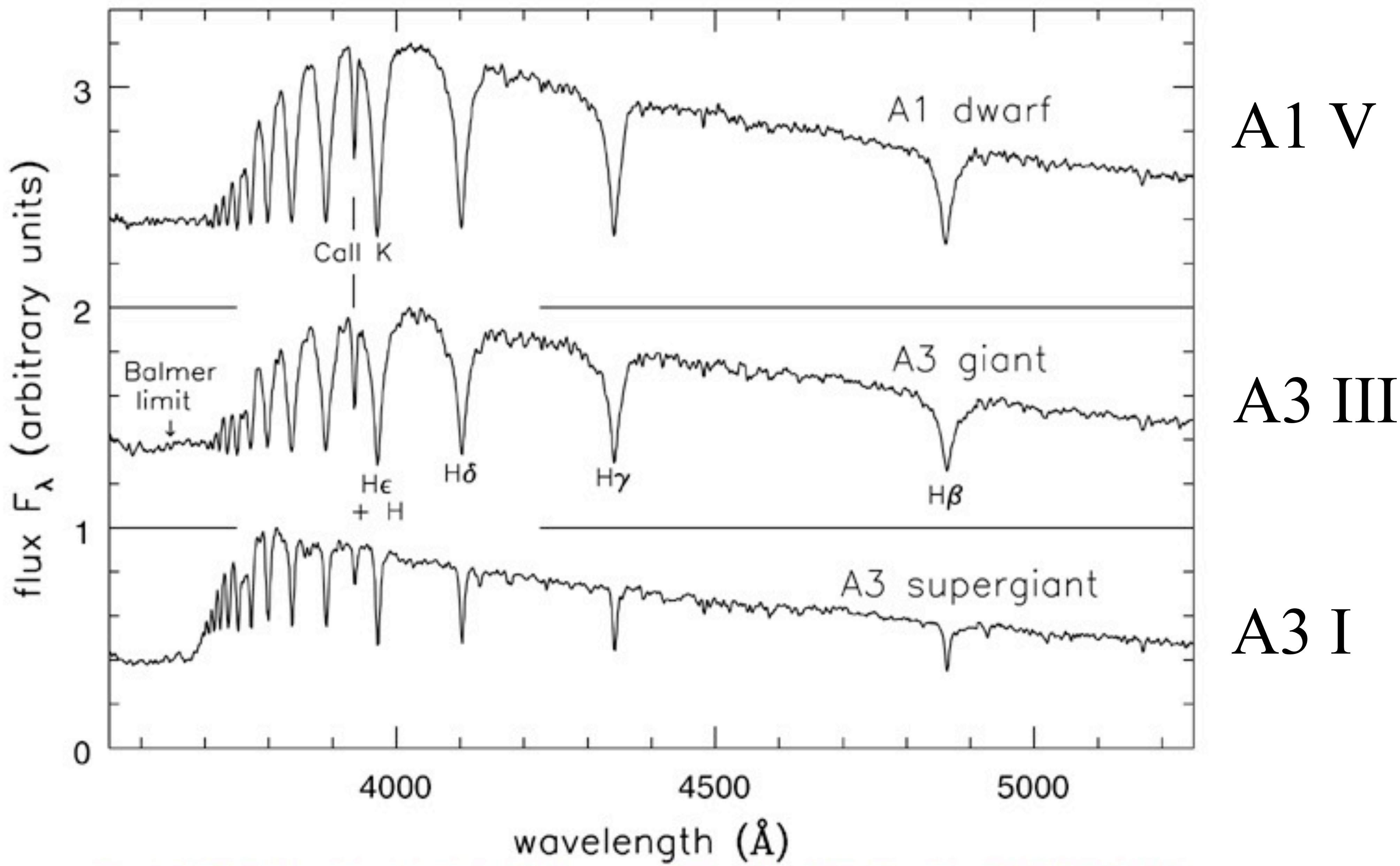


Fig 1.2 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The more poofy the star, the narrower the lines

Typical Stellar composition

- Hydrogen mass fraction $X = 0.74$
- Helium mass fraction $Y = 0.25$
- Heavier elements ("metals"): $Z \approx 0.01$

Abundances of H & He set during Big Bang.
Heavier elements made in previous generations of stars.
Z often called "metallicity" and sometimes referenced to the iron abundance, [Fe/H].

open cluster

Stellar populations

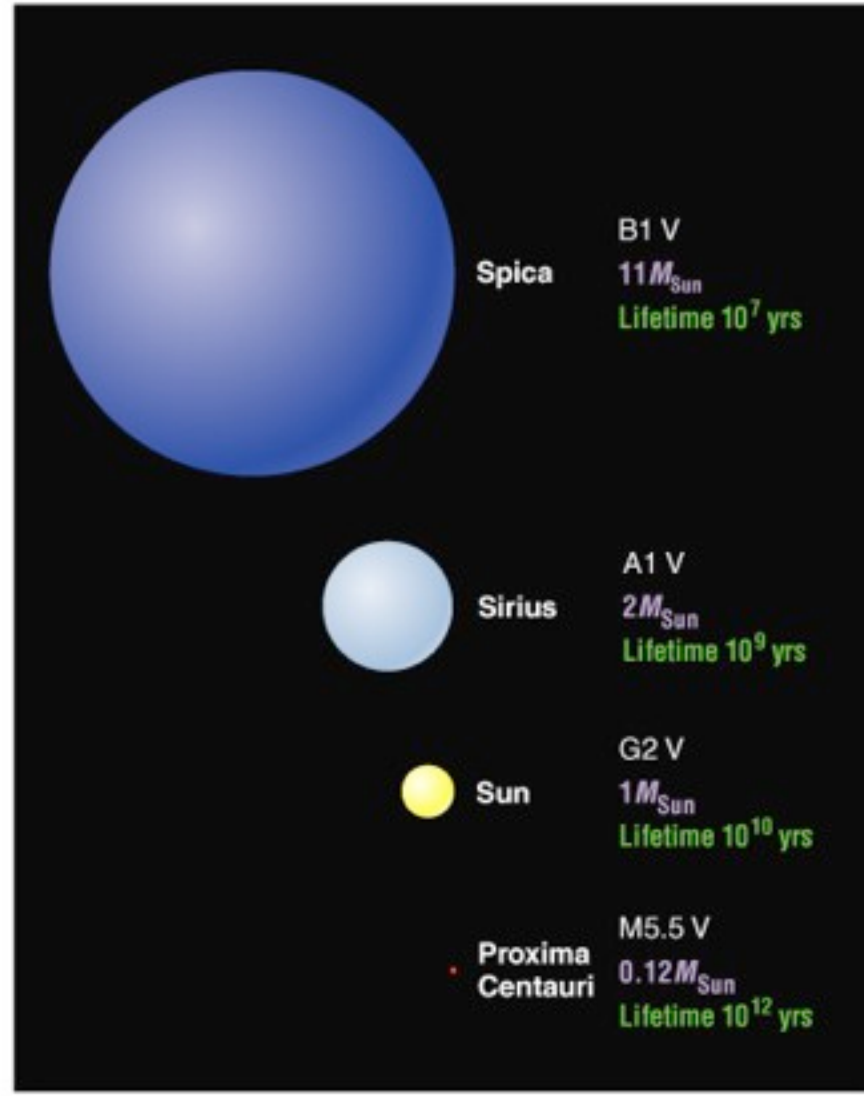
- Simple Single Population (SSP)
  - stars of all masses born at the same time
  - e.g., a star cluster

