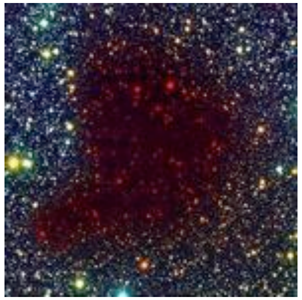
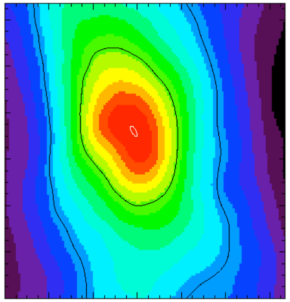
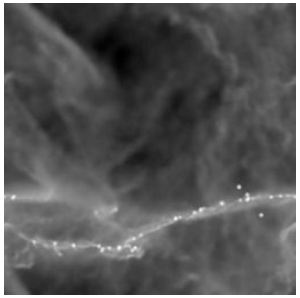
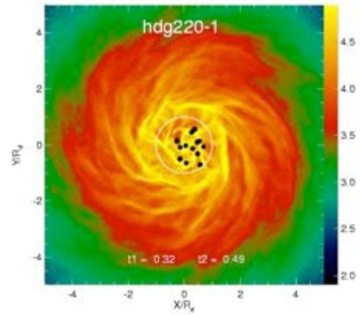
stellar astrophysics









Ralf Klessen / Stefan Jordan

Zentrum für Astronomie der Universität Heidelberg

important data

- **lecturers:**
  - Ralf Klessen (ZAH/ITA), Albert-Ueberle-Str. 2, 69120 Heidelberg
    rklessen@ita.uni-heidelberg.de, 06221 / 548978
  - Stefan Jordan (ZAH/ARI), Möchhofstr. 12-14, 69120 Heidelberg
    jordan@ari.uni-heidelberg.de, 06221 / 541842
- **time and location:**
  - Thursday, 15:15 - 17:00 hours
    Philosophenweg 12 -- Kleiner Hörsaal
- **tutorial:**
  - Tutorial: time and day to be determined

Zentrum für Astronomie Heidelberg
ARI+ITA+LSW

time line

#	Date	Topic	Lecturer
1	10.4.	introduction (stars / stars in the galaxy / observational facts)	Klessen
2	17.4.	stellar structure (basic equations)	Klessen
3	24.4.	stellar structure (equation of state / convection)	Klessen
	1.5.	MAIFEIERTAG / MAY HOLIDAY	
4	8.5.	stellar structure (energy production / main sequence)	Klessen
5	15.5.	stellar structure (rotation / magnetic fields)	Klessen
	22.5.	FRONLEICHNAHM / CORPUS CHRISTI	
6	29.5.	stellar structure (pulsation, stellar wind)	Jordan
7	5.6.	star formation	Klessen
8	12.6.	end phases of stellar evolution (giant stars)	Jordan
9	19.6.	end phases of stellar evolution (white dwarfs)	Jordan
10	26.6.	end phases of stellar evolution (neutron stars / black holes)	Jordan
11	3.7.	stellar atmospheres (basic quantities)	Dozent
12	10.7.	stellar atmospheres (applications 1)	Jordan
13	17.7.	stellar atmospheres (applications 2)	Jordan

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literature I

- list of recommended literature for the course

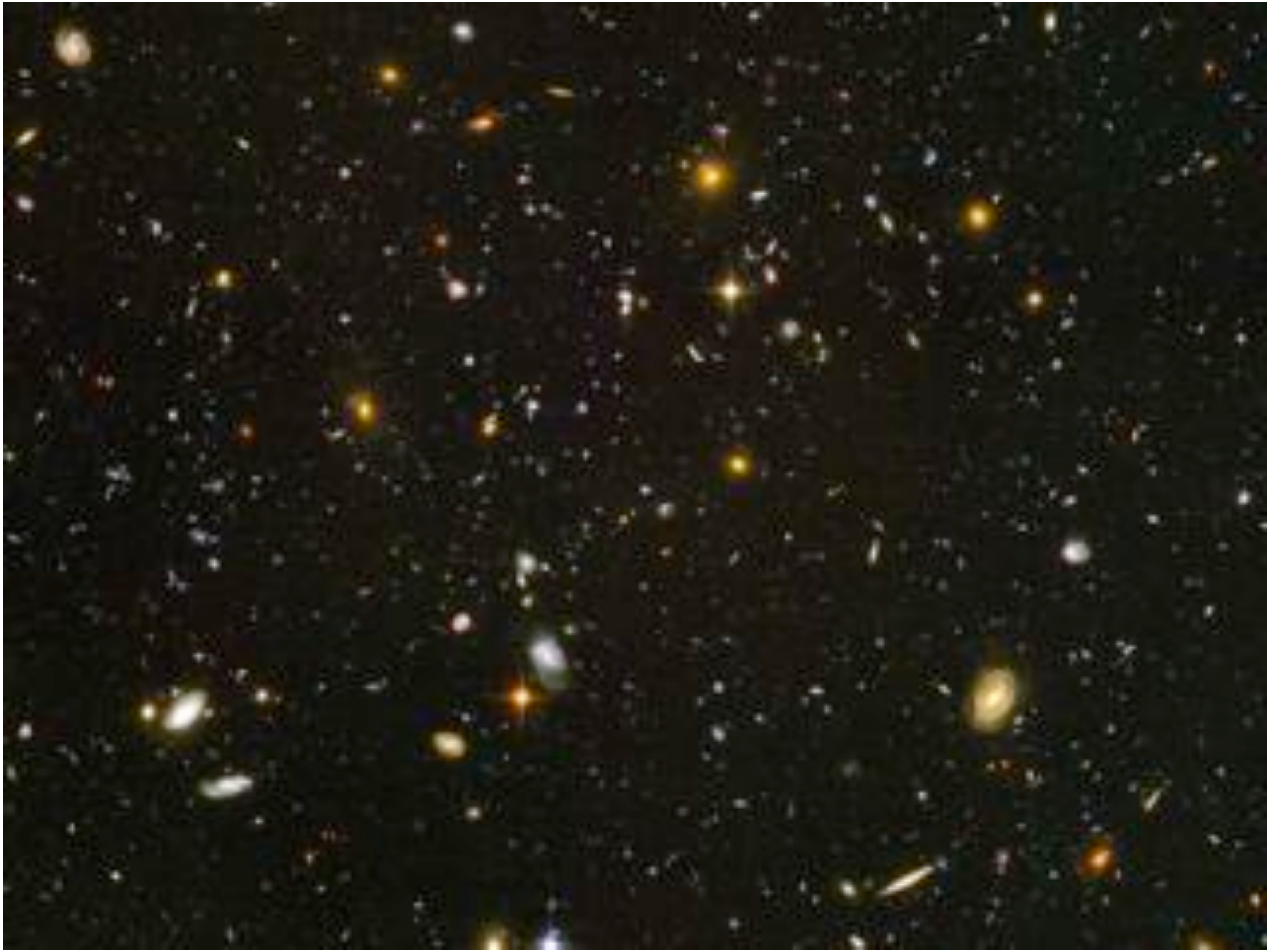
- Carroll, B.W., & Ostlie, D. A. 1996, "In Introduction into Moder Stellar Astrophysics" (Addison Welsey) -- Chapters 7 - 17
- Clayton, D. D. 1968, "Principles of Stellar Evolution and Nucleosynthesis" (McGraw-Hill, New York)
- Hansen, C.J., & Kawaler, S.D. 1994, "Stellar Interiors: Physical Principles, Structure, and Evolution" (Springer Verlag, Heidelberg Berlin New York)
- Kippenhahn, R., & Weigert, A. 1990, "Stellar Structure and Evolution" (Springer Verlag, Heidelberg Berlin New York)
- Shore, S. N. 2003, "The Tapestry of Modern Astrophysics" (Wiley, Hoboken, New Jersey) - Chapters 3 - 5

literature II

- general literature

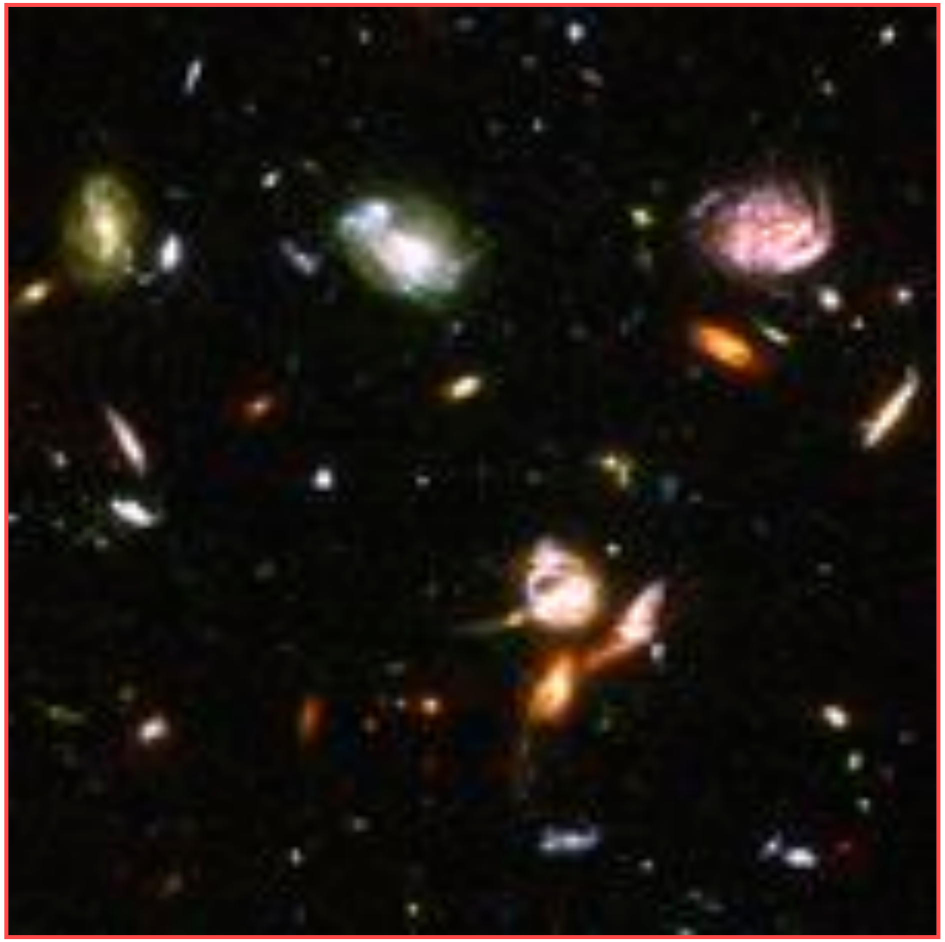
- Binney, J. & Merrifield, M. 1998, "Galactic Astronomy" (Princeton University Press)
- Scheffler, H. & Elsässer, H. 1990, "Physik der Sterne und der Sonne" (BI, Mannheim Wien Zürich)
- Shu, F. 1991, "The Physical Universe: An Introduction to Astronomy" (University Science Books, Mill Valey, California)
- Shu, F. 1991, "The Physics of Astrophysics I: Radiation" (University Science Books, Mill Valley)
- Shu, F. 1991, "The Physics of Astrophysics II: Gas Dynamics" (University Science Books, Mill Valley)
- Stahler, S. W. & Palla, F. 2004, "The Formation of Stars" (Whiley-VCH, Weinheim)
- Unsöld, A. & Baschek, B. 1991, "The New Cosmos" (Springer Verlag)
- Voigt, H.-H. 2002, "Abriss der Astronomie" (Spektrum Akademischer Verlag)
- Weigert, A, Wendker, H. J., & Wisotzki, L. 2004, "Astronomie und Astrophysik" (Wiley-VCH, Berlin)

where we find stars...



(Hubble Ultra-Deep Field, from HST Web site)

where we find stars...



