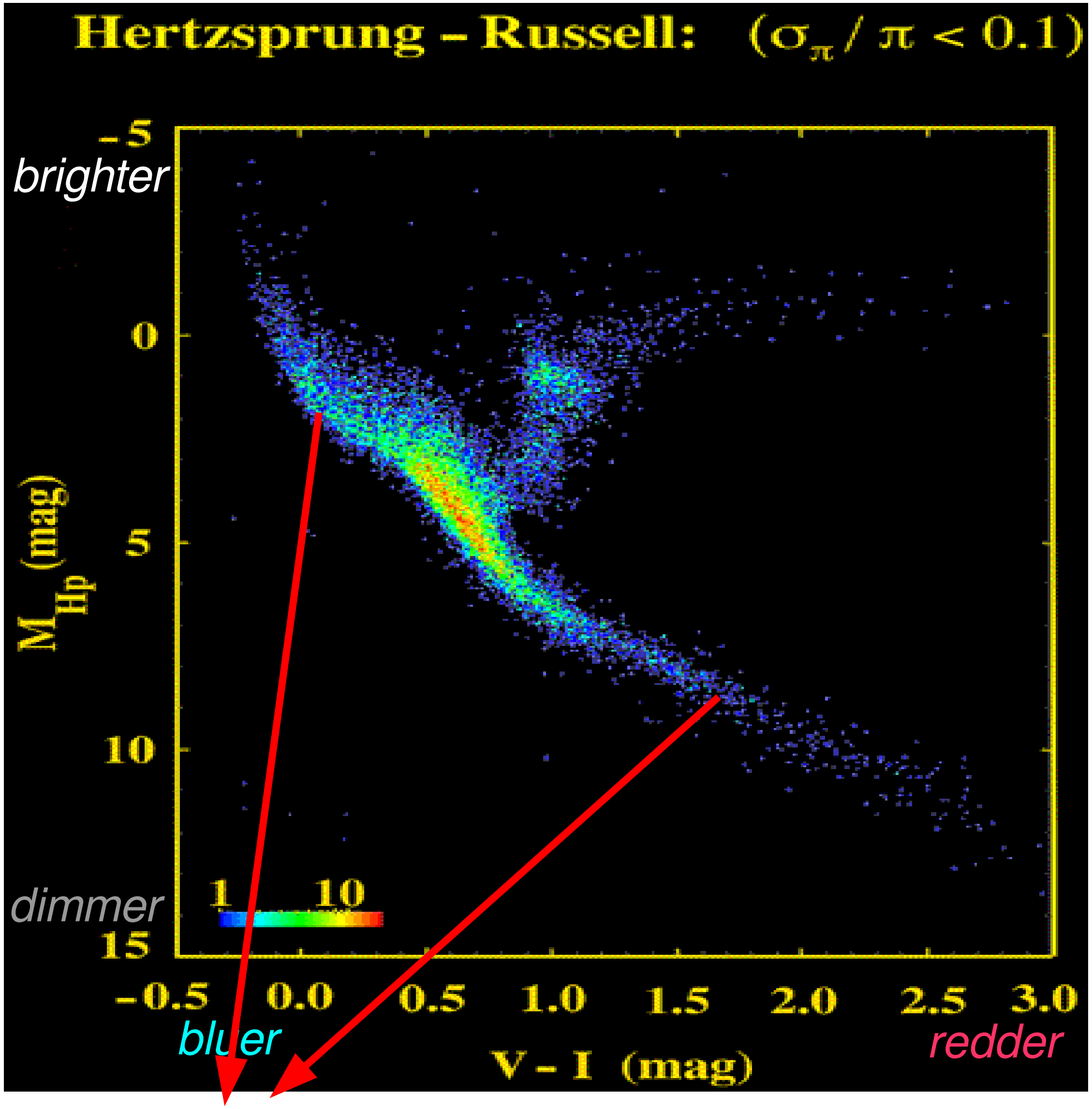
Finally,
the stars themselves

Stars are divided according to their stage in life.

Lecture 1:	Main-sequence stars: H $\rightarrow$ He in core What is the main sequence? How do radius, luminosity & life-time depend on stellar mass? Hertzsprung-Russell Diagram Stellar spectral types, UBV photometry
Lecture 2:	Giants: high-mass stars (He $\rightarrow$ C and on to Fe)
Lecture 3:	Giants: low-mass stars (H shell, He flash, ...)
Lecture 4:	Stellar corpses: white dwarfs, neutron stars & black holes
Lecture 5:	Birth of stars, which also leads to
Lectures 6...:	planets...



Hipparcos catalogue of nearby stars (with parallax inaccuracy < 10% of parallax measurement) colours indicate density of stars