- Complex stellar population
  - Convolution of many star forming events
  - need to know
    - IMF (initial mass function)
    - Birthrate (star formation rate history)

globular cluster

Main Sequence Stars

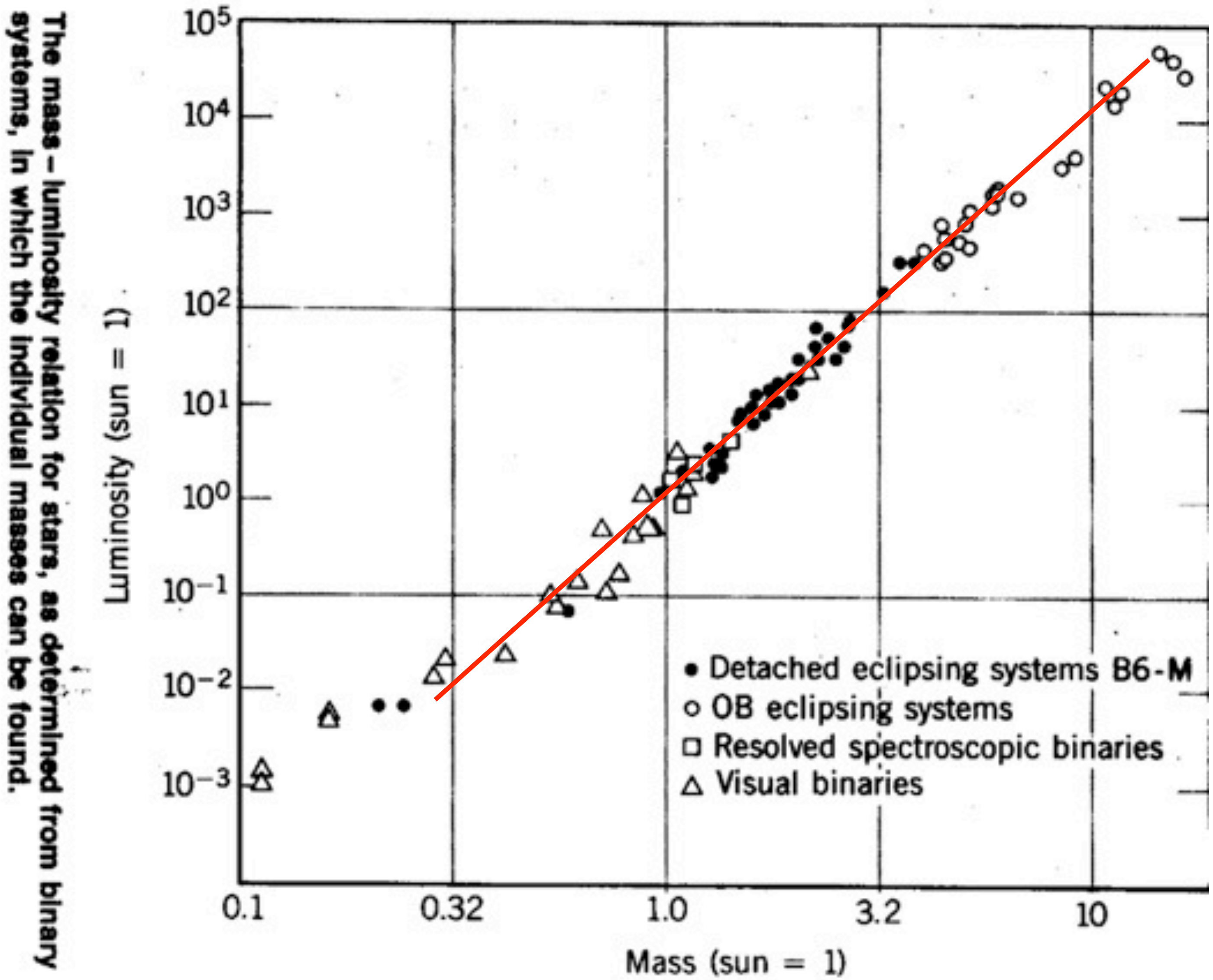
- Obey scaling relations
- Mass-Radius relation
  - more massive stars are bigger
- Mass-Luminosity relation
  - more massive stars are brighter



Main-sequence stars (to scale)

Mass-Luminosity Relation

$$L \propto M^{3.5}$$



0.08 M$_\odot$ = minimum mass for a star

Mass-Luminosity Relation

roughly $L \propto M^{3.5}$

- more massive stars **much** brighter
- use their fuel **much** faster
  - Mass: fuel supply ($E = mc^2$)
  - Luminosity: rate of fuel usage

Mass is finite - the stars don't shine forever!