(Hubble Ultra-Deep Field, from HST Web site)

(HST: Whitmore & Schweizer: Antennae galaxies)

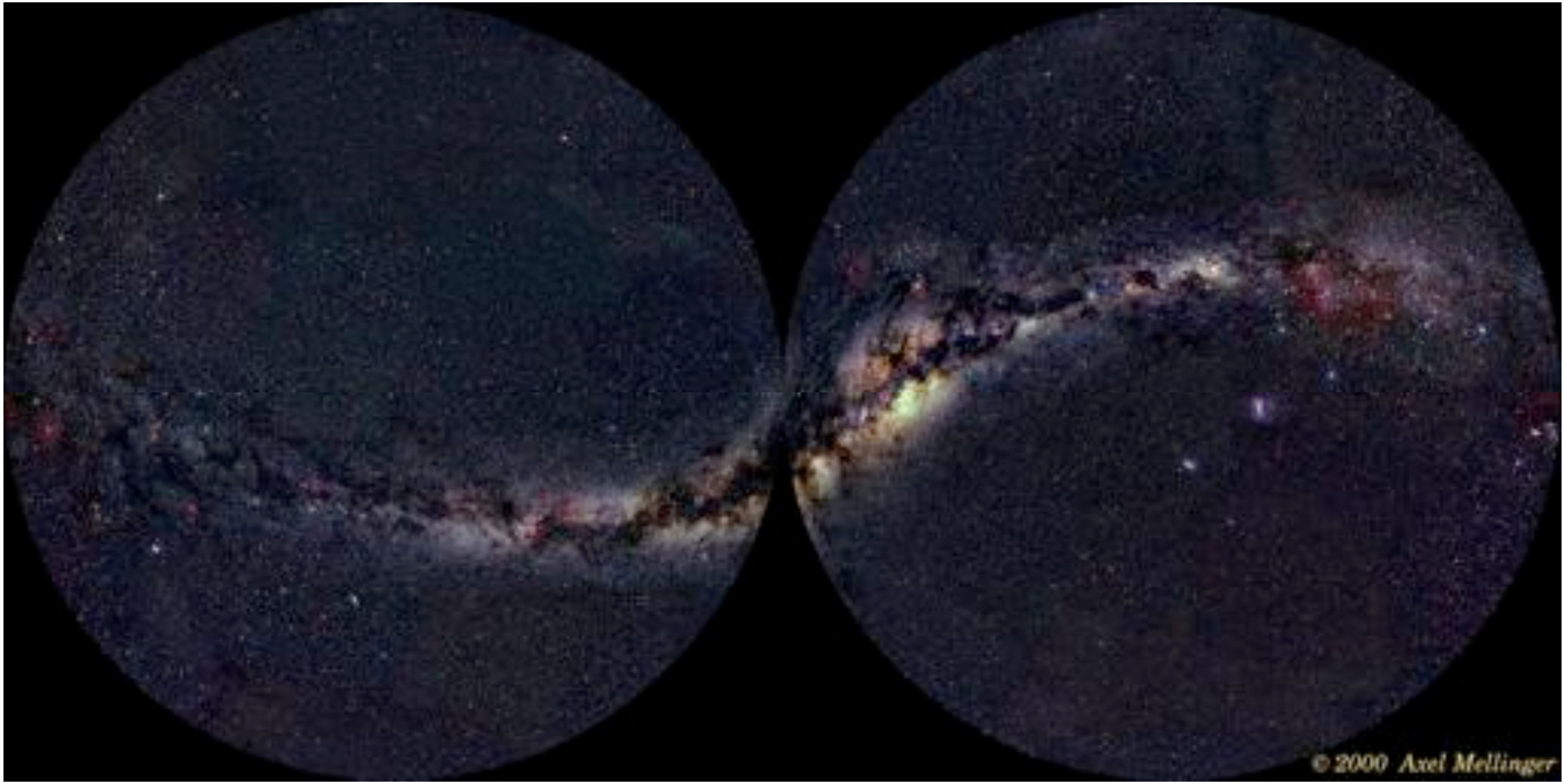
(NGC4622: from the Hubble Heritage Team)

young (massive) stars are associated with spiral density waves

older stars are more evenly distributed throughout the galaxy


The Sombrero Galaxy — M104
HUBBLESITE.org

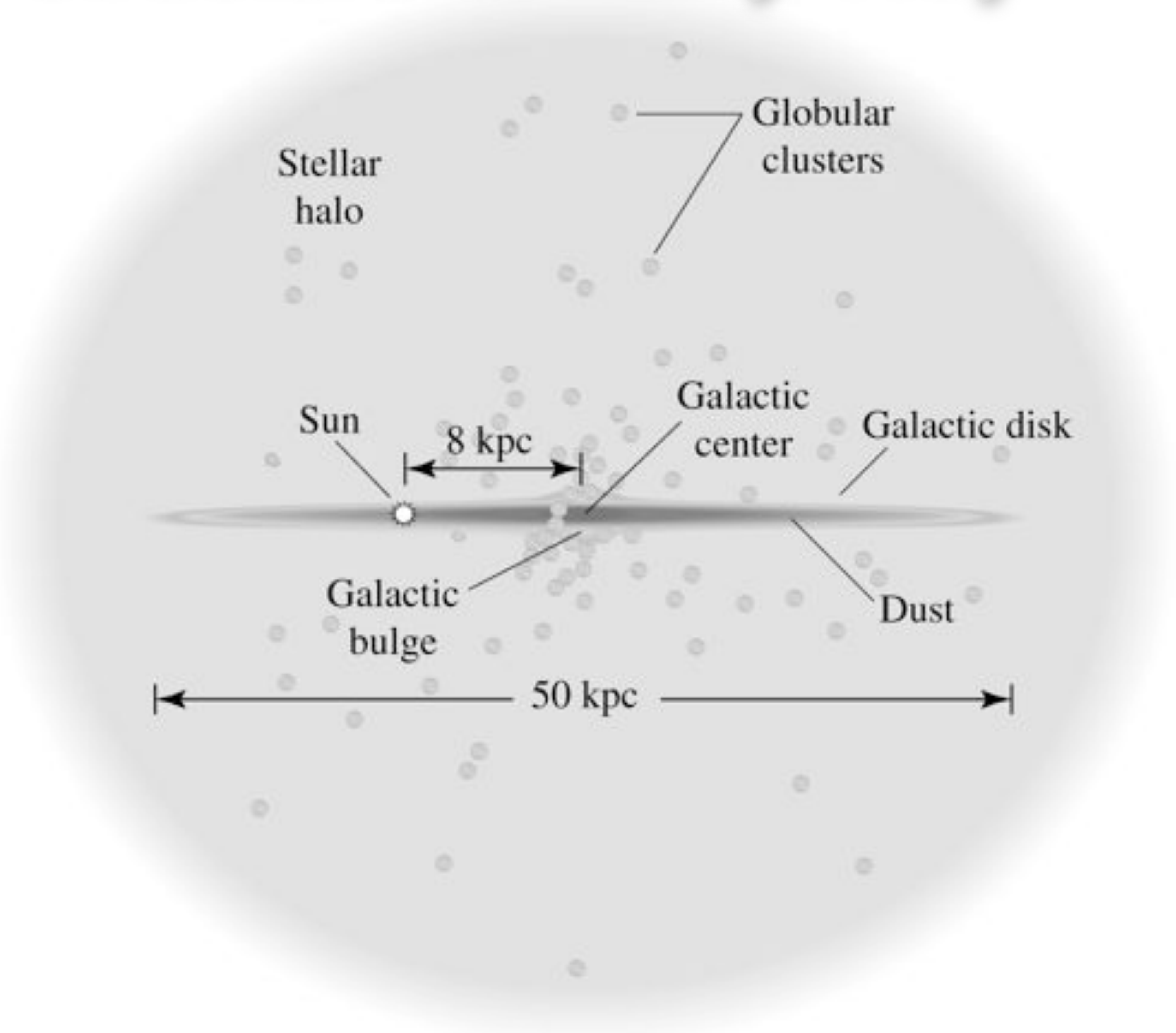
distribution of stars in the Milky Way



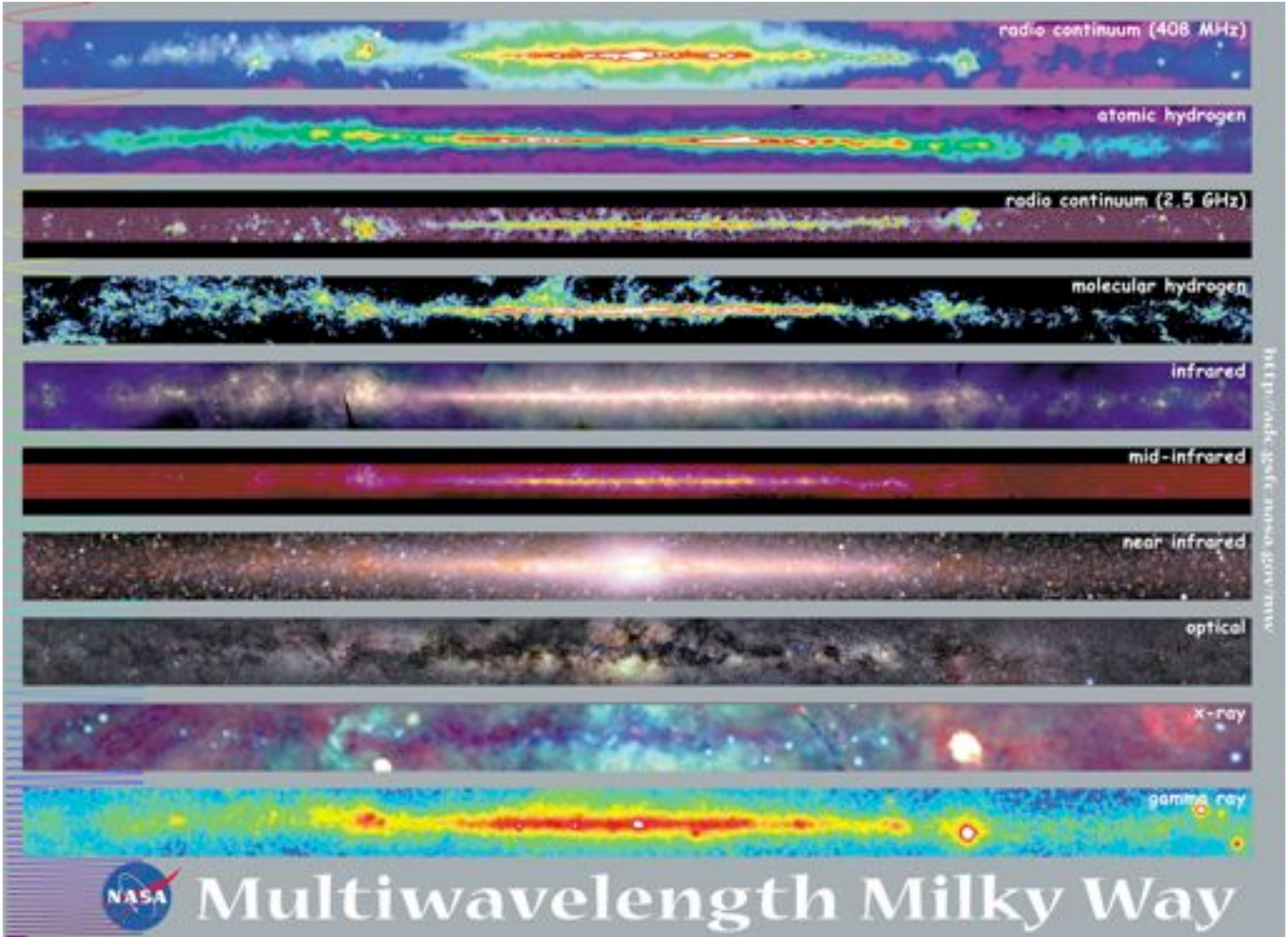
On the night sky, you see ***stars*** and ***dark clouds***. Most stars are in the disk of the Milky Way.

The brightest stars are massive and therefore young (or very close).