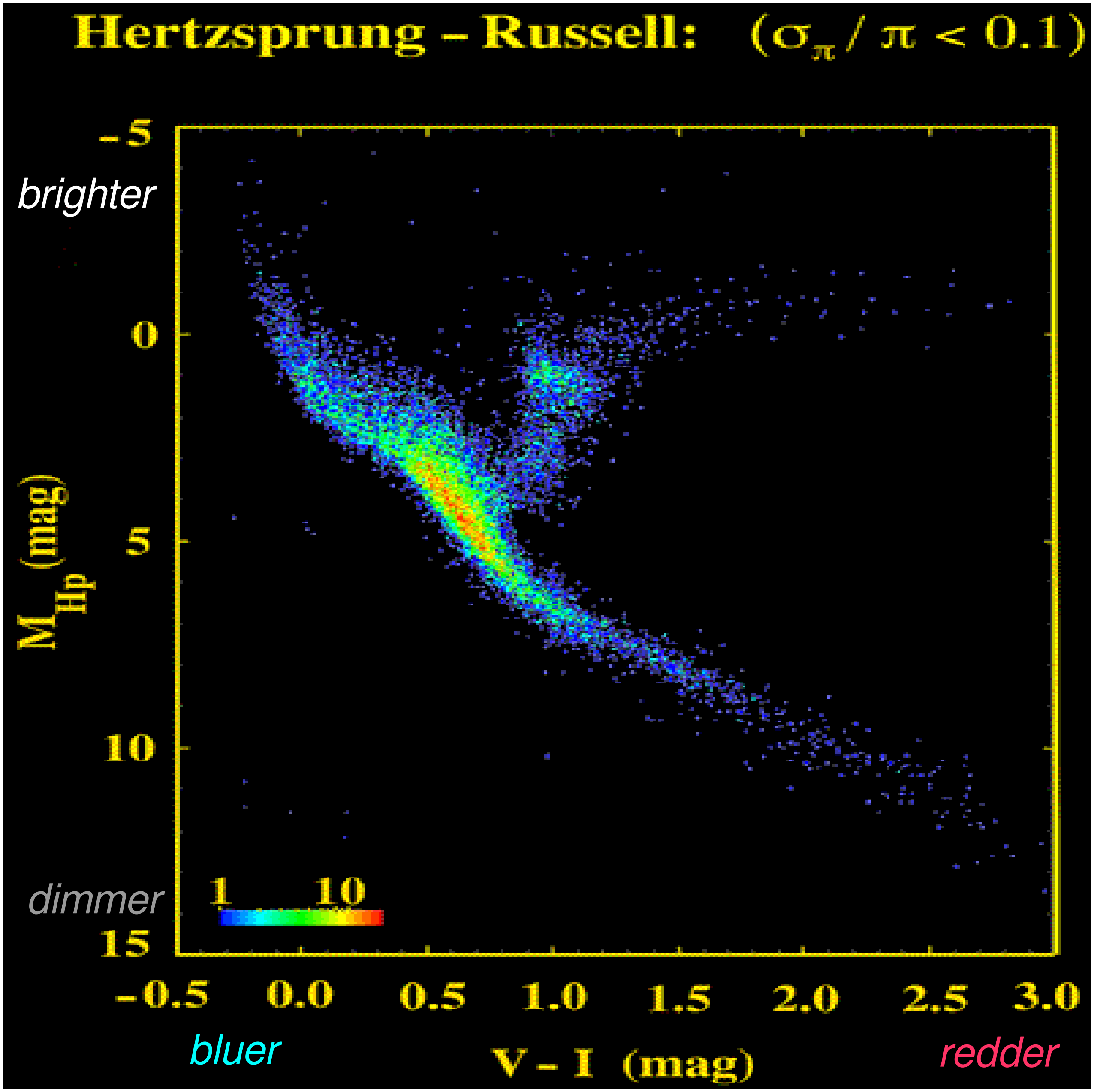
Main-sequence stars

- Most common
- Stars that are steadily burning H into He in center
- The longest stage in a star's life
- Only small changes in appearance

(most people are adults, fewer infants, adolescents & seniors)

The Color-Magnitude Diagram
(Hertzsprung-Russell Diagram)