Mass and Lifetime: $t \propto \dfrac{M}{L}$

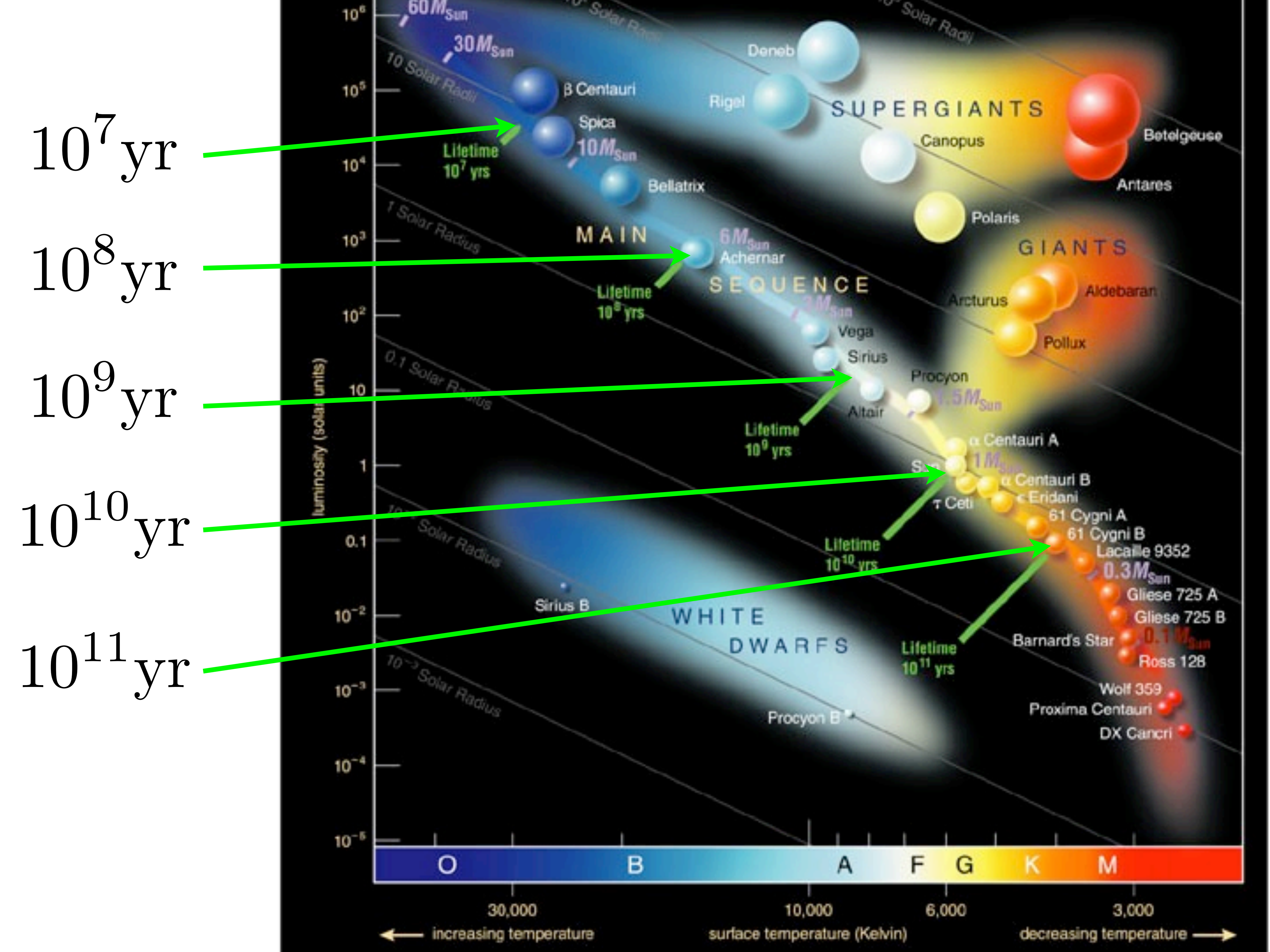
M ← fuel

L ← rate of fuel use

Mass-Luminosity Relation: $L \propto M^{3.5}$

$$t \propto \frac{M}{L} \propto \frac{M}{M^{3.5}} \propto M^{-2.5}$$

So as mass increases, the main sequence lifetime decreases.



10^7yr
10^8yr
10^9yr
10^10yr
10^11yr
60 M_Sun
30 M_Sun
10 Solar Radii
β Centauri
Spica
10 M_Sun
Lifetime 10^7 yrs
Bellatrix
Deneb
Rigel
SUPERGIANTS
Canopus
Betelgeuse
Antares
Polaris
1 Solar Radius
MAIN
6 M_Sun
Achernar
SEQUENCE
Lifetime 10^8 yrs
GIANTS
Arcturus
Aldebaran
3 M_Sun
Vega
Pollux
Sirius
Procyon
1.5 M_Sun
0.1 Solar Radius
Altair
Lifetime 10^9 yrs
α Centauri A
Sun
1 M_Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lifetime 10^10 yrs
Lacaille 9352
0.3 M_Sun
Gliese 725 A
Gliese 725 B
Barnard's Star
0.1 M_Sun
Ross 128
Lifetime 10^11 yrs
Sirius B
WHITE
DWARFS
10^-3 Solar Radius
Wolf 359
Proxima Centauri
Procyon B
DX Cancri
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
10^-5
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

Off the Main Sequence

- Stellar properties depend on both mass and age: those that have finished fusing H to He in their cores are no longer on the main sequence.

- All stars become larger and redder after exhausting their core hydrogen: **giants** and **supergiants.**