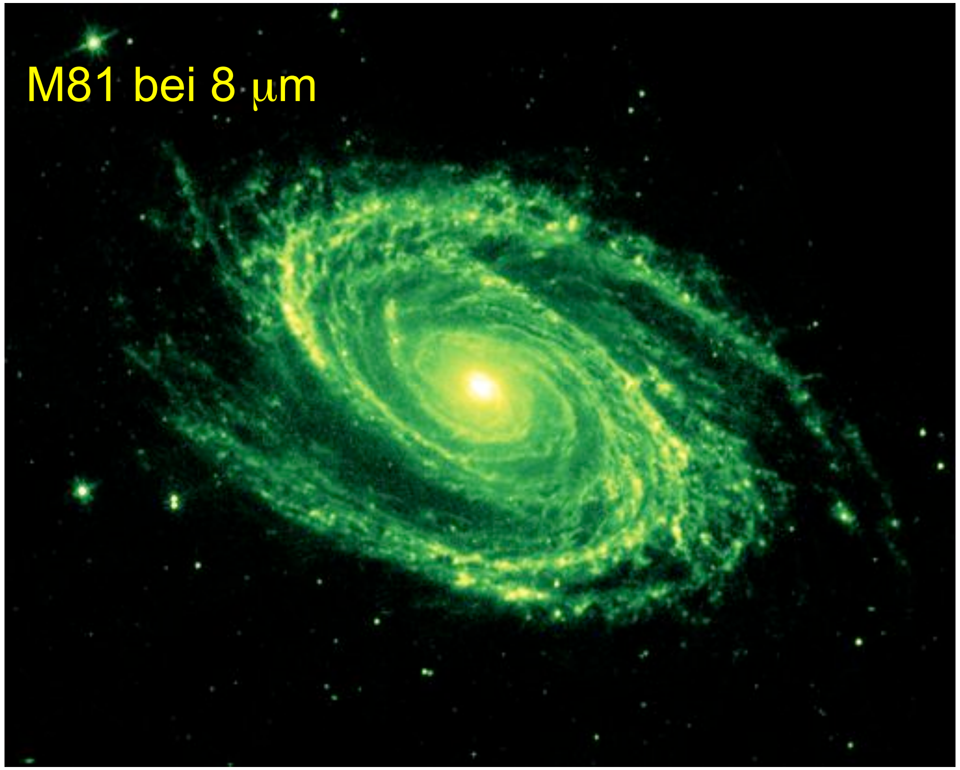
structure of Milky Way

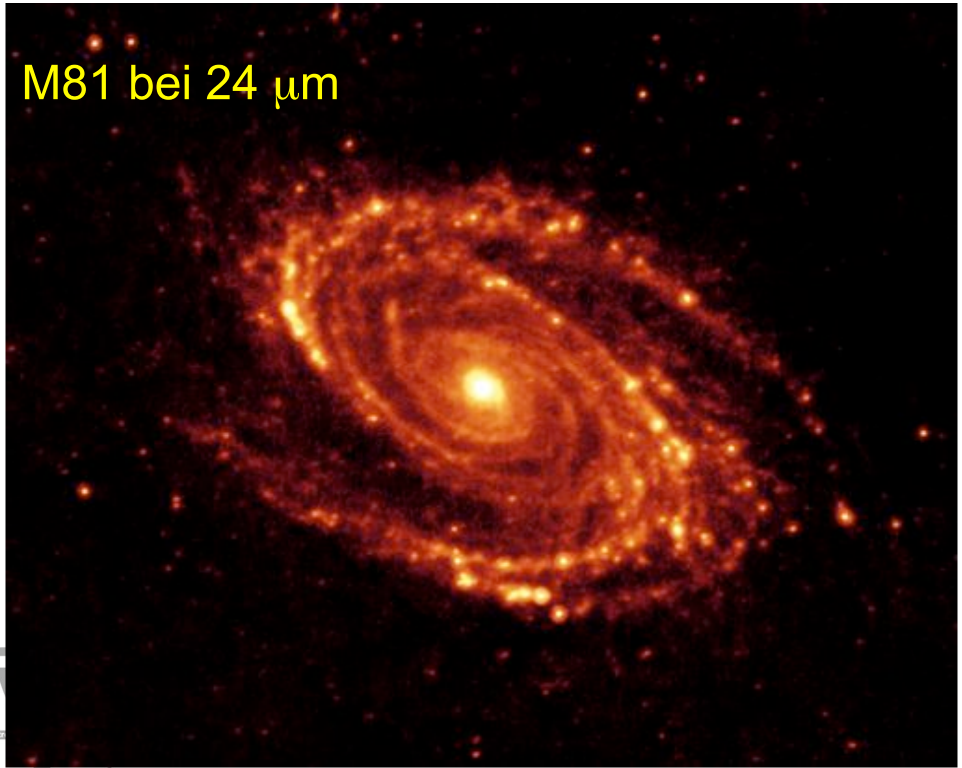


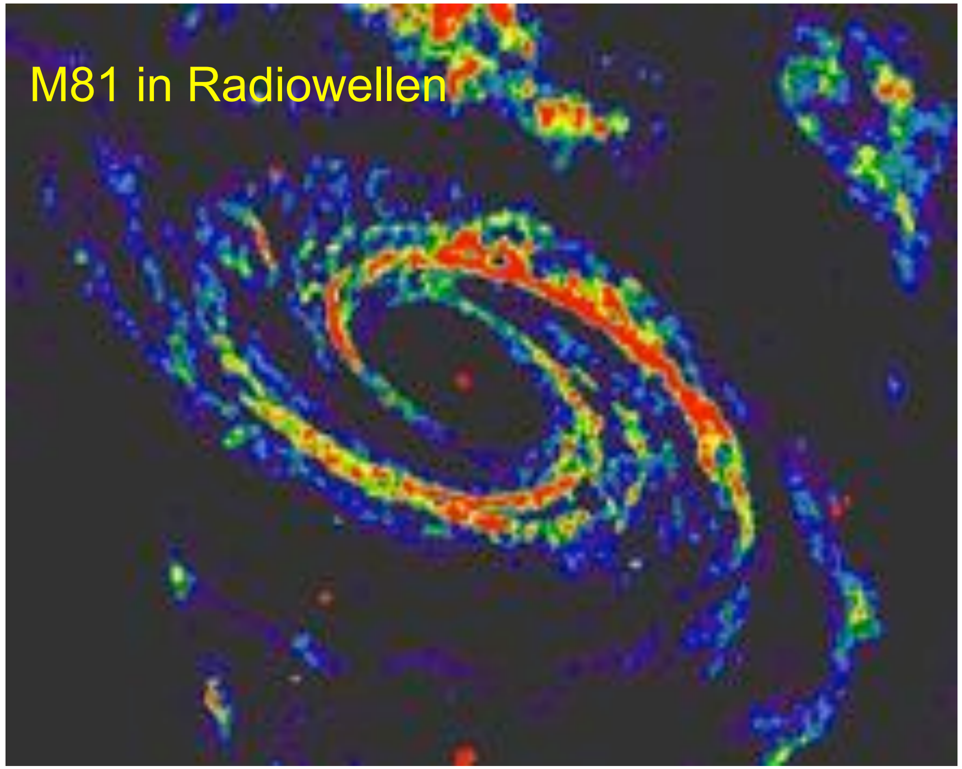
(from Carroll & Ostlie, Fig 24.6)


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
NASA
Multiwavelength Milky Way

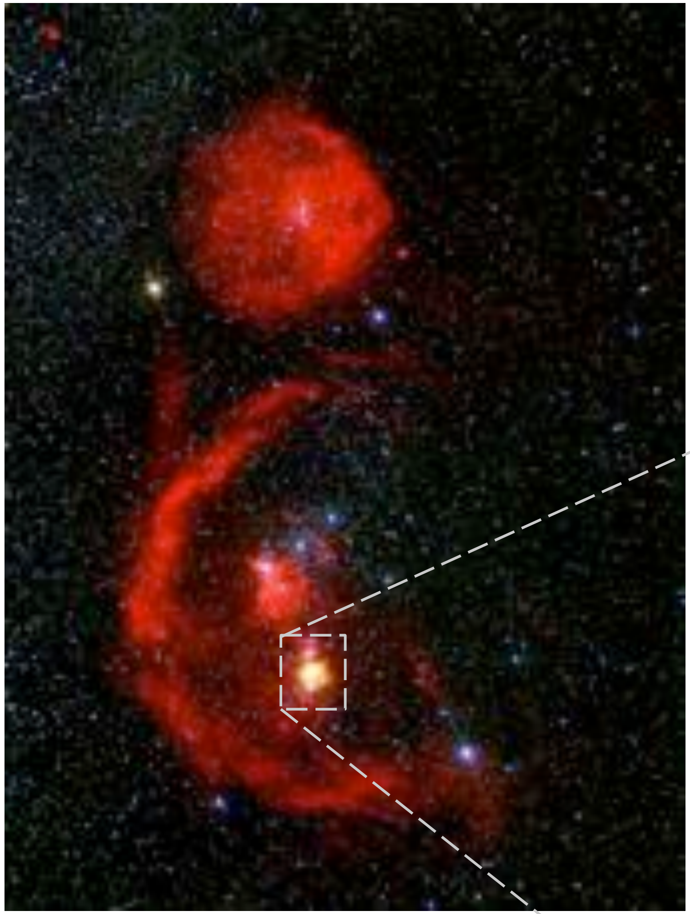
Zusammenhang zwischen Sternbildung und Gasverteilung am Beispiel von M81







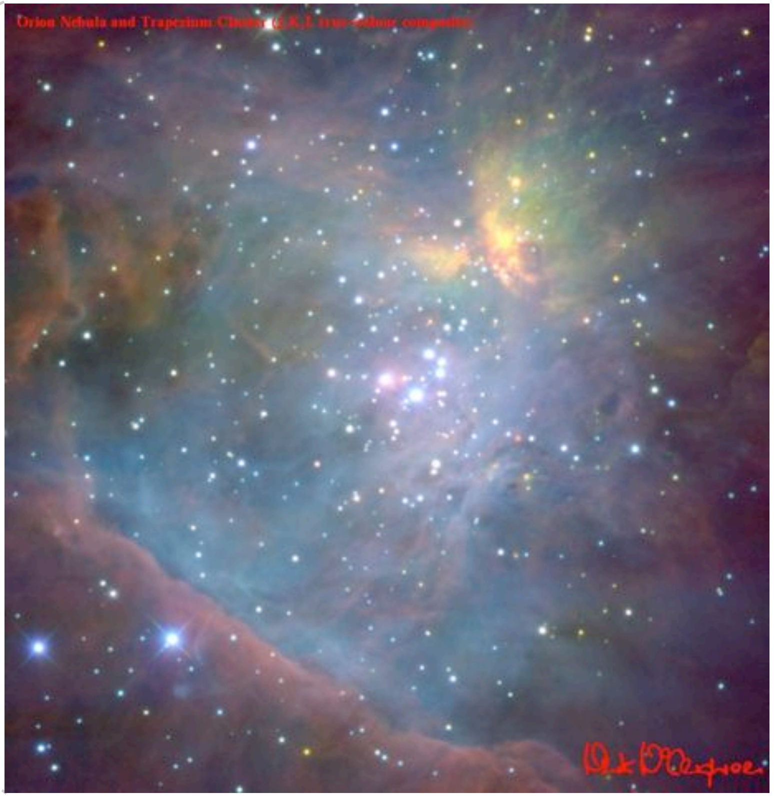
nearby young cluster: the Trapezium in Orion



Orion molecular cloud

The Orion molecular cloud is the birth- place of several young embedded star clusters.

The Trapezium cluster is only visible in the IR and contains about 2000 newly born stars.



Trapezium cluster

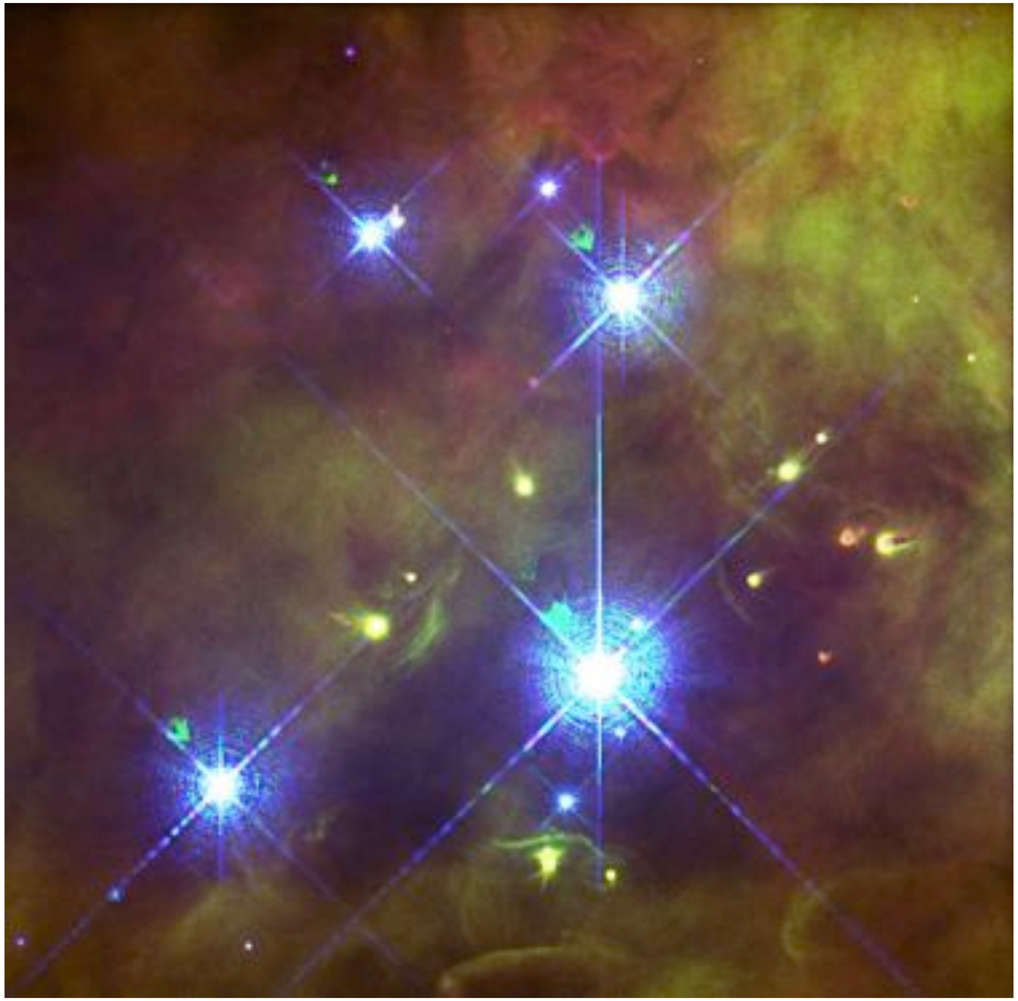
Trapezium Cluster

(detail)