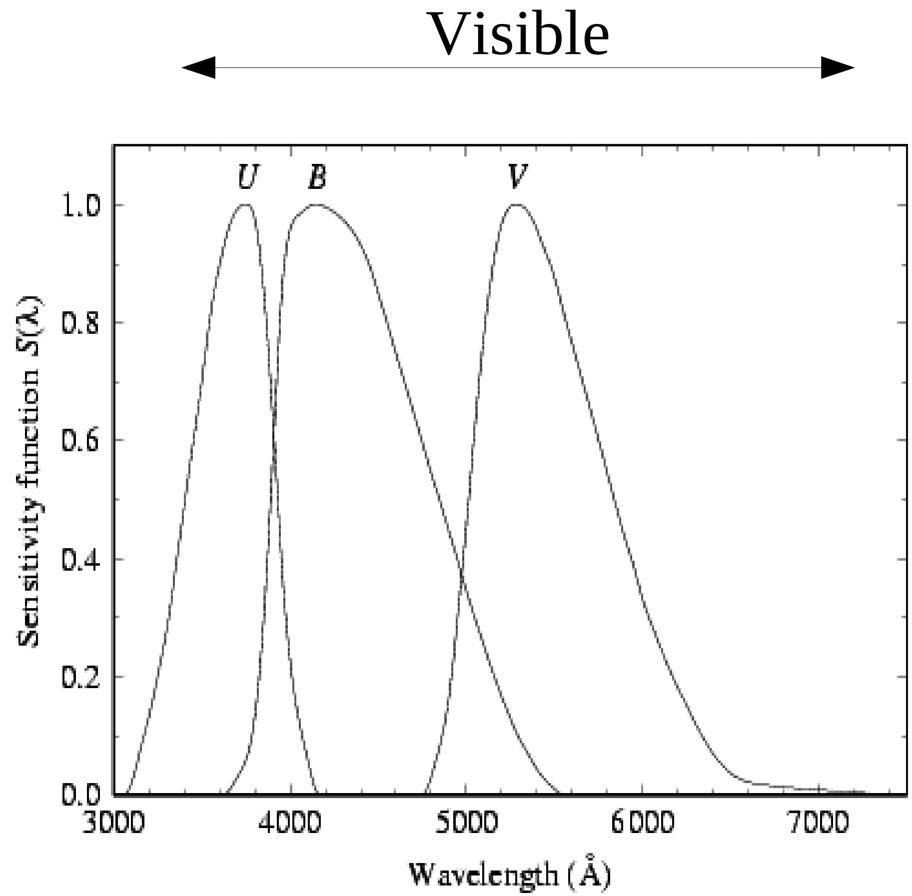
Color is a surrogate for temperature



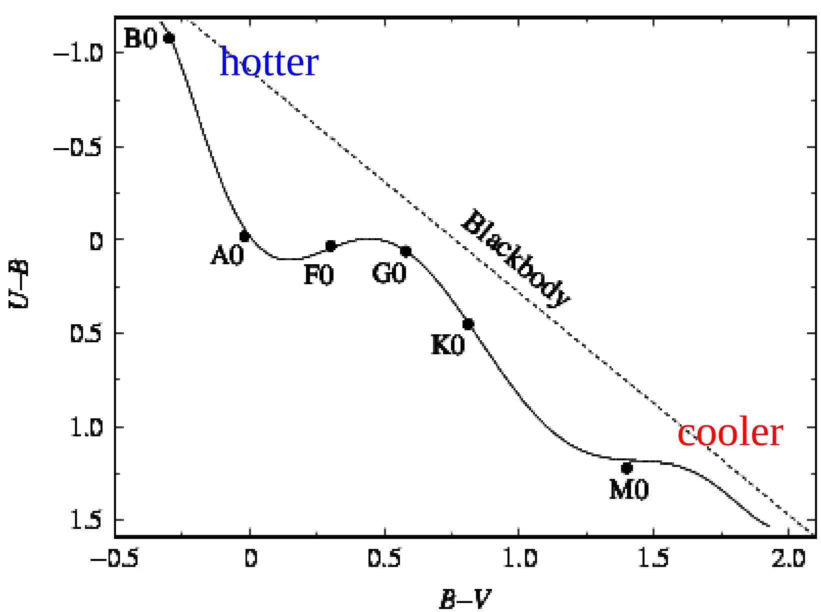
The Color Index

- easier to measure than the entire B.B. Curve
- a good surrogate for T

magnitudes defined in photometric bands:
U: ultraviolet
B: blue
V: visual
R: red
I: infrared
(continuing with J, H, K, L, M.....)
Many systems; e.g., in optical, also u,g,r,i,z

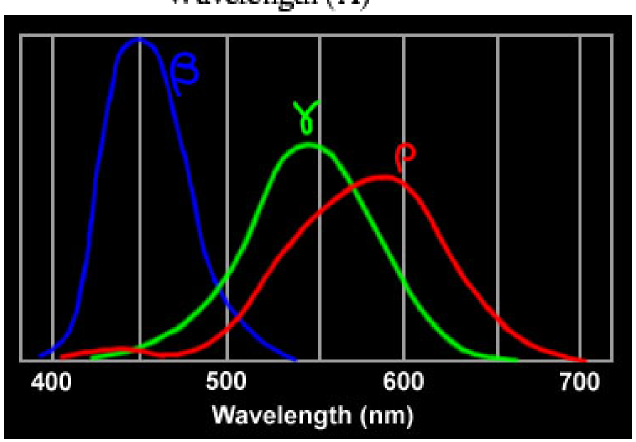


Color-Color plot



Vega (~10,000K) defines U-V = B-V = 0
Sun (~5770K): U-V=+0.16, B-V=+0.64

Sensitivity for...?



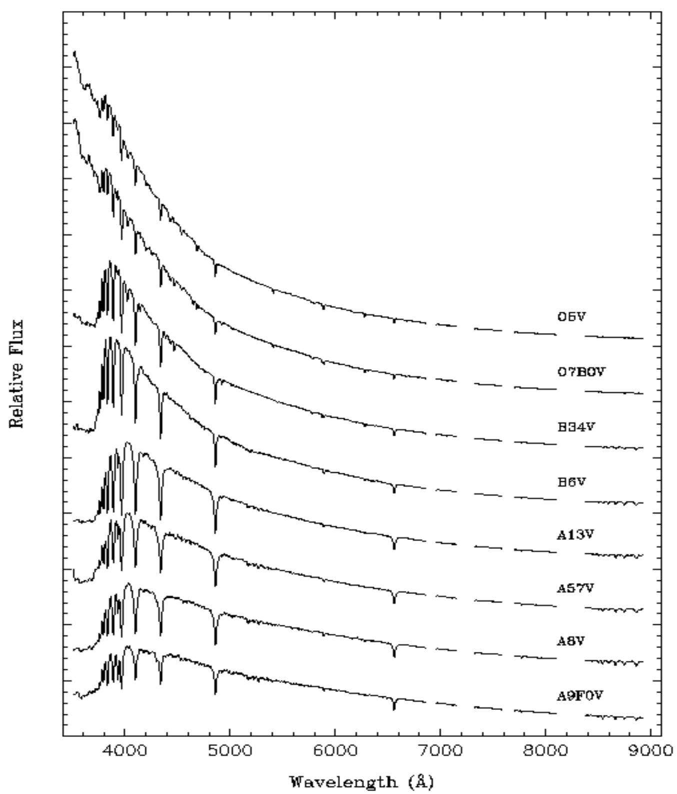
Spectral Types of Stars

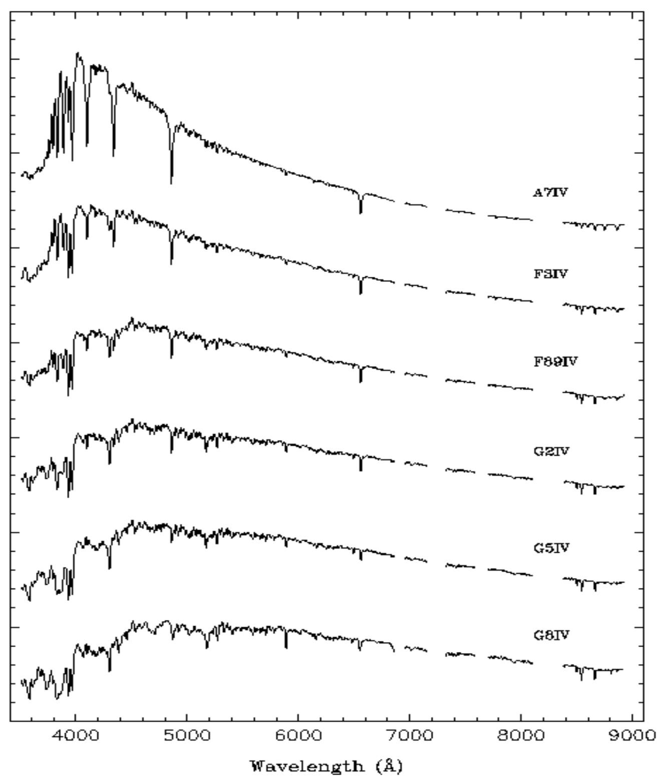
One can also use spectral types as surrogates for stellar surface temperature