- Most stars end up small and dim after fusion has ceased: **white dwarfs.**

The MAIN SEQUENCE
is a sequence in MASS

For stars, mass is destiny

more massive stars
- are much brighter
- live shorter lives

Theoretical evolutionary tracks

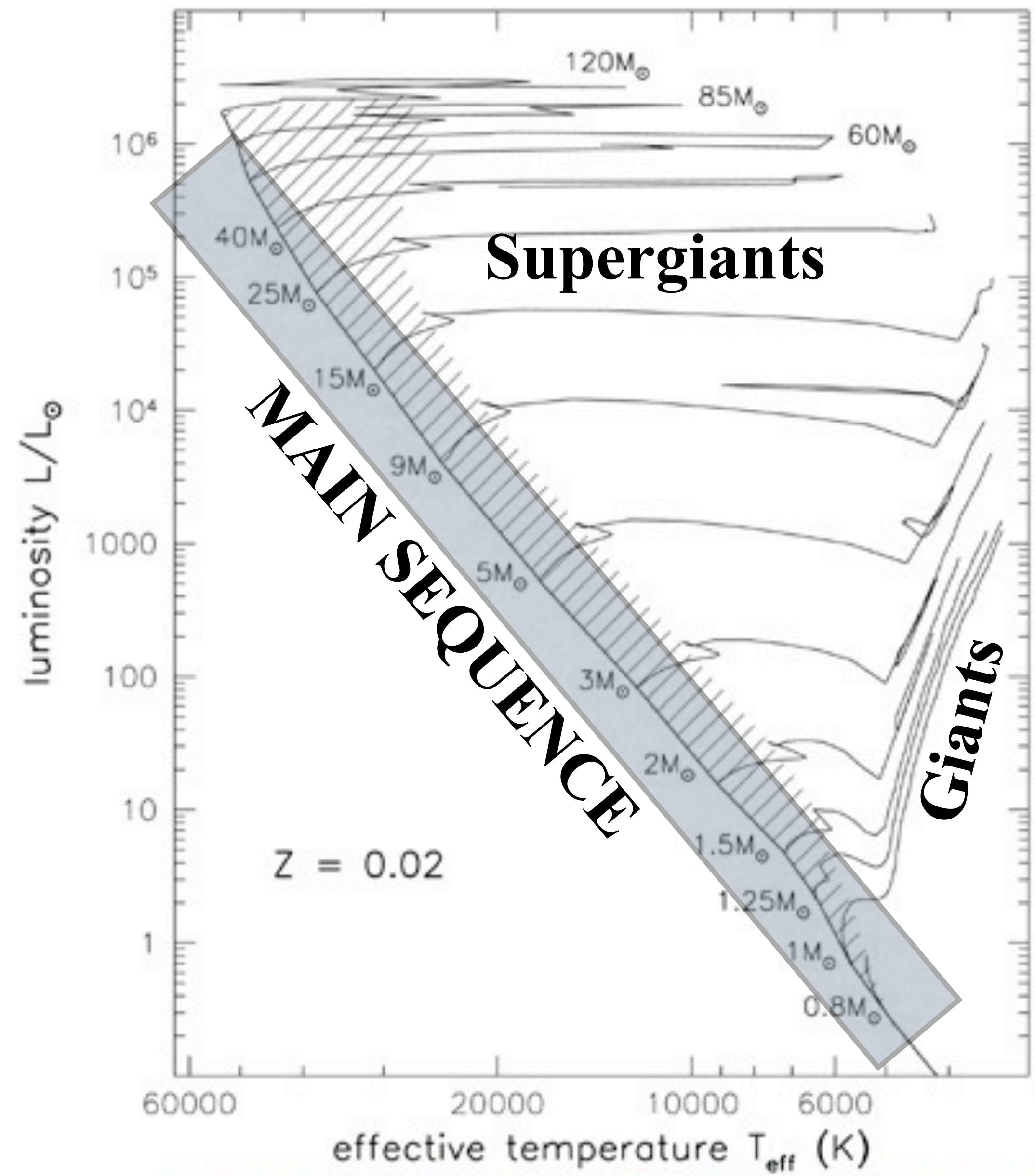
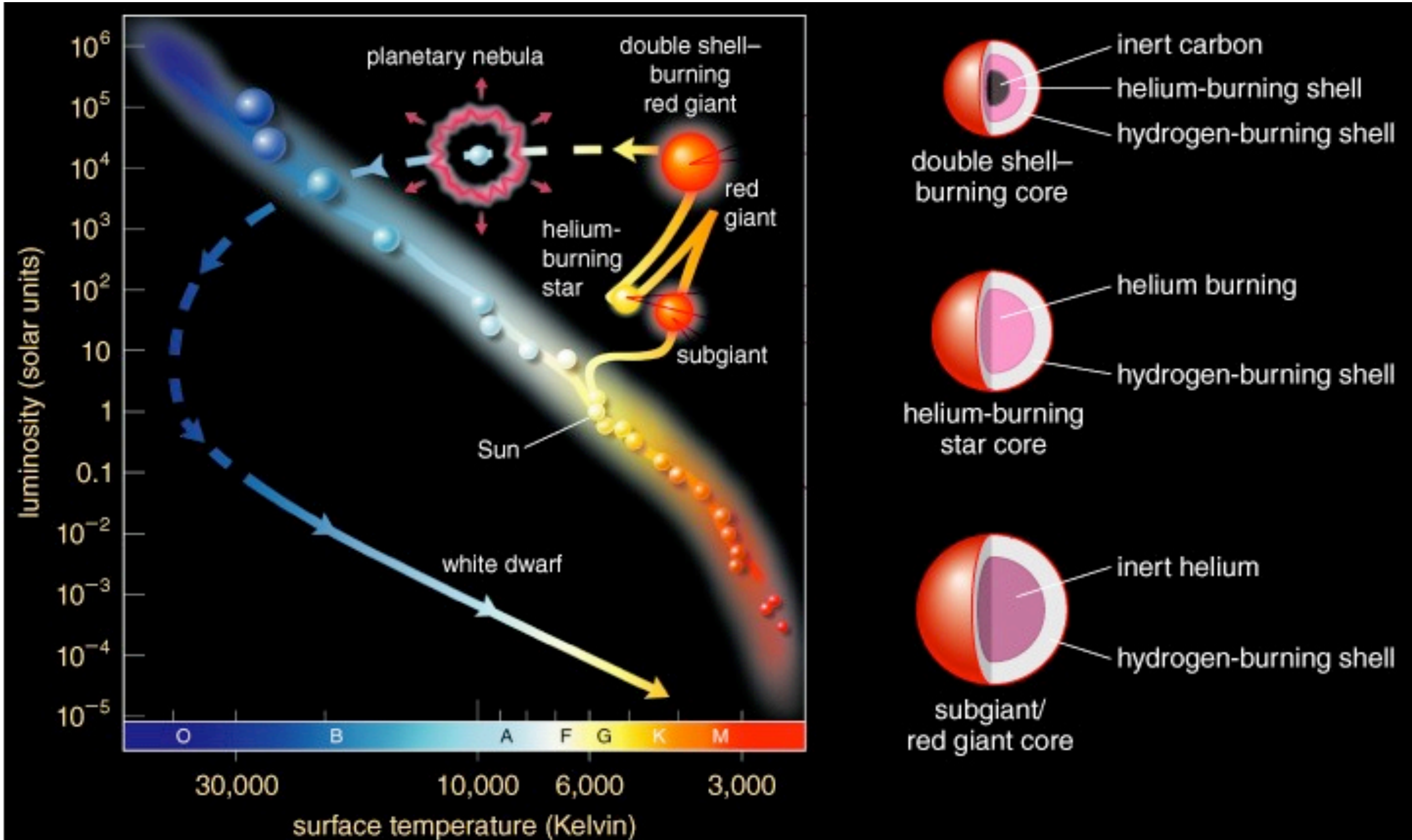
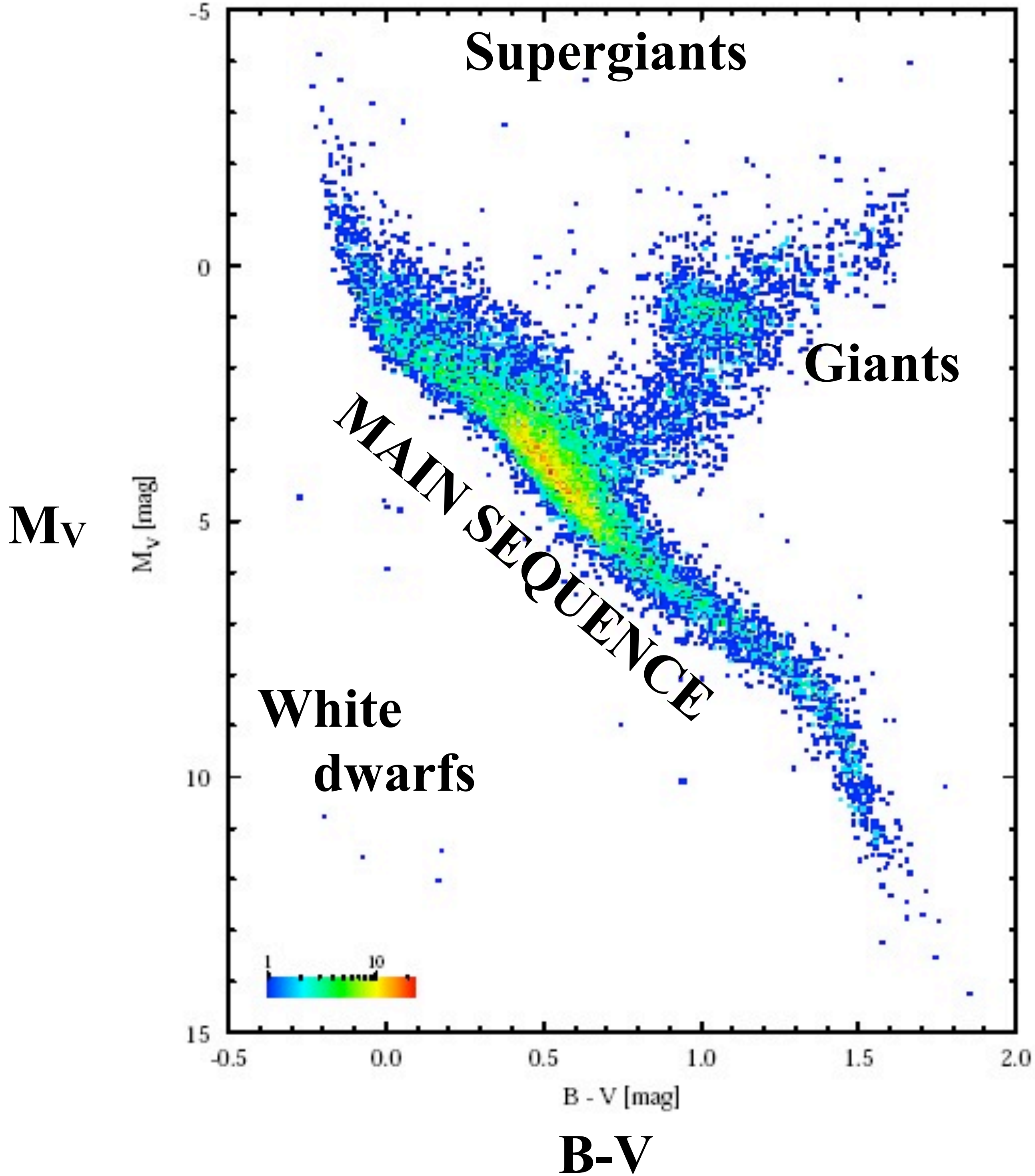