- stars form in clusters
- stars form in molecular clouds
- (proto)stellar feedback is important

(color composite J,H,K by M. McCaughrean, VLT, Paranal, Chile)

Trapezium stars in Orion

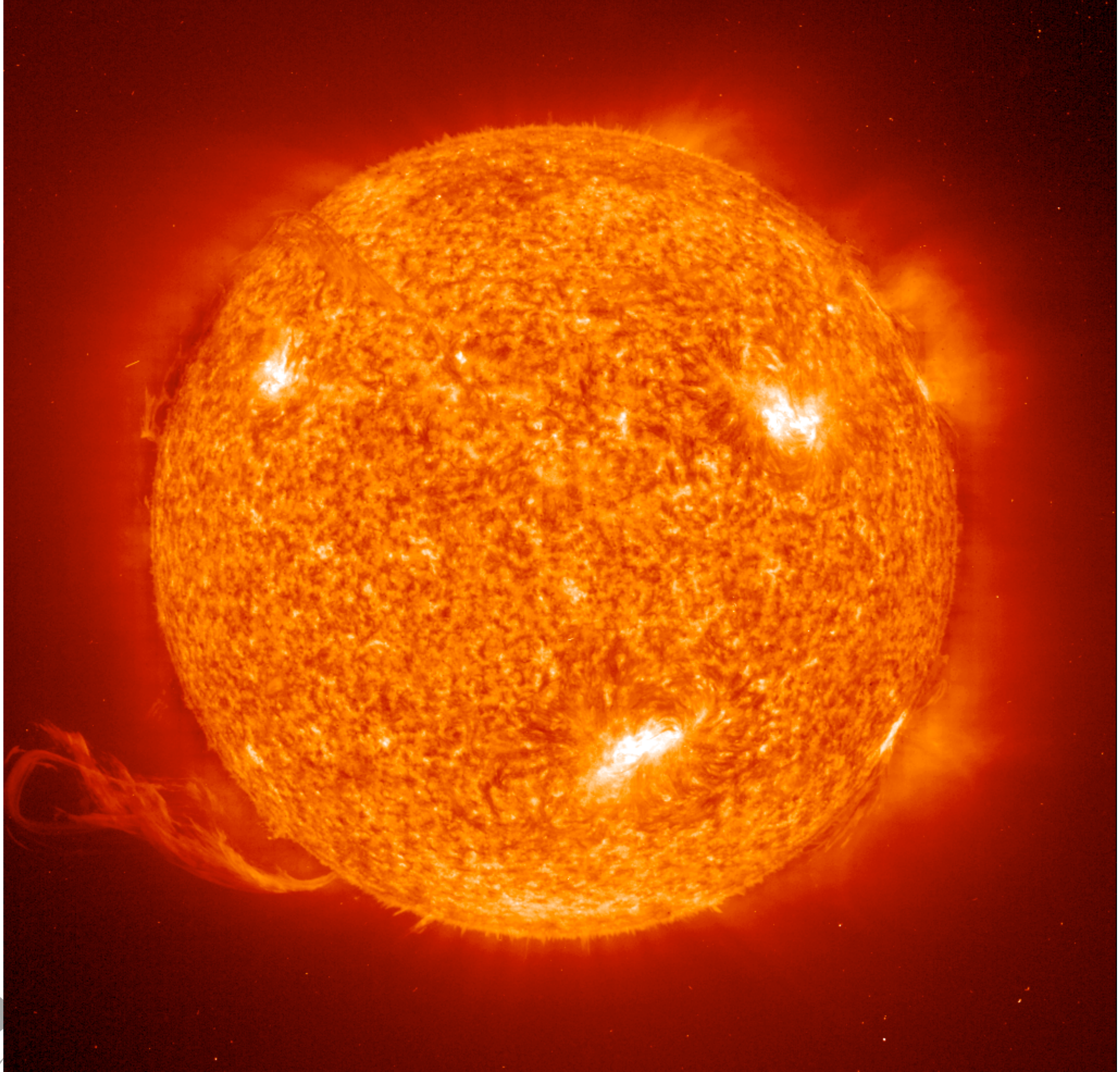


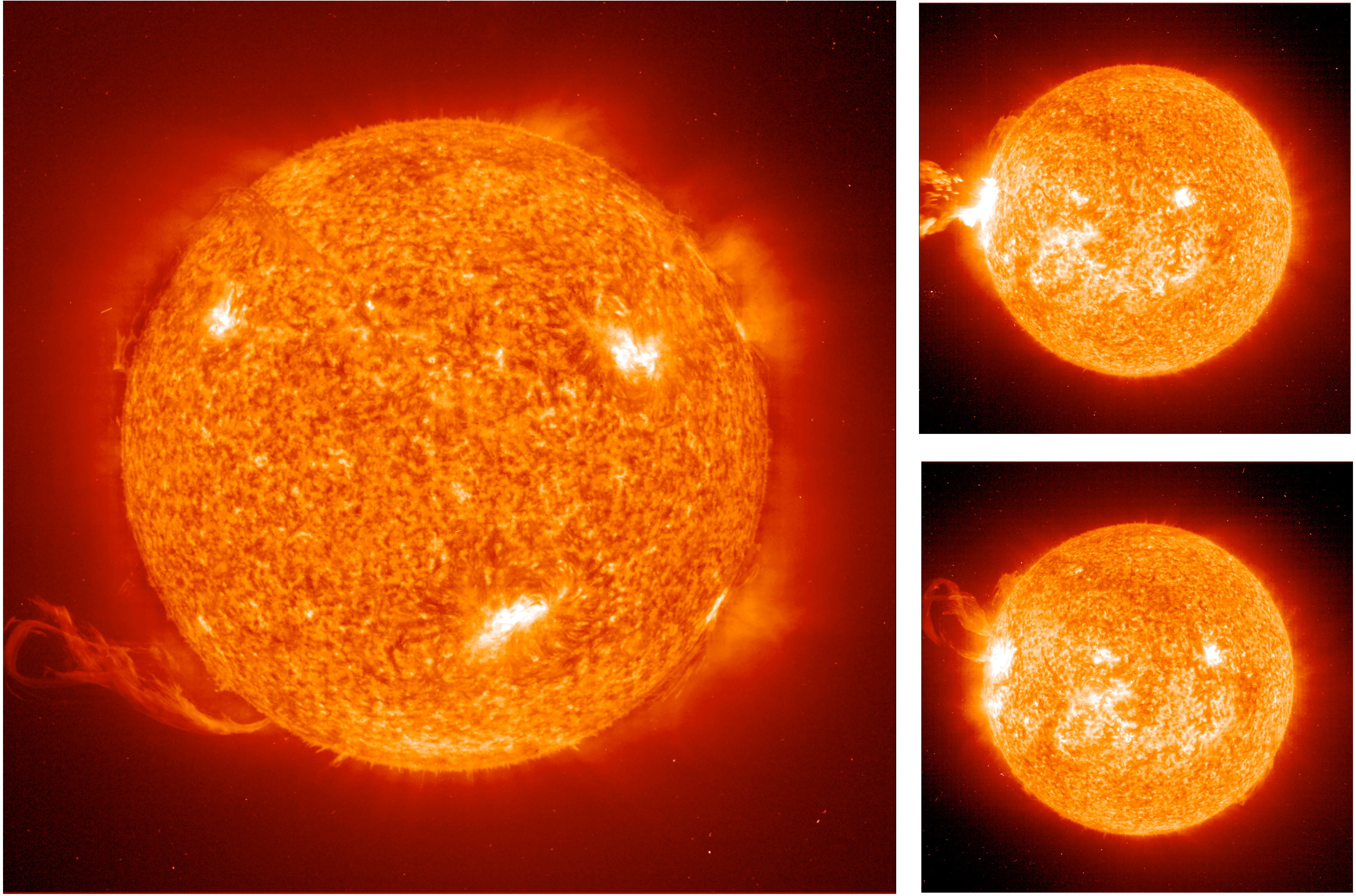
Ionizing radiation from central star
Θ1C Orionis

Proplyds: Evaporating ``protoplanetary´´ disks around young low-mass protostars

(Pleiades: skyfactory.org)

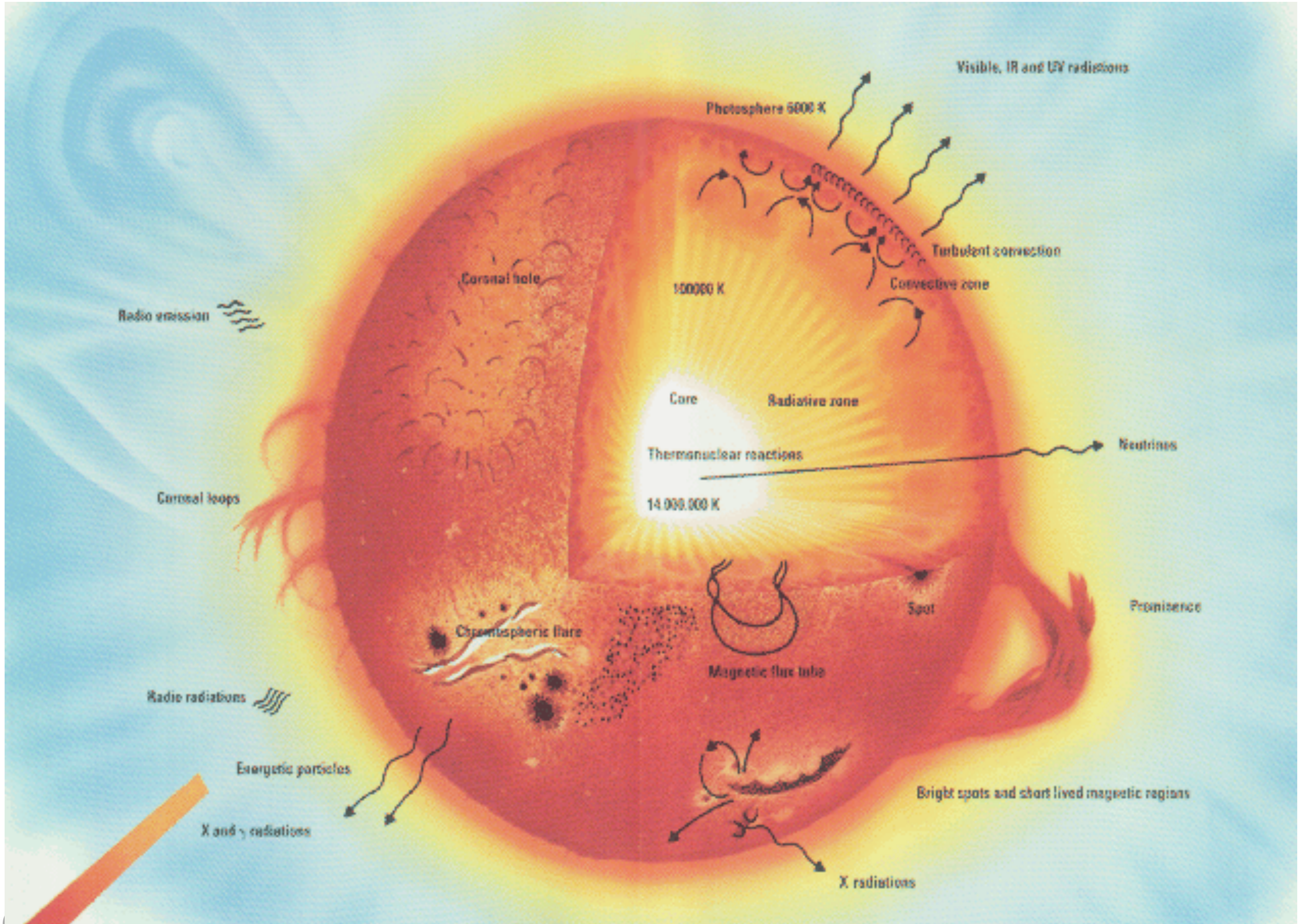
Unsere Sonne





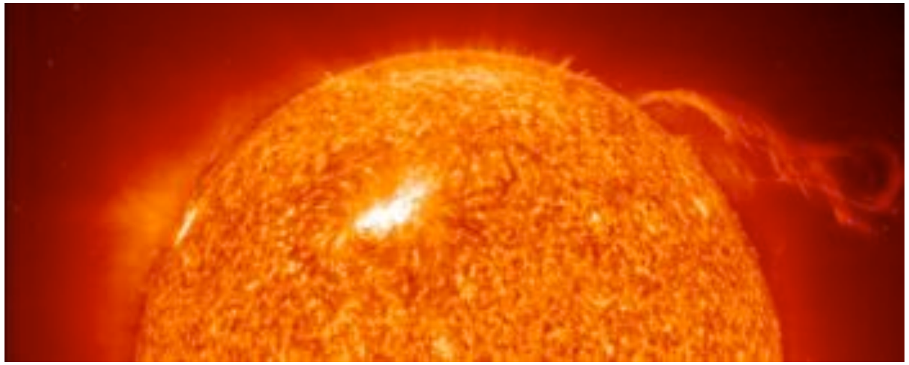
Unsere Sonne in verschiedenen Aktivitätsphasen