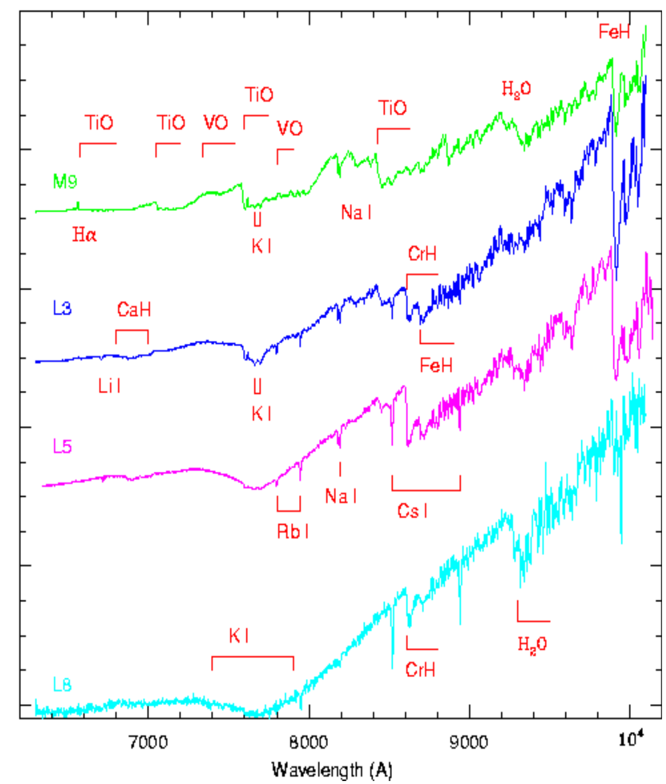
1) historically based on the presence/strength of certain spectral lines (H,He,Ca,Fe...)
2) later shown to be related to temperature

	O	B	A	F	G	K	M	(L	T)
	O0-----O9	B0----B9	A0......A9	F0......F9	G0.....G9	K0.....K7	M0.....M9		
T_{eff}	O5:40,000K		A0:10,000K		G2:5800K		M0:4000K		T:<1000K
		H all ionized			the Sun		molecular absorption bands		

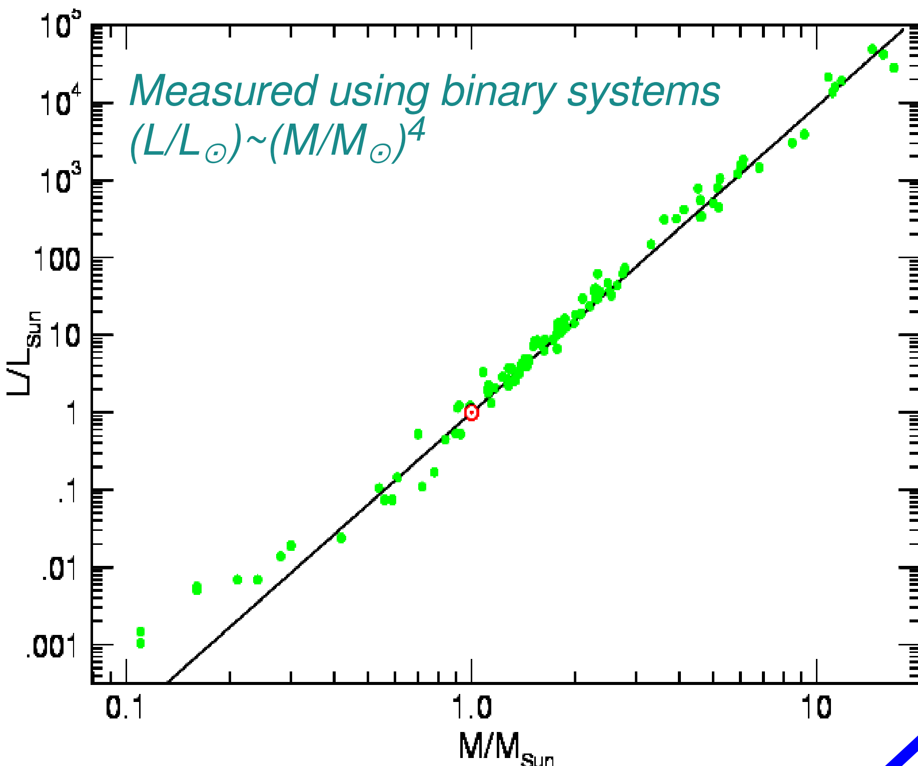
O5-A9 (helium,hydrogen) *A7-G8 (hydrogen, metals)* *M9-L8 (molecular bands)*