Fig 1.4 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Life Track of a Sun-Like Star



Hipparcos color-magnitude diagram

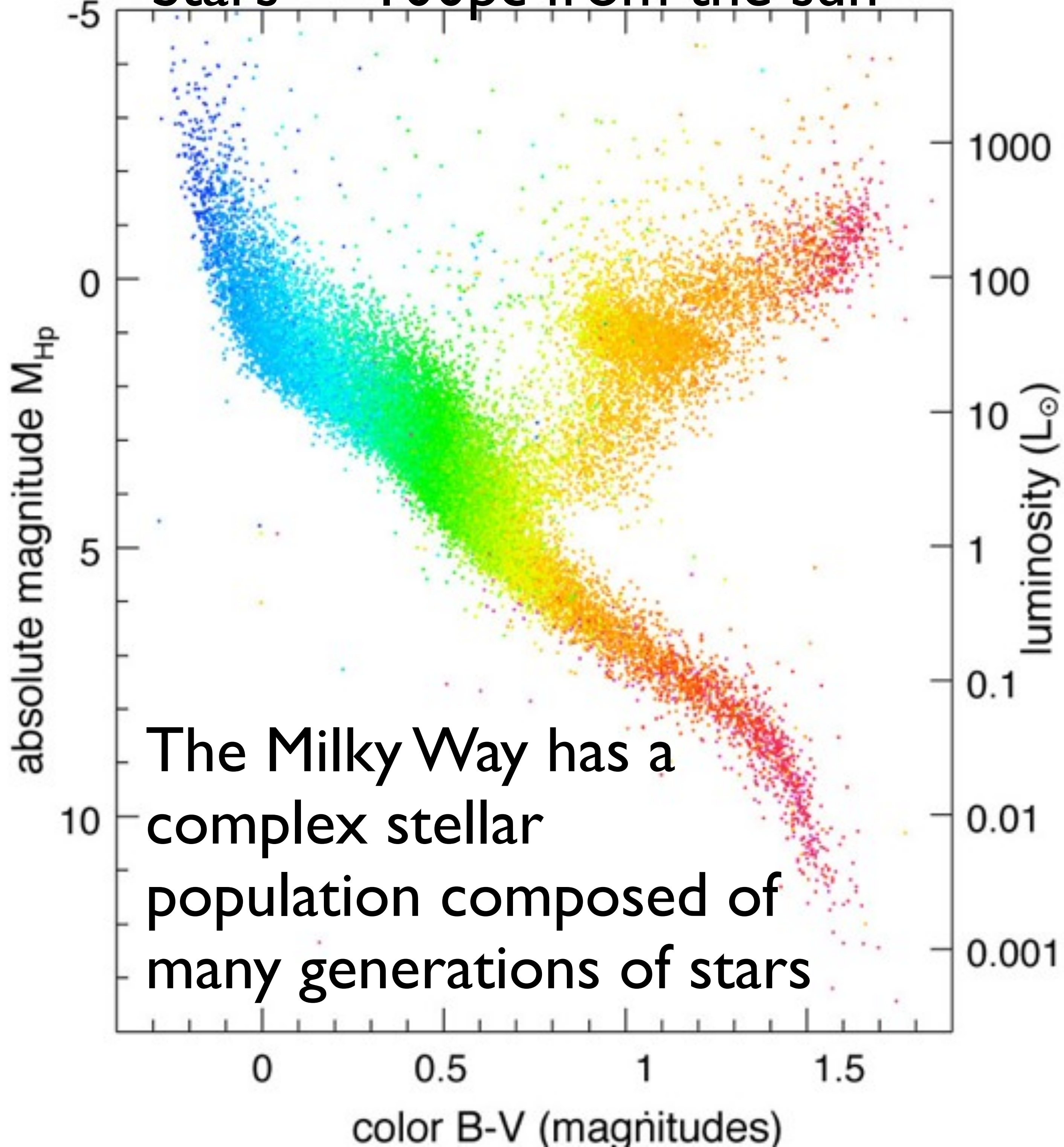


Dead Stars leave corpses

- White dwarfs
  - remnants of low mass stars like the sun
- Neutron stars
- Black Holes
  - remnants of high mass stars

Sequester mass but emit little light

Stars < 100pc from the sun



The Milky Way has a complex stellar population composed of many generations of stars

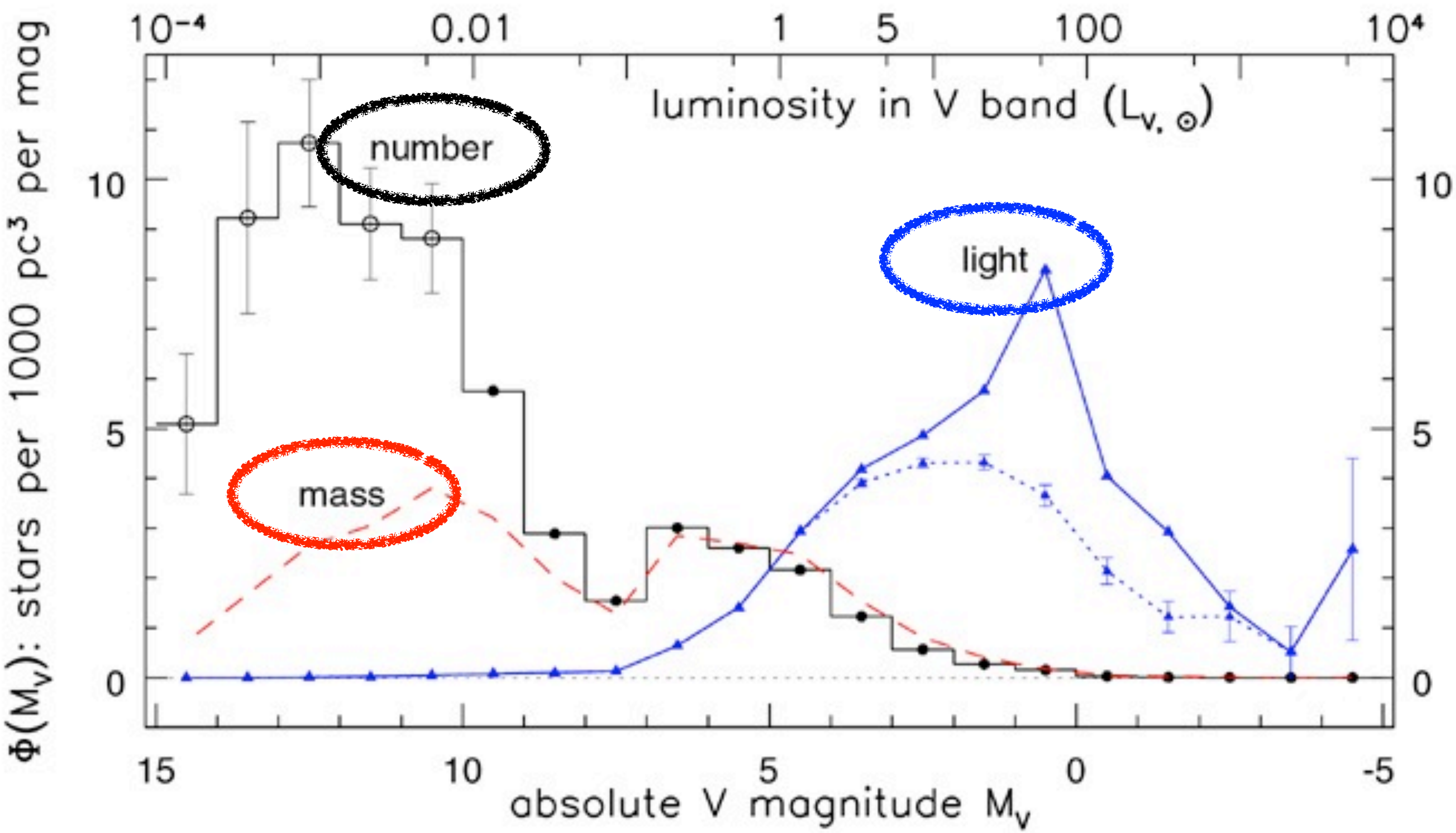


Fig 2.3 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Low mass stars exist in the greatest numbers and contain most of the mass.
High mass stars produce most of the light.