Größenvergleich: Sonne - Erde



Visible, IR and UV radiations
Photosphere 6000 K
Turbulent convection
Convective zone
100000 K
Coronal hole
Radio emission
Core
Radiative zone
Thermonuclear reactions
Neutrinos
14.000.000 K
Coronal loops
Spot
Prominence
Chromospheric flare
Magnetic flux tube
Radio radiations
Energetic particles
Bright spots and short lived magnetic regions
X and γ radiations
X radiations

Sterne: die Sonne



Eigenschaften der Sterne
(Stellare Zustandsgrößen):

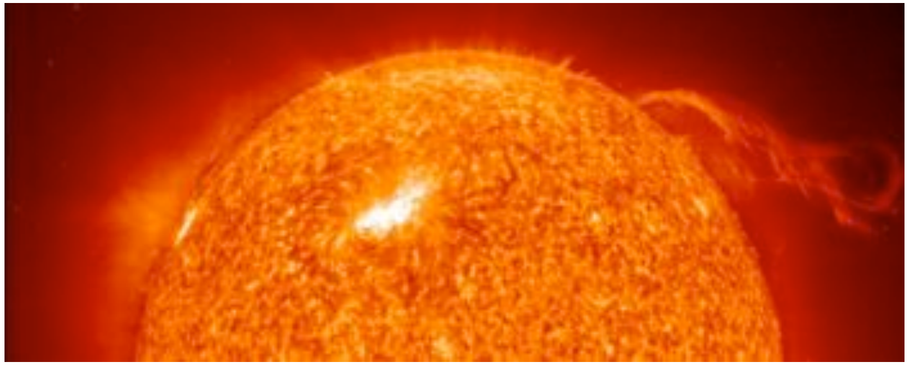
Unsere Sonne ⊙ als Referenzstern

Radius	$R_{\odot}$	696 000 km	
Masse	$M_{\odot}$	$1{,}989 \times 10^{30}$ kg	
Leuchtkraft	$L_{\odot}$	$3{,}86 \times 10^{26}$ W	
effektive Temperatur	T_{eff}	5800 K	(Oberfläche)
Zentraltemperatur	$T_{zentral}$	15×10^{6} K	
Alter	$t_{\odot}$	4.5×10^{9} a	

auf der Erde:
Solarkonstante
1.37 kW/m²

Spektraltyp G2
Leuchtkraftklasse V
chemische Zusammensetzung (Massenanteil)
73% Wasserstoff X
25% Helium Y
2% Metalle Z

Sterne: die Sonne



Eigenschaften der Sterne
(Stellare Zustandsgrößen):

Unsere Sonne ⊙ als Referenzstern

Radius	$R_\odot$	7×10^{10} cm
Masse	$M_\odot$	2×10^{33} g
Leuchtkraft	$L_\odot$	4×10^{33} erg/s
effektive Temperatur	T_{eff}	5800 K
Zentraltemperatur	$T_{zentral}$	15×10^{6} K
Alter	$t_\odot$	1.7×10^{17} s

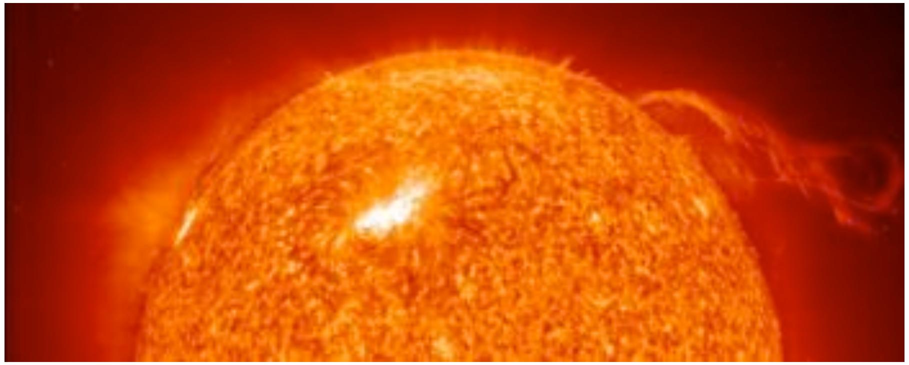
in cgs Einheiten

Spektraltyp	G2
Leuchtkraftklasse	V

chemische Zusammensetzung (Massenanteil)

73% Wasserstoff X
25% Helium Y
2% Metalle Z

Sterne: Statistische Charakeristika



Massenverteilung:

minimale Masse $\approx 0{,}07\ M_\odot$

Grenze des Wasserstoffbrennens

maximale Masse $\approx 120\ M_\odot$

Eddington-Limit, $F_{rad} = F_{grav}$

Ursprüngliche Massenverteilung

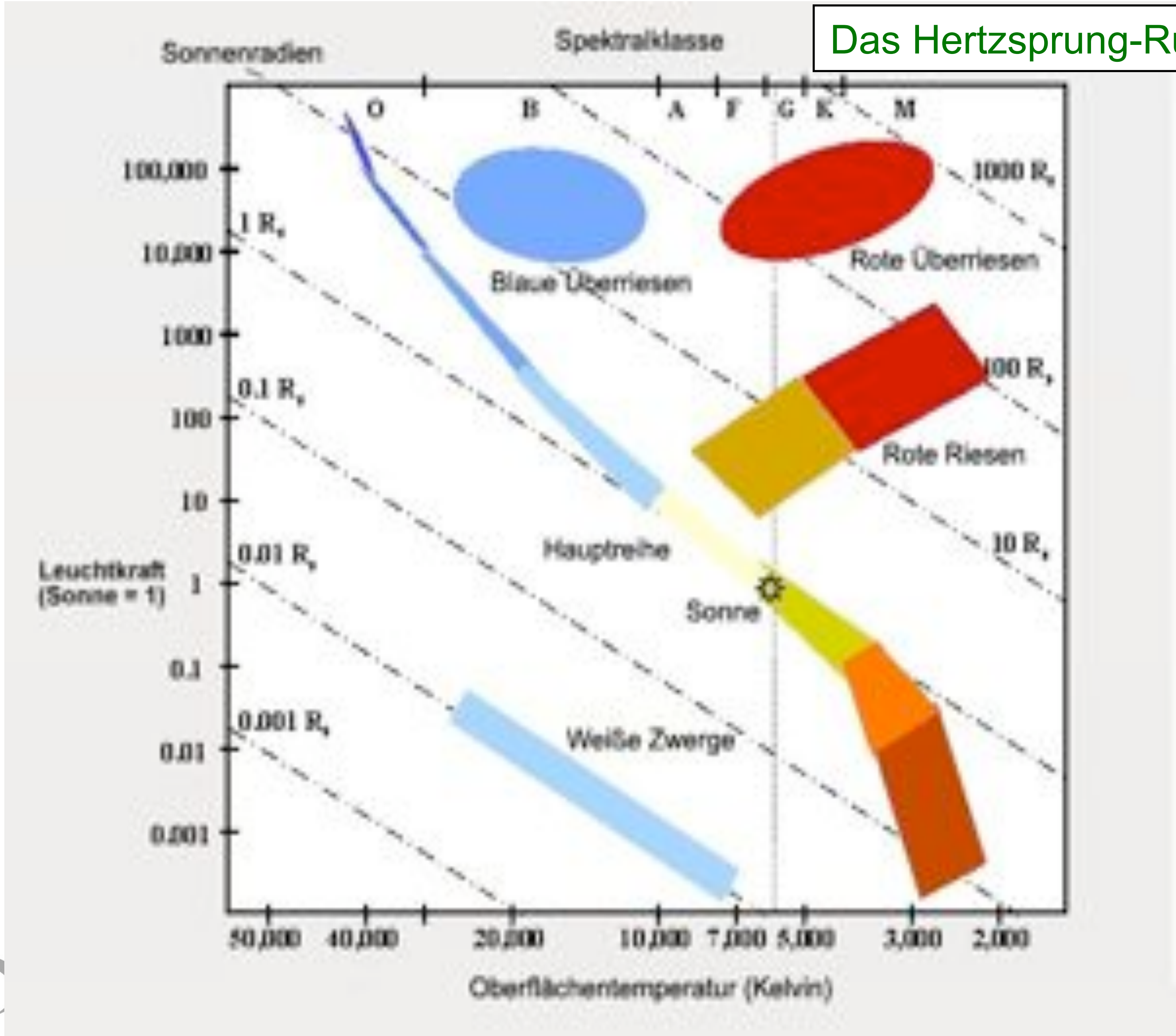
$dN(M) \propto M^{\alpha}\ dM,\ \alpha \approx -2.3$ für Sterne massereicher als die Sonne

Weitere Eigenschaften:

Spektraltyp	T_{eff} [K]	$M[M_\odot]$	$L\ [L_\odot]$	T_{HR} [a]
O7.5	38 000	25	80 000	$2x10^6$
B0	33 000	16	10 000	$1x10^7$
B5	17 000	6	600	$6x10^7$
A0	9 500	3	60	$3x10^8$
F0	6 900	1,5	6	$1.5x10^9$
G0	5 800	1	1	$6x10^9$
K0	4 800	0,8	0,4	$12x10^9$
M0	3 670	0,5	0,08	$35x10^9$