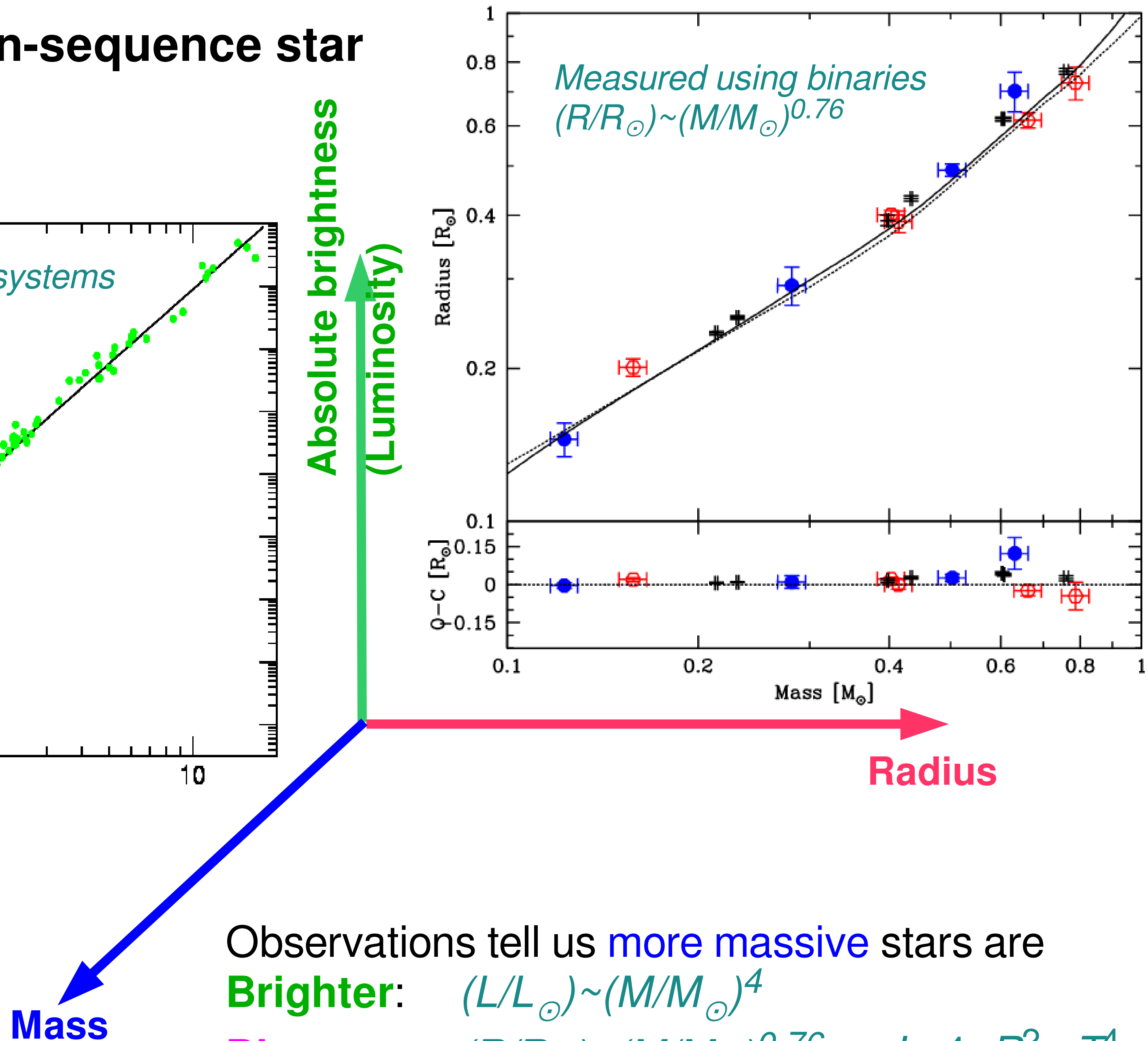






Quantifying a main-sequence star
(surface quantities)





Observations tell us more massive stars are

Brighter: $(L/L_\odot) \sim (M/M_\odot)^4$

Bigger: $(R/R_\odot) \sim (M/M_\odot)^{0.76}$ $L = 4\pi R^2 \sigma T^4$

Hotter: $(T/T_\odot) \sim (M/M_\odot)^{0.6}$

More massive stars are

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Stars on Main Sequence follow a 1-parameter sequence

All described using

hydrostatic equilibrium
mass conservation
nuclear burning
photon propagation (opacity)

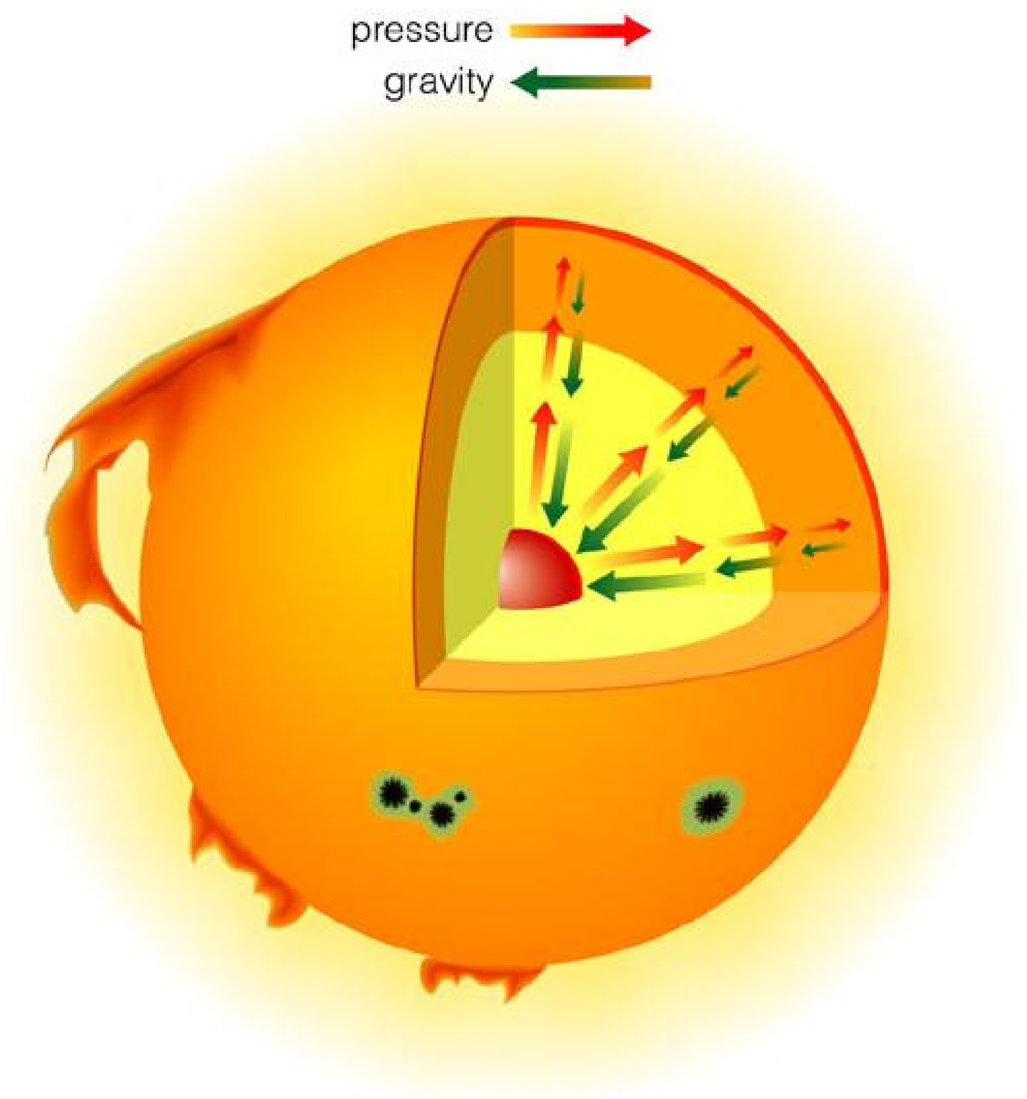
Stars are modeled numerically:

input parameters: M_* and chemical composition

equation of state: $\rho = \rho(P, T, \text{composition})$
energy production: $\epsilon = \epsilon(\rho, T, \text{composition})$
opacity: $\kappa = \kappa(\rho, T, \text{composition})$