IMF vs PDF

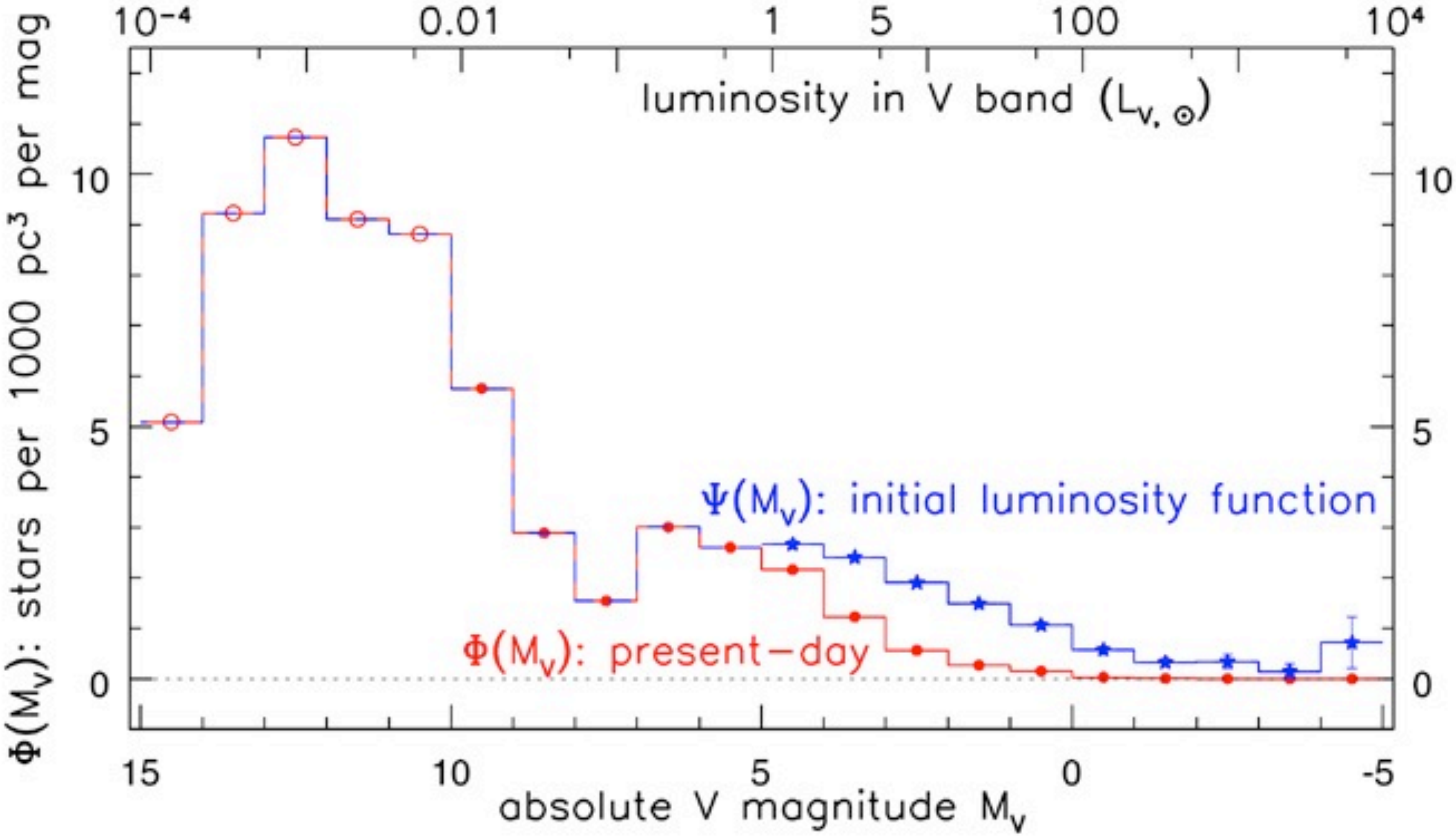


Fig 2.4 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Pleiades:

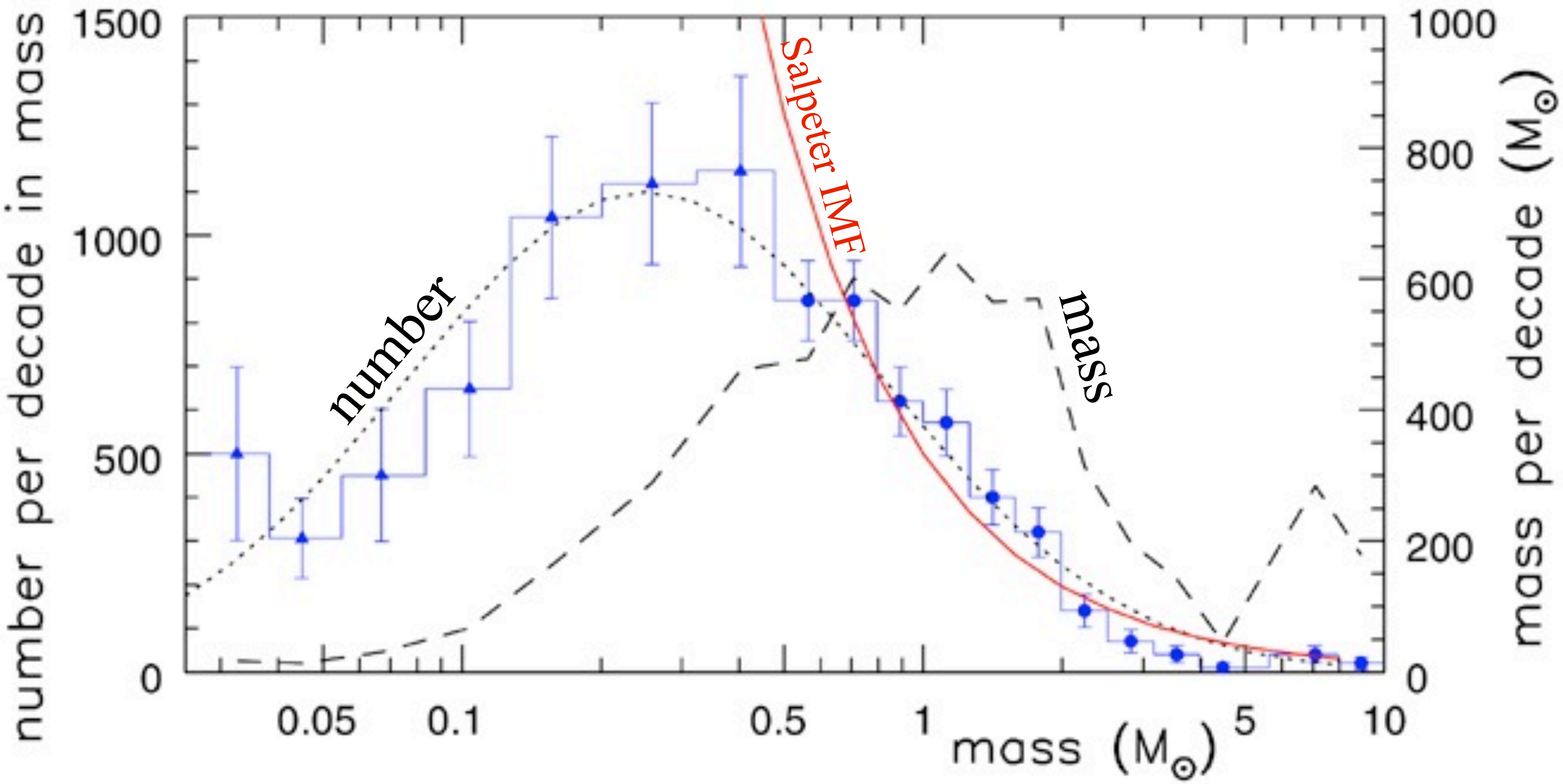


Fig 2.5 (E. Moreau) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Bell & de Jong (2001) models