Sterne: Farben-Helligkeits-Diagramm

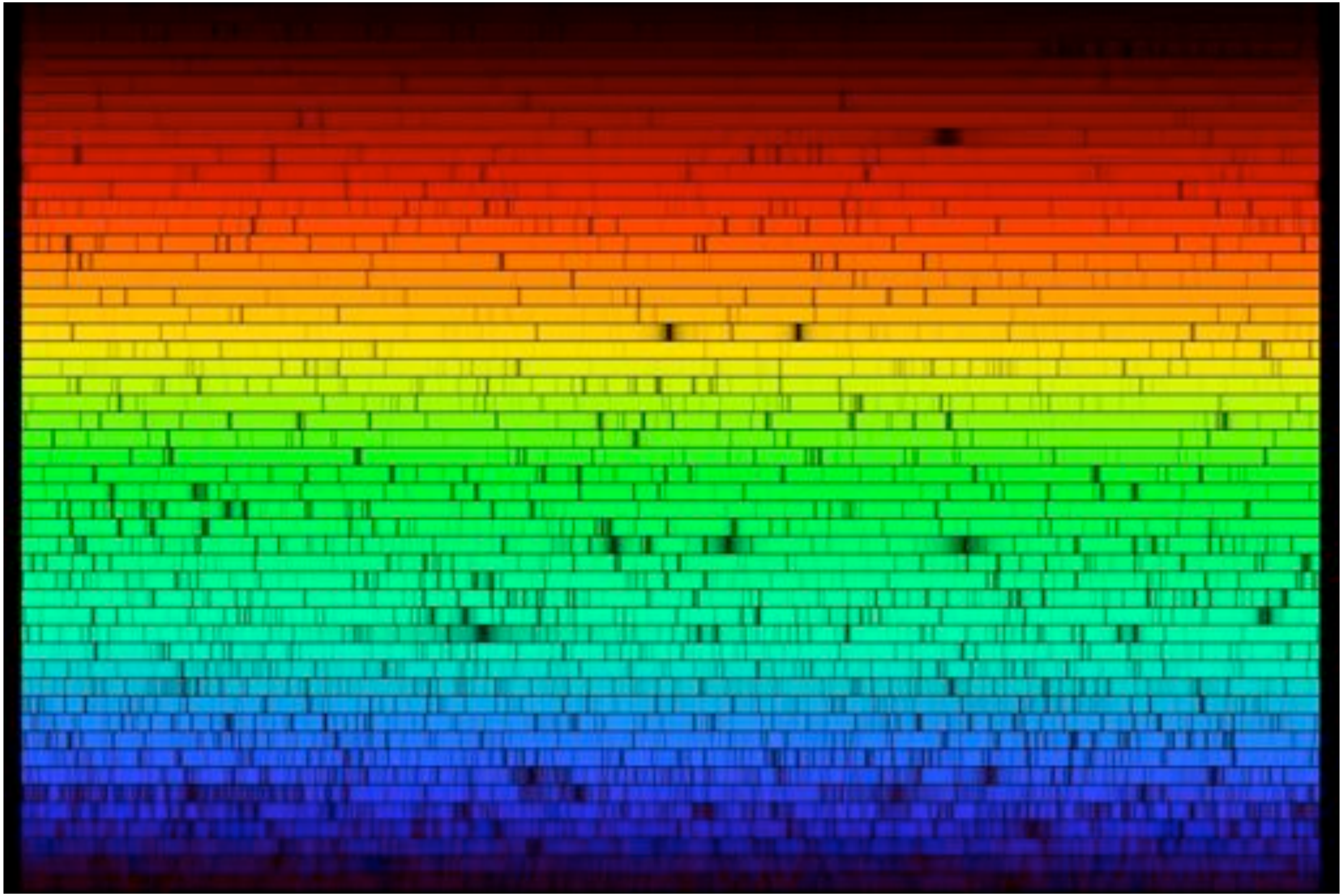
Das Hertzsprung-Russell-Diagramm



Helligkeit / Leuchtkraft

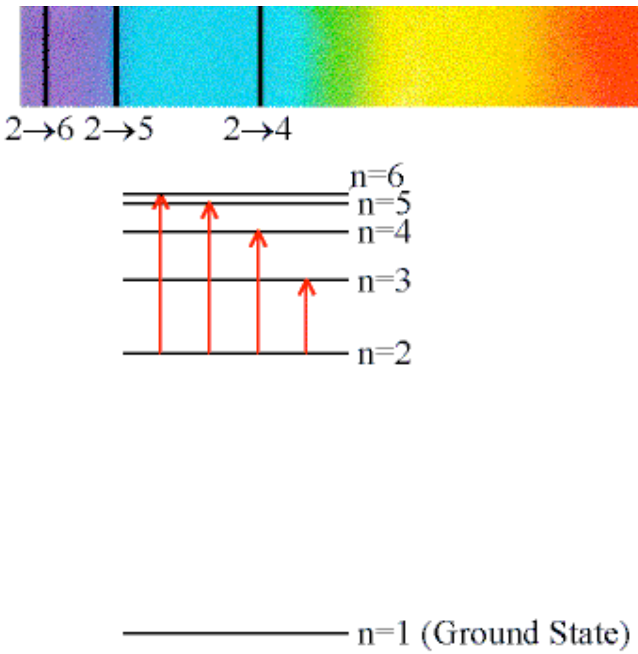
Farbe / Temperatur

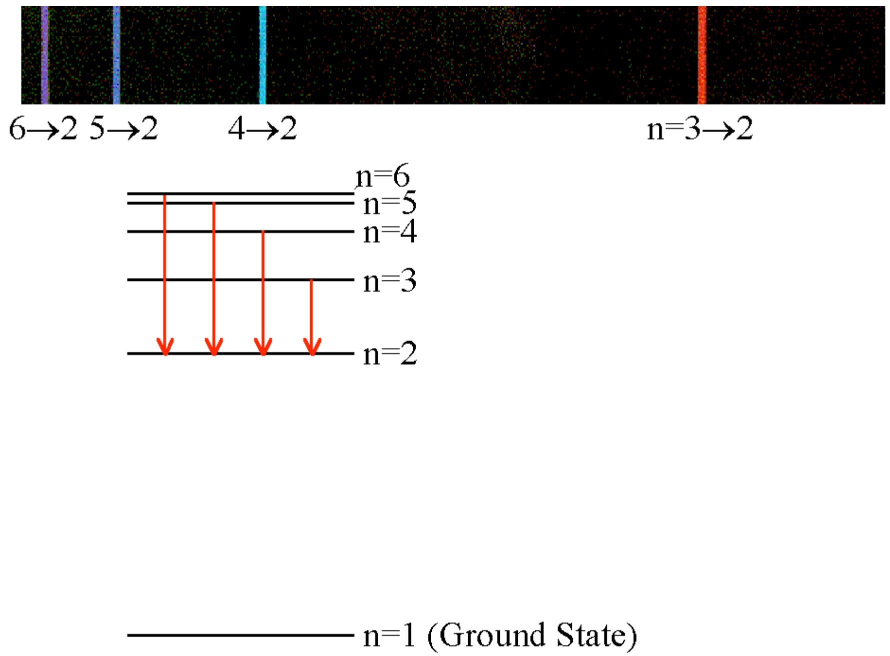
spectrum of Sun



(credit: NOAO)

atomic lines





absorption lines

emission lines

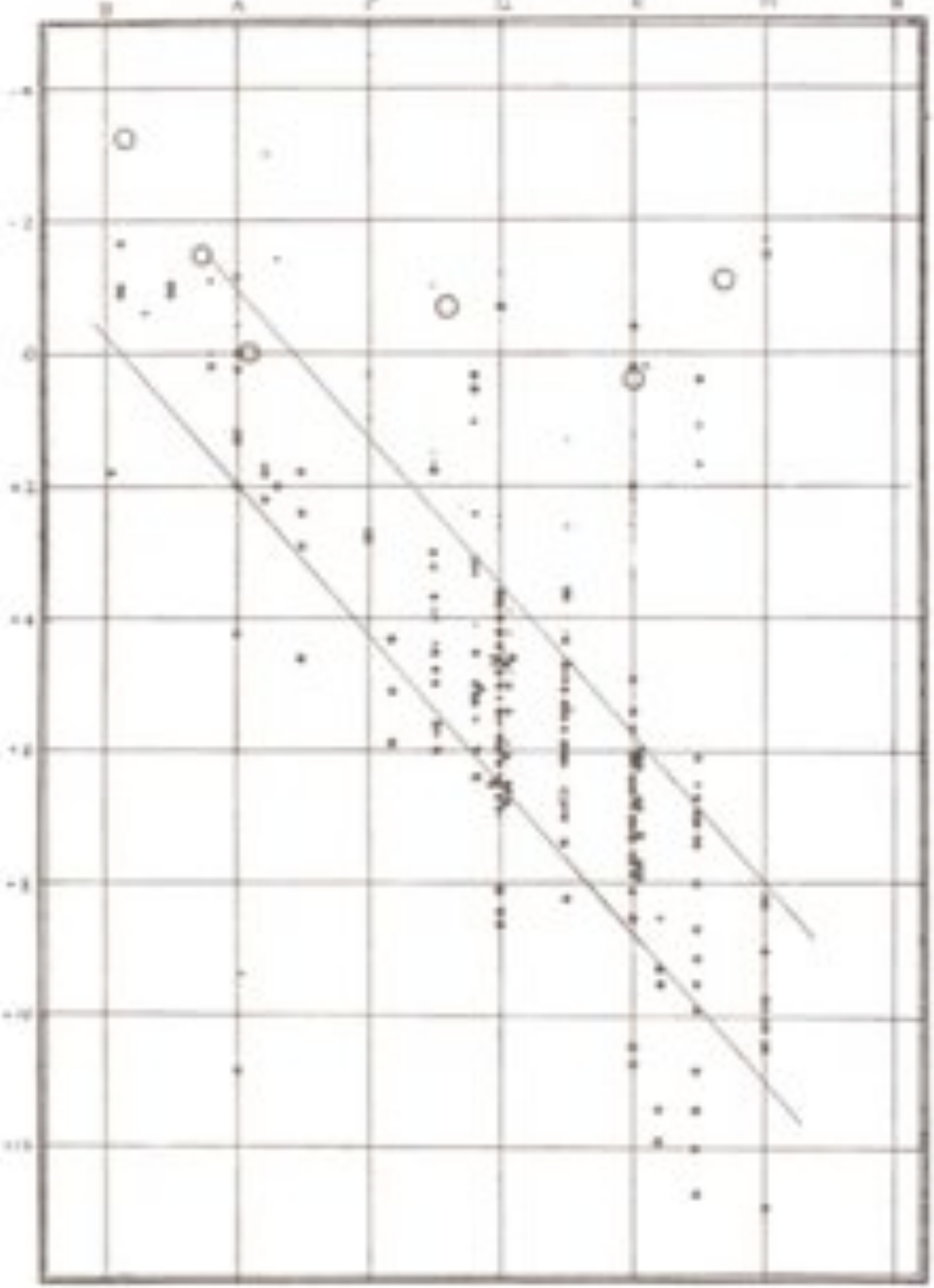
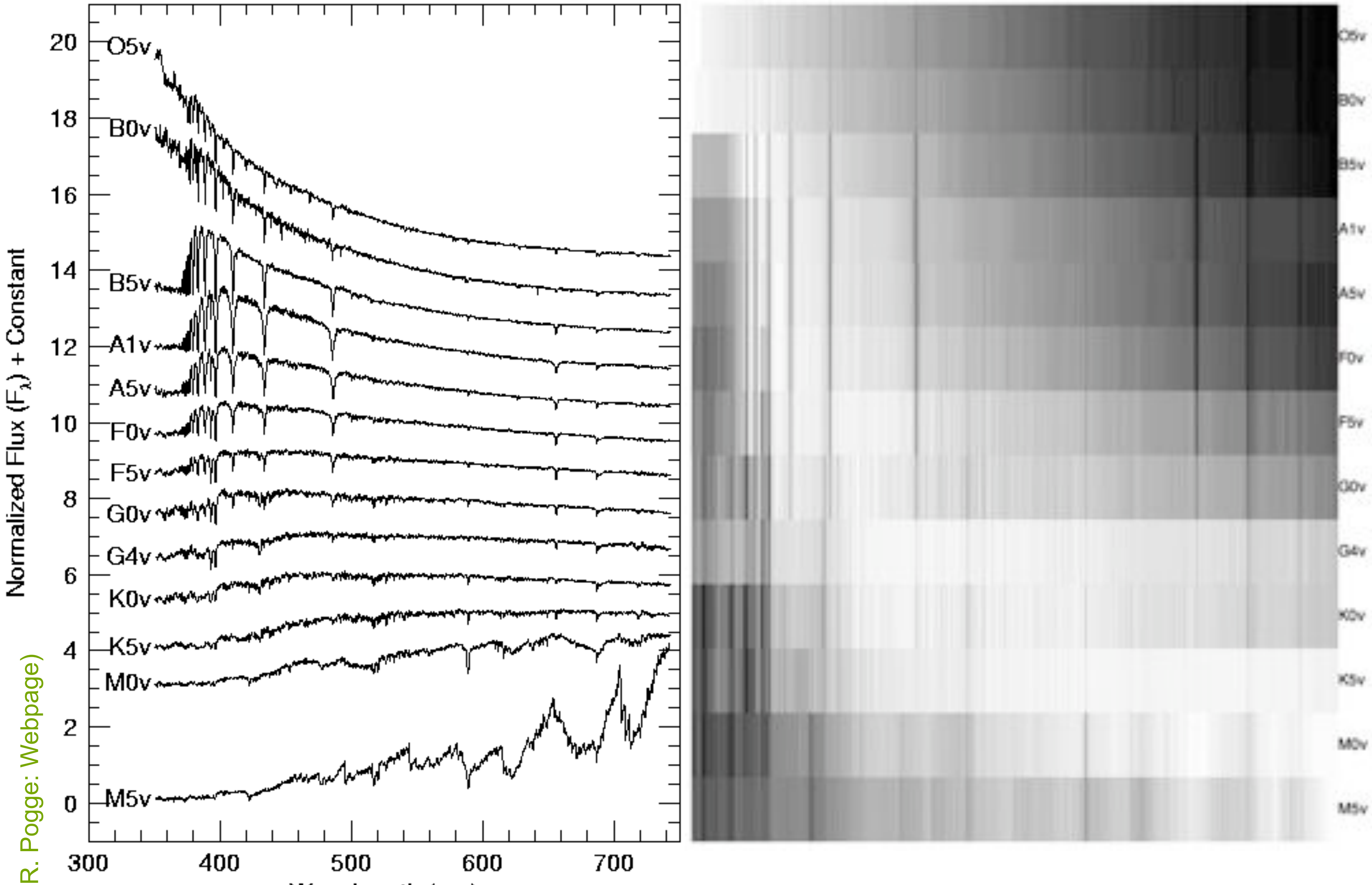


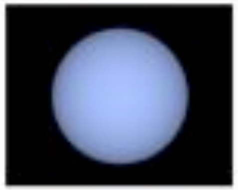
Figure 8.10 Henry Norris Russell's first diagram, with spectral types listed along the top and absolute magnitudes on the left-hand side. (Figure from Russell, Nature, 93, 252, 1914.)

sample spectra



R. Pogge: Webpage

O Stars



Hottest Stars: T>30,000 K; Strong He^{+} lines; no H lines (or only very weak at O9).

Spectrum of an O5v star

T = 11,000 - 30,000 K; Strong neutral He lines; very weak H lines, getting stronger from B0 through B9.

Spectra of B0v (top) and B5v (bottom) stars

B Stars

T = 11,000 - 30,000 K; Strong neutral He lines; very weak H lines, getting stronger from B0 through B9.

Spectra of B0v (top) and B5v (bottom) stars

F Stars

T = 5900 - 7500 K; H grows weaker through F9, Ca^{+} grows stronger, weak metals begin to emerge.

Spectra of F0v (top) and F5v (bottom) stars

G Stars

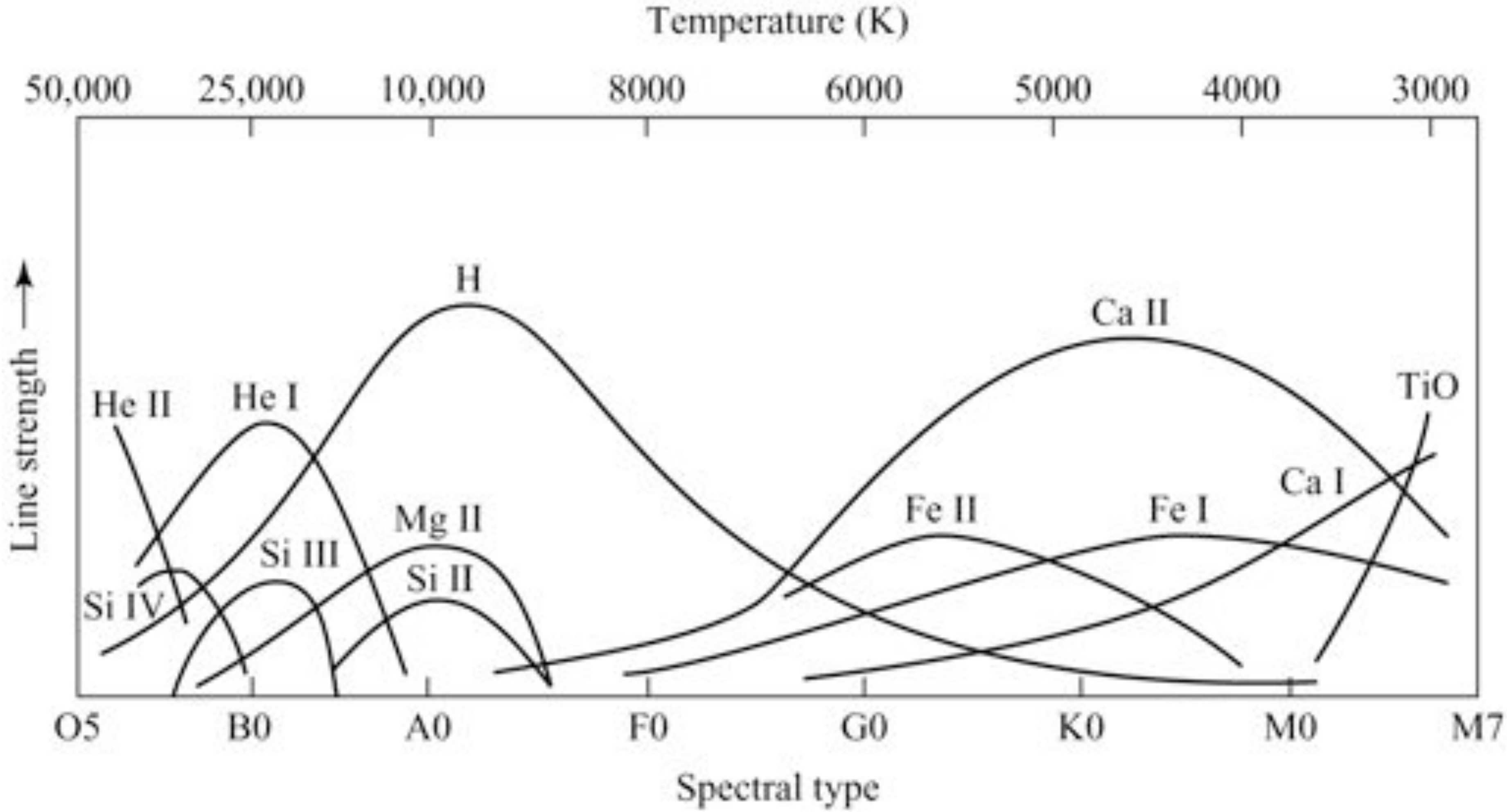
T = 5200 - 5900 K; Strong Ca^{+}, Fe^{+} and other metals dominate, H grows weaker through the class.

K Stars

T = 3900 - 5200 K; Strong metal lines, weak CH & CN molecular bands begin to appear, growing through the class. H lines nearly gone.

R. Pogge: Webpage)

spectroscopic classification



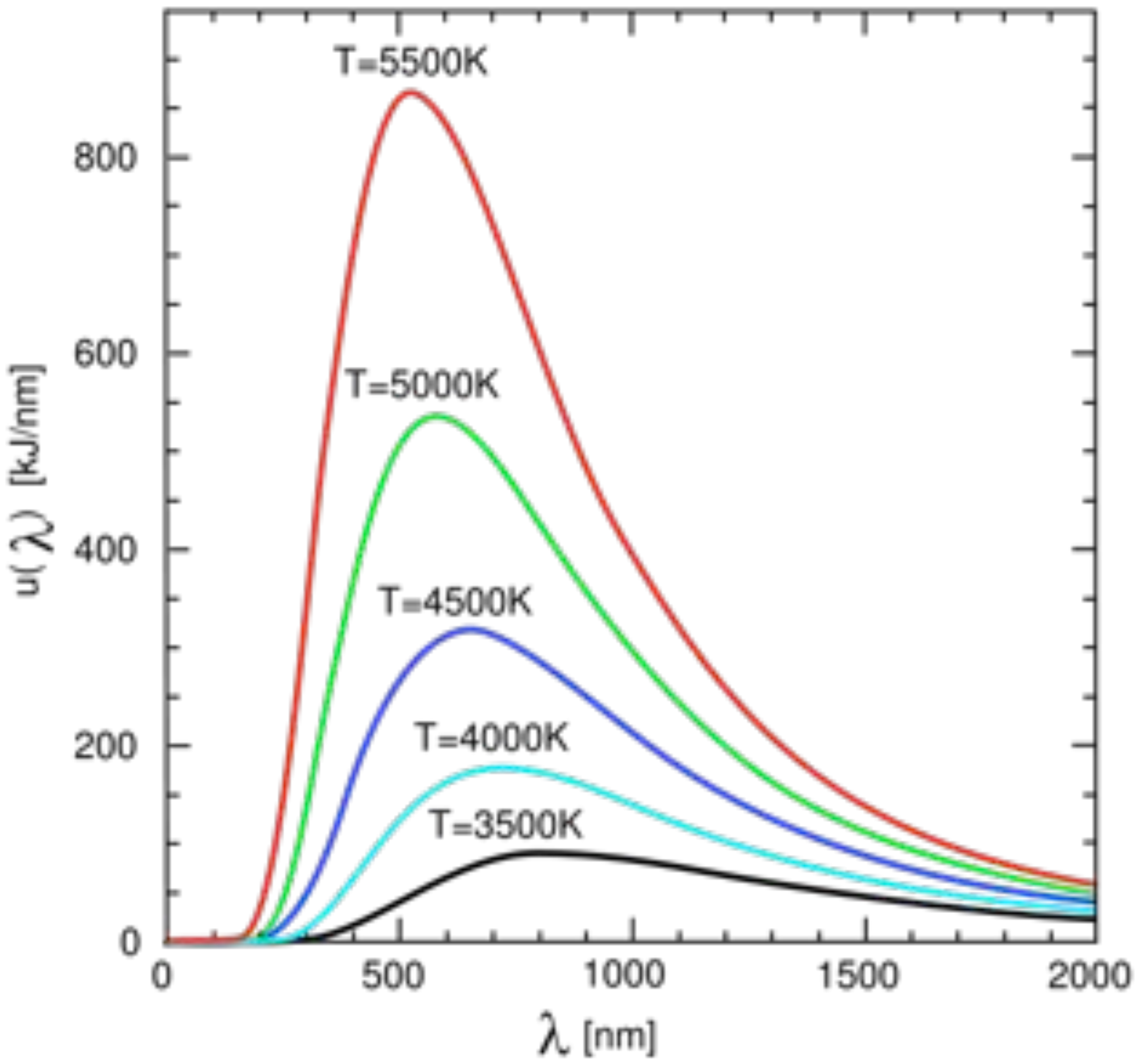
stars of different mass (and temperature) show different absorption and emission lines --> this can be used to build a *spectral classification scheme*

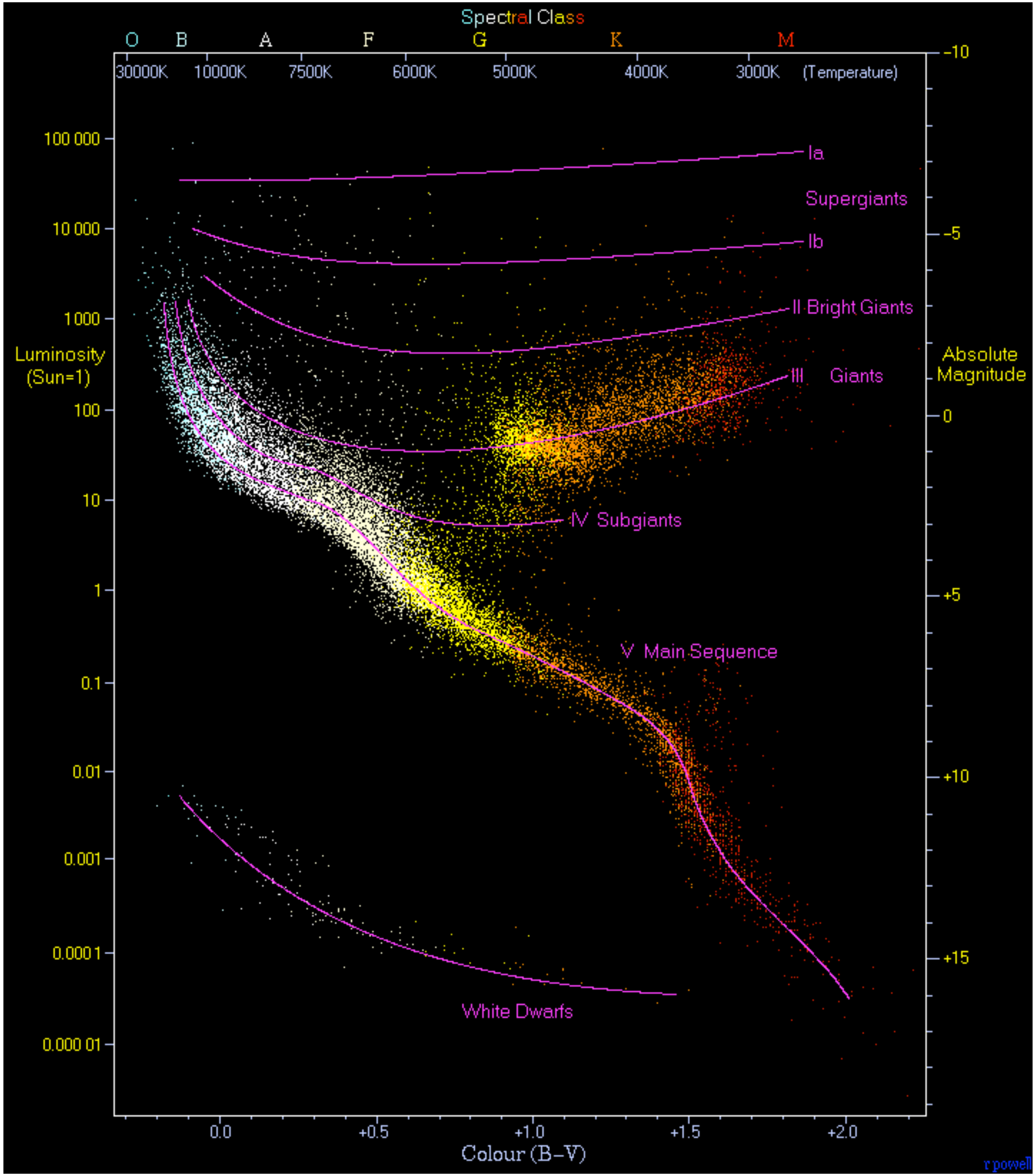
(Carroll & Ostlie: Figure 8.11)

statistical characteristics

- Hertzsprung Russell diagram: using ***color*** and ***(absolute) magnitude***

- ***spectral type*** corresponds to specific ***color*** (and ***temperature***)

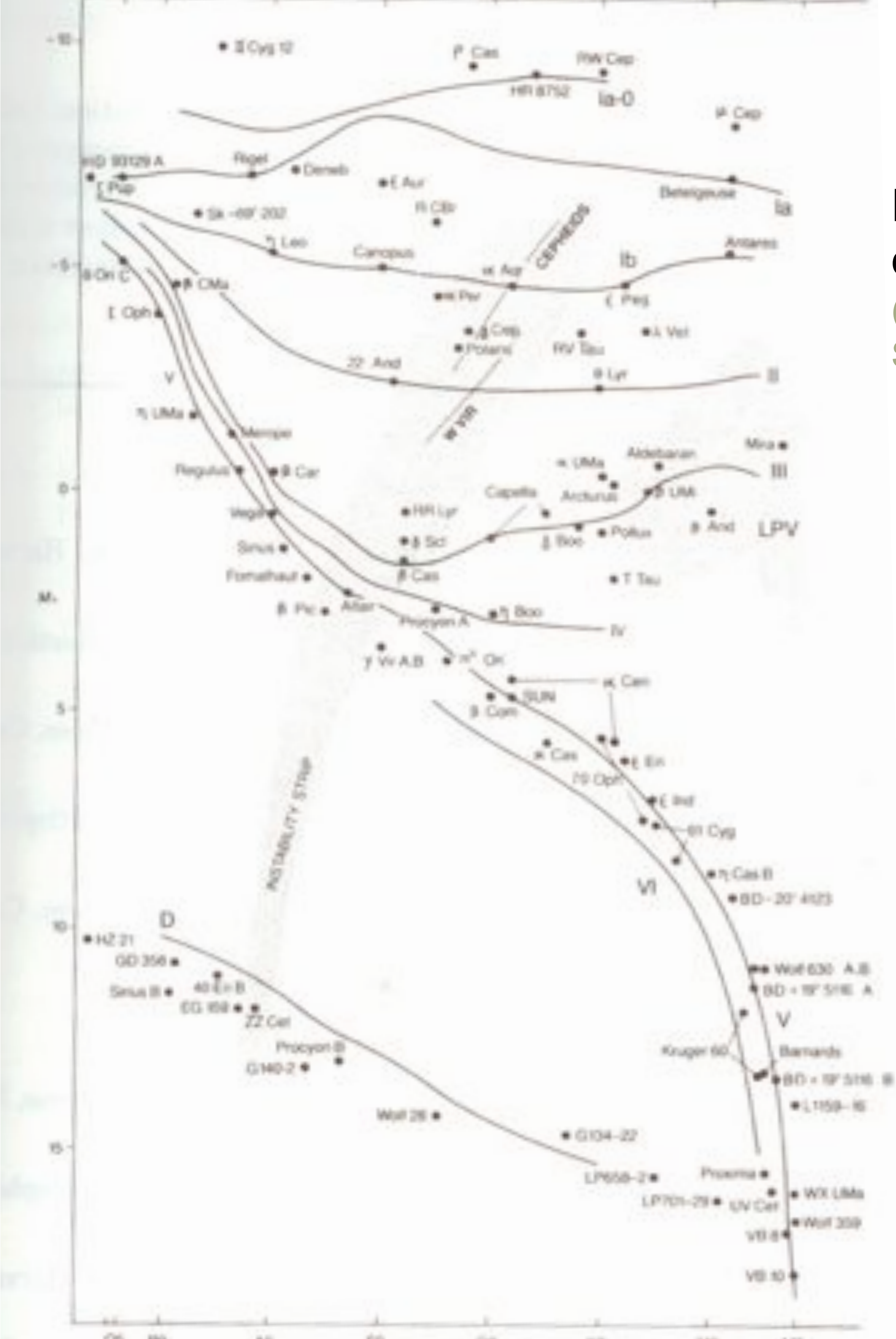




(color magnitude diagram: copyright Creative Commons)

Stellar classification scheme:

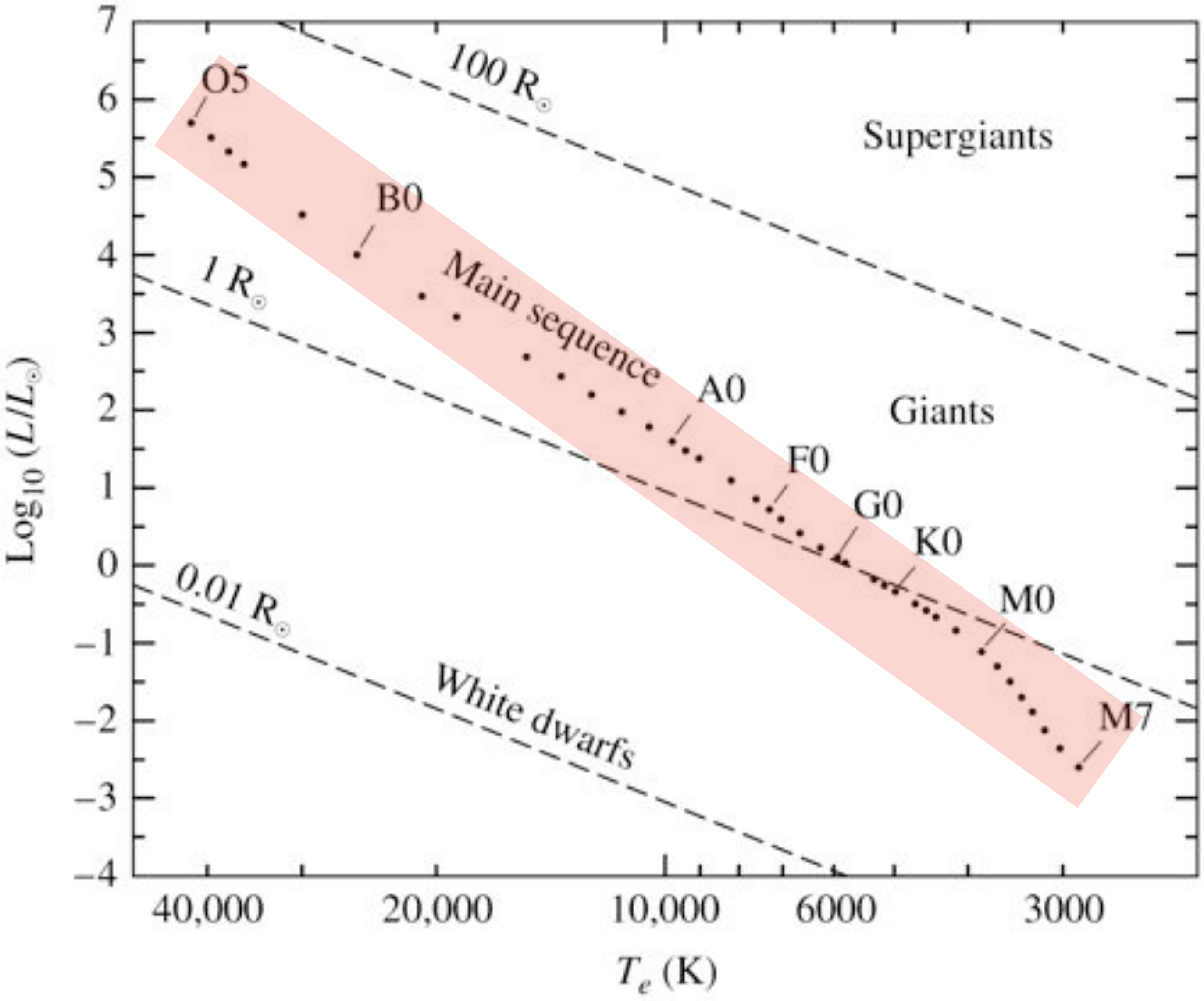
- supergiants **(I)**
- bright giants **(II)**
- normal giants **(III)**
- subgiants **(IV)**
- main-sequence (dwarf) stars **(V)**
- subdwarfs **(VI)**
- white dwarfs



Herzsprung Russell diagram with known stars

(from Kaler: Stars and Stellar Spectra)

physical interpretation

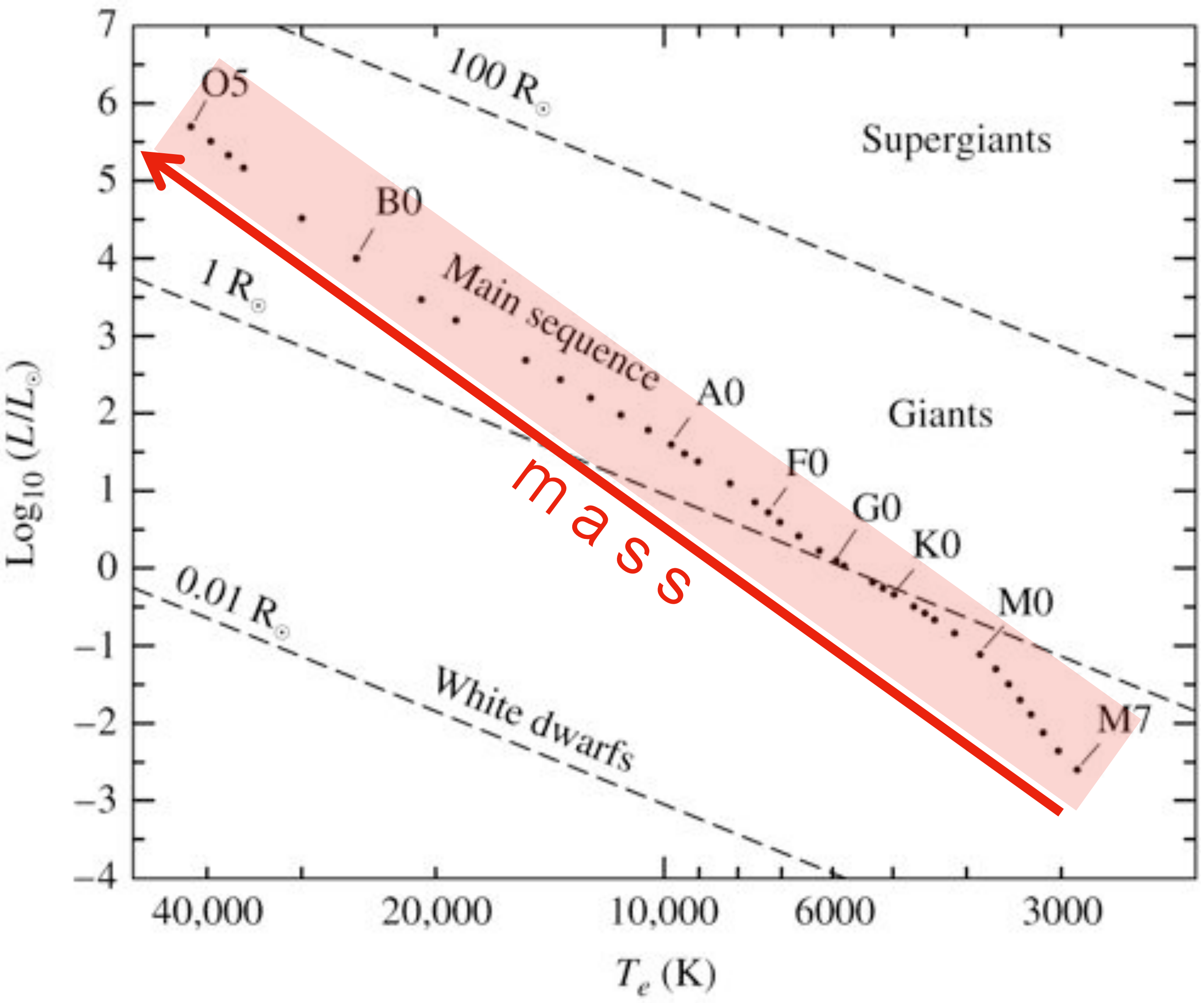


abs. magn. → luminosity

color → temperature

(Carroll & Ostlie: Figure 8.14)

physical interpretation