Solve for: $P = P(r)$, $T=T(r)$, $M=M(r)$, $L=L(r)$

Star's life: Protracted battle with gravity



ALWAYS

To support weight:

⇒ need high pressure

MOSTLY

⇒ need high temperature

⇒ will loose energy

⇒ need energy source:
- Gravitational contraction
- Nuclear fusion

Ultimately,
Can something else than thermal pressure balance gravity?

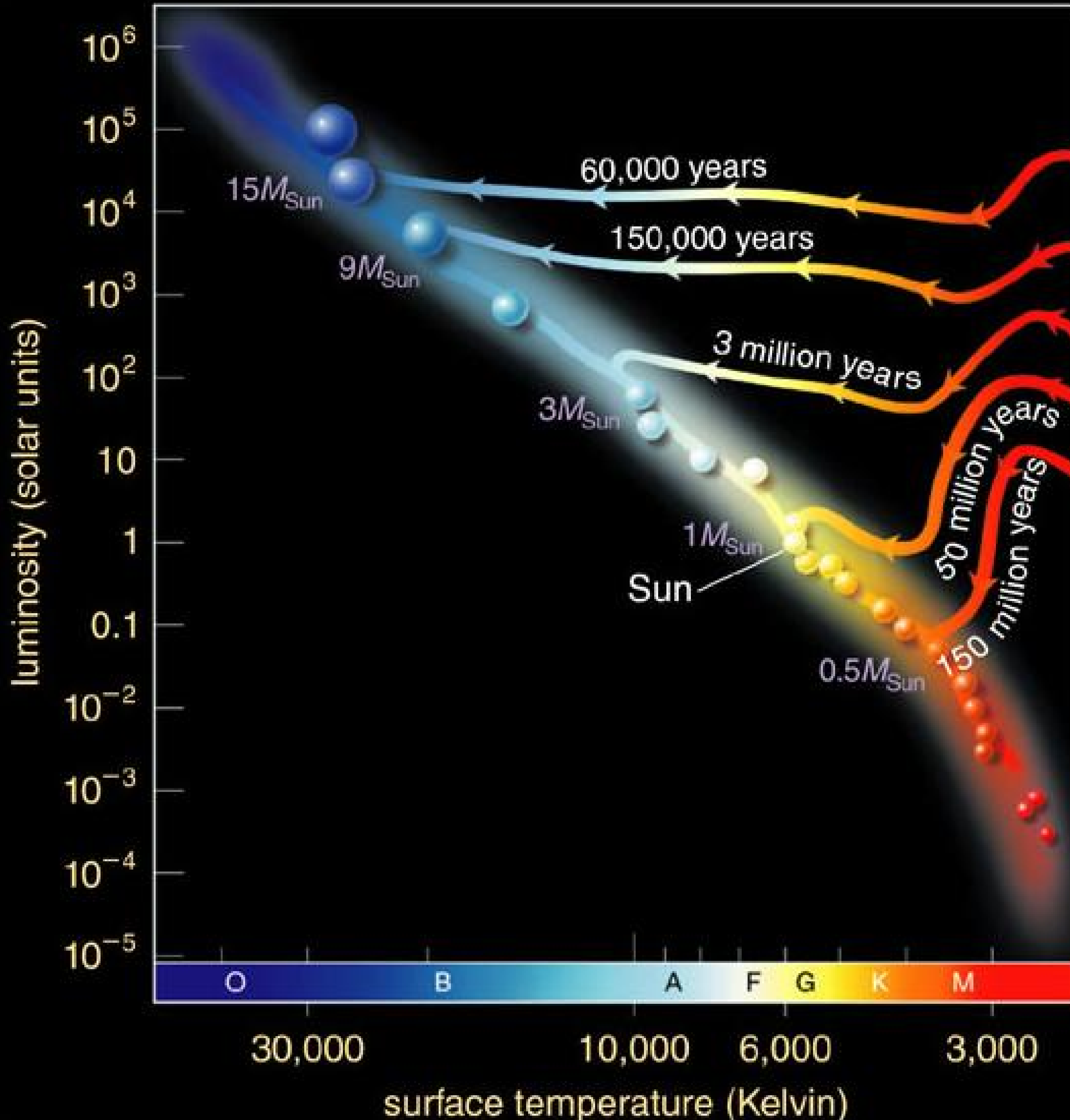
Protostellar life tracks

Contraction

⇒ Heating

⇒ Ignition

Or: Ignominy



Why are more massive stars bigger? $(R/R_\odot) \sim (M/M_\odot)^{0.76}$

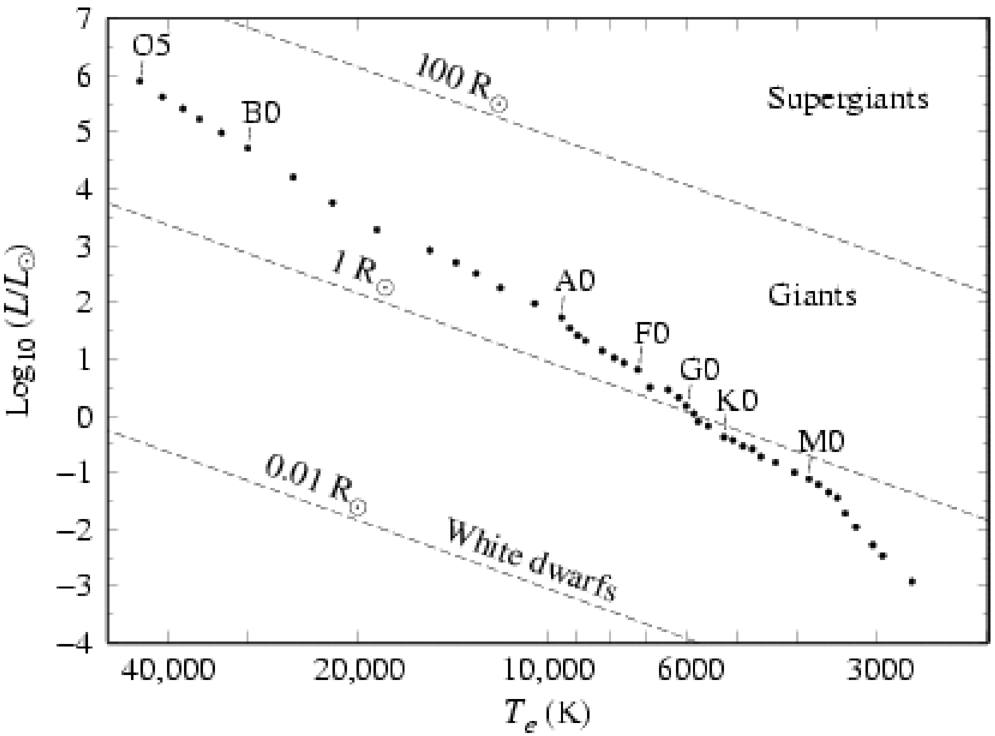
1) Assume all main-sequence stars have the same T_c

   Virial Theorem: $T_c \propto \frac{M}{R}$

   (massive star has slightly hotter T_c ...)

2) mean density of the star

$$\bar{\rho} \sim \frac{M}{R^3} \propto M^{-2}$$



Low mass limit

For sufficiently small stellar mass (~ 0.08 M_o), electron degeneracy sets in, and the material is no longer as compressible (e.g., a piece of metal)

$$\text{Pressure } P \propto \rho^{5/3} \quad \rightarrow \quad R \propto M^{-1/3}$$

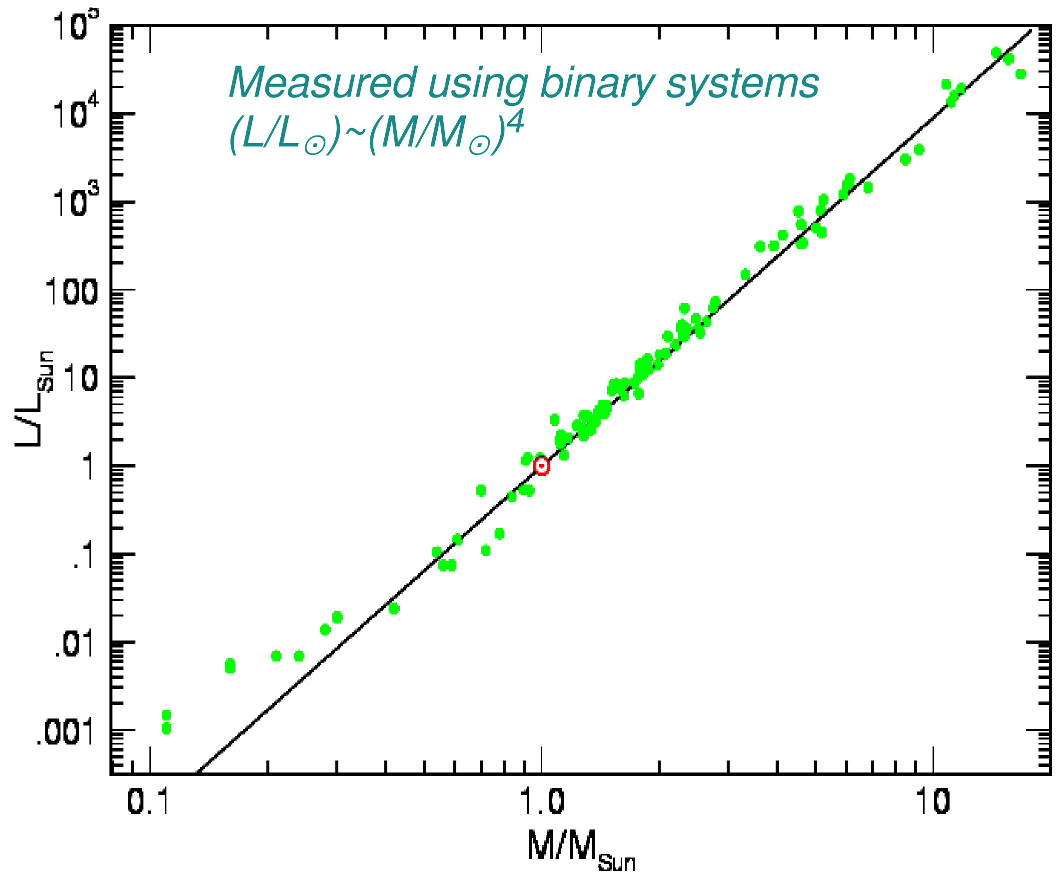
No hydrogen fusion possible ---> Brown Dwarfs

(at about 0.013M_o ~13 M_J, we encounter yet another division: planet/star)

Why are more massive stars brighter? $(L/L_\odot) \sim (M/M_\odot)^4$

Follows from
- hydrostatic equilibrium and ideal gas law (stars are hot)
- equation of radiative transfer (heat leaks out to space)

See PS III.1!
(use constant opacity, e.g., electron scattering, good for hot stars)



- More massive stars have shorter main-sequence life-time:
  Available nuclear fuel ~ M
  Efficiency of Hydrogen burning 0.7%
  Life-time ~ $0.007 * Mc^2/L$ scales as $1/M^3$

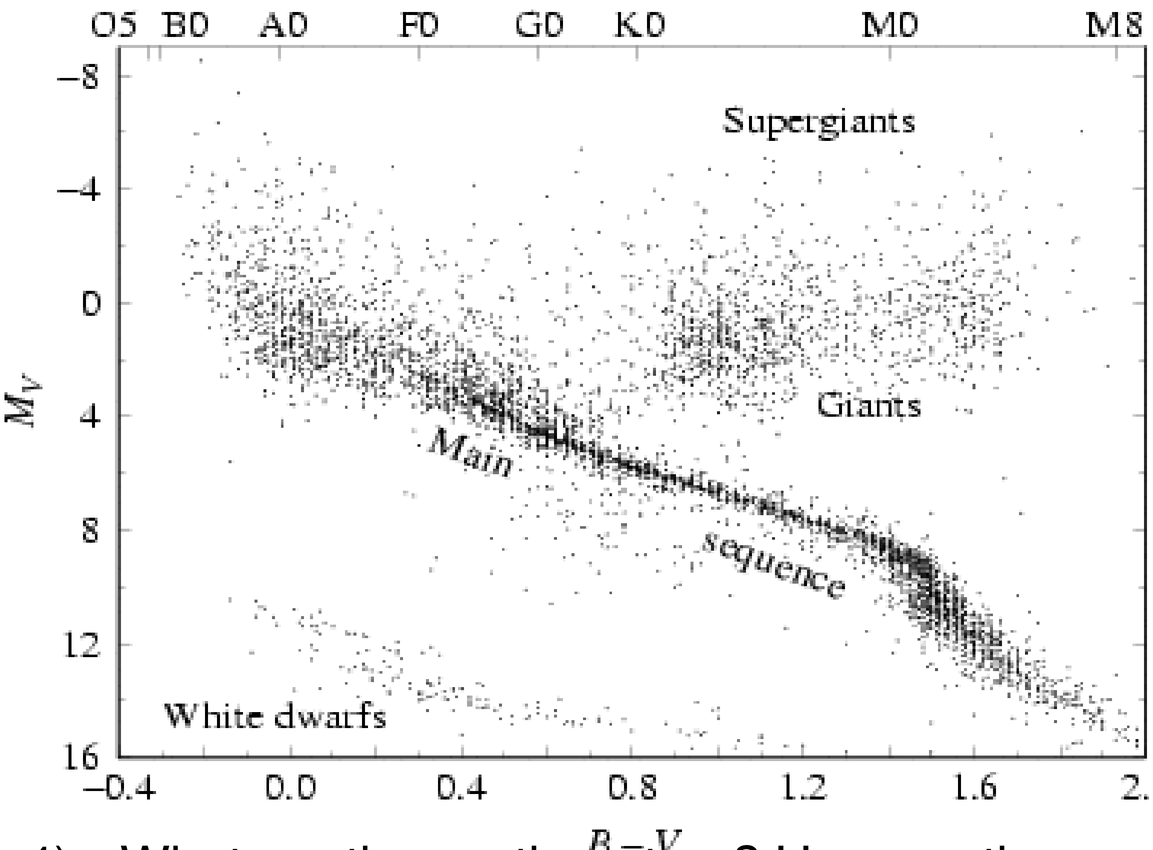
- Very low mass stars are fully 'convective'
  Radiation (slow photon diffusion) replaced by (more efficient) turbulence;
  → luminosity higher than expected based on just photon diffusion

Summary

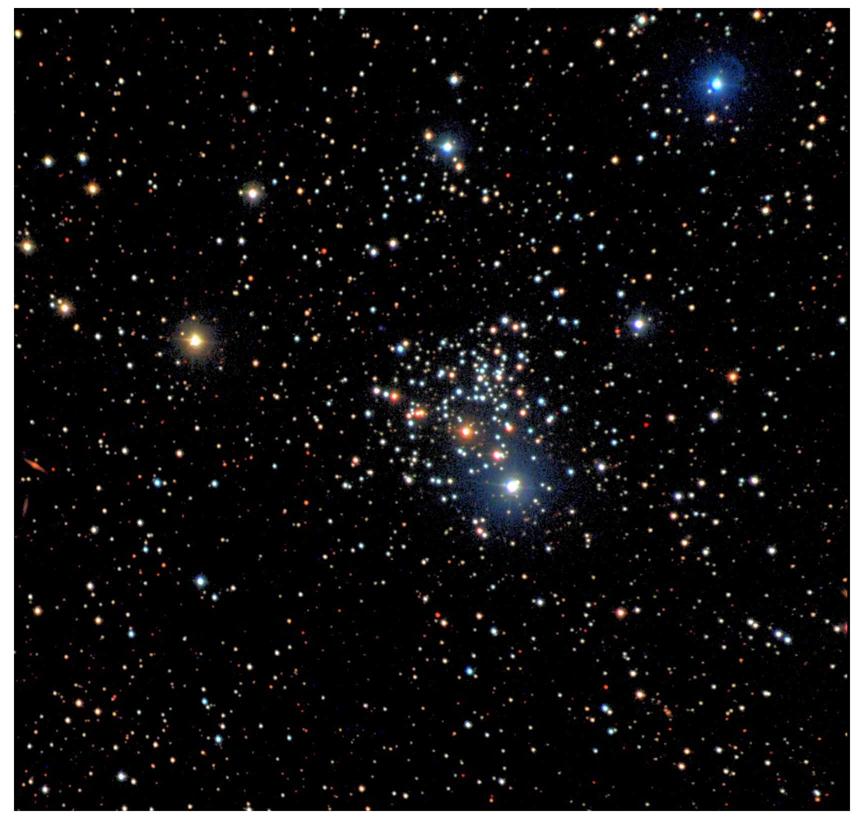
1) On MS, Mass (or T_{eff} or L) tells all (small variations due to metallicity, age)

2) Hertzsprung-Russell Diagram (HRD, or color-magnitude diagram, CMD)

3) Observational proxies for Luminosity and temperature: M_V, $B\text{-}V$ ($V\text{-}I$,…), spectral types



HRD for stars in the Solar neighbourhood



4) What are these other stars? How are they related to each other?
------ next lecture