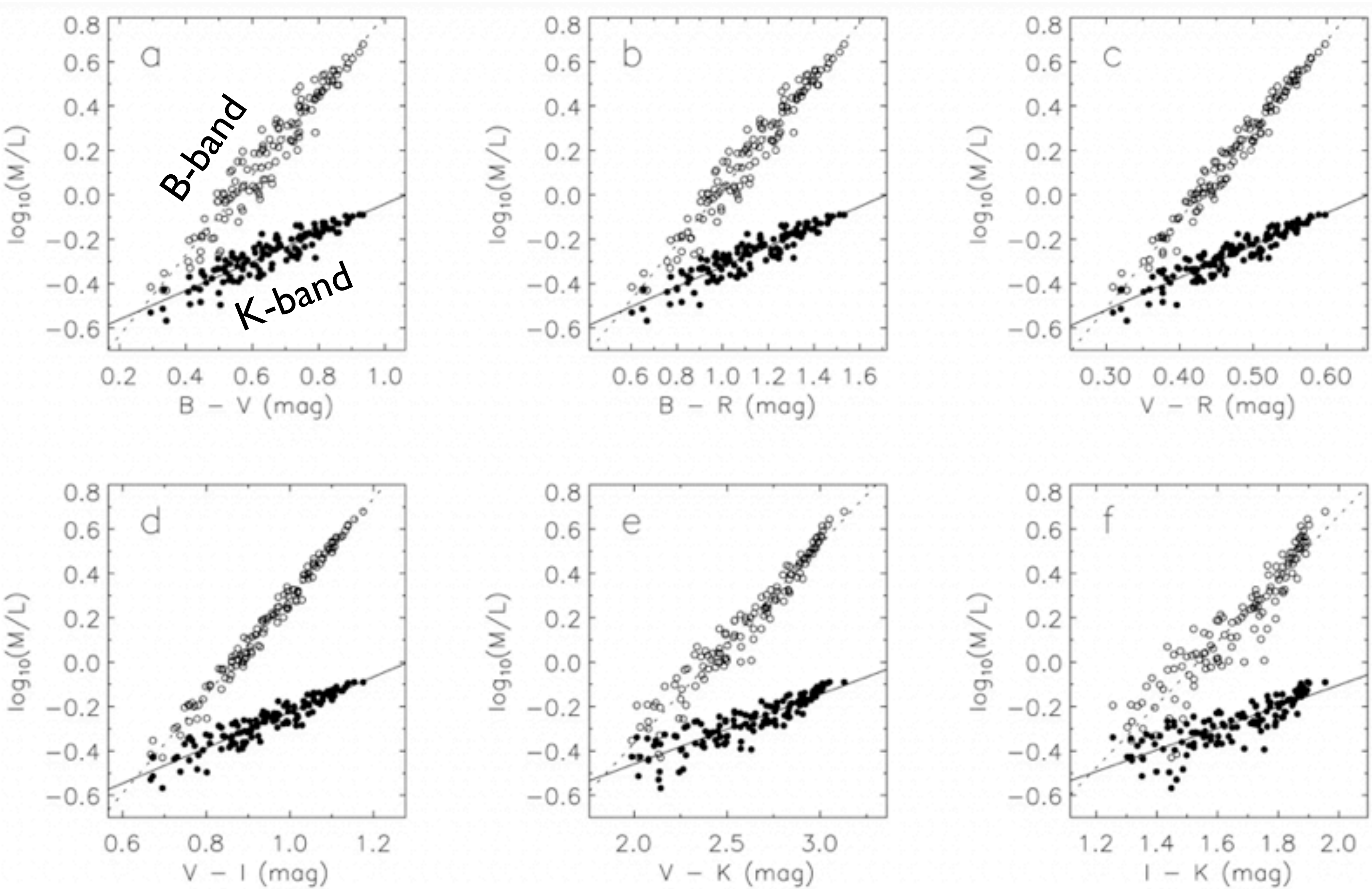


Table 5
Self-Consistent Population Synthesis Mass-to-Light Ratios

Model	a_V	b_V	α_I	β_I	$\alpha_{[3.6]}$	$\beta_{[3.6]}$	$\Upsilon_{0.6}^{V}$	$\Upsilon_{0.6}^{I}$	$\Upsilon_{0.6}^{[3.6]}$
Bell et al. (2003)	−0.628	1.305	−0.259	0.565	−0.313	−0.043	1.43	1.20	0.46
Portinari et al. (2004)	−0.654	1.290	−0.302	0.644	−0.575	0.394	1.32	1.22	0.46
Zibetti et al. (2009)	−1.075	1.837	−0.446	0.915	−1.115	1.172	1.07	1.27	0.39
Into & Portinari (2013)	−0.900	1.627	−0.394	0.820	−0.841	0.771	1.19	1.25	0.42

Note. — Stellar mass-to-light ratios in the V, I, and K-bands given by the formula $\log \Upsilon_*^j = \alpha_j + \beta_j(B-V)$. For each model, the V-band is identical to that in Table 3, but the I and [3.6] bands have been revised to attain self-consistency with the V-band (see text). For reference, the mass-to-light ratio at $B-V = 0.6$ is also given.

$$\log\left(\frac{M_*}{L_i}\right) = a_i + b_i(B-V)$$

Older populations (like in Elliptical galaxies) can have larger mass-to-light ratios, but usually $\left(\frac{M_*}{L}\right) < 5\ \frac{\mathrm{M}_\odot}{\mathrm{L}_\odot}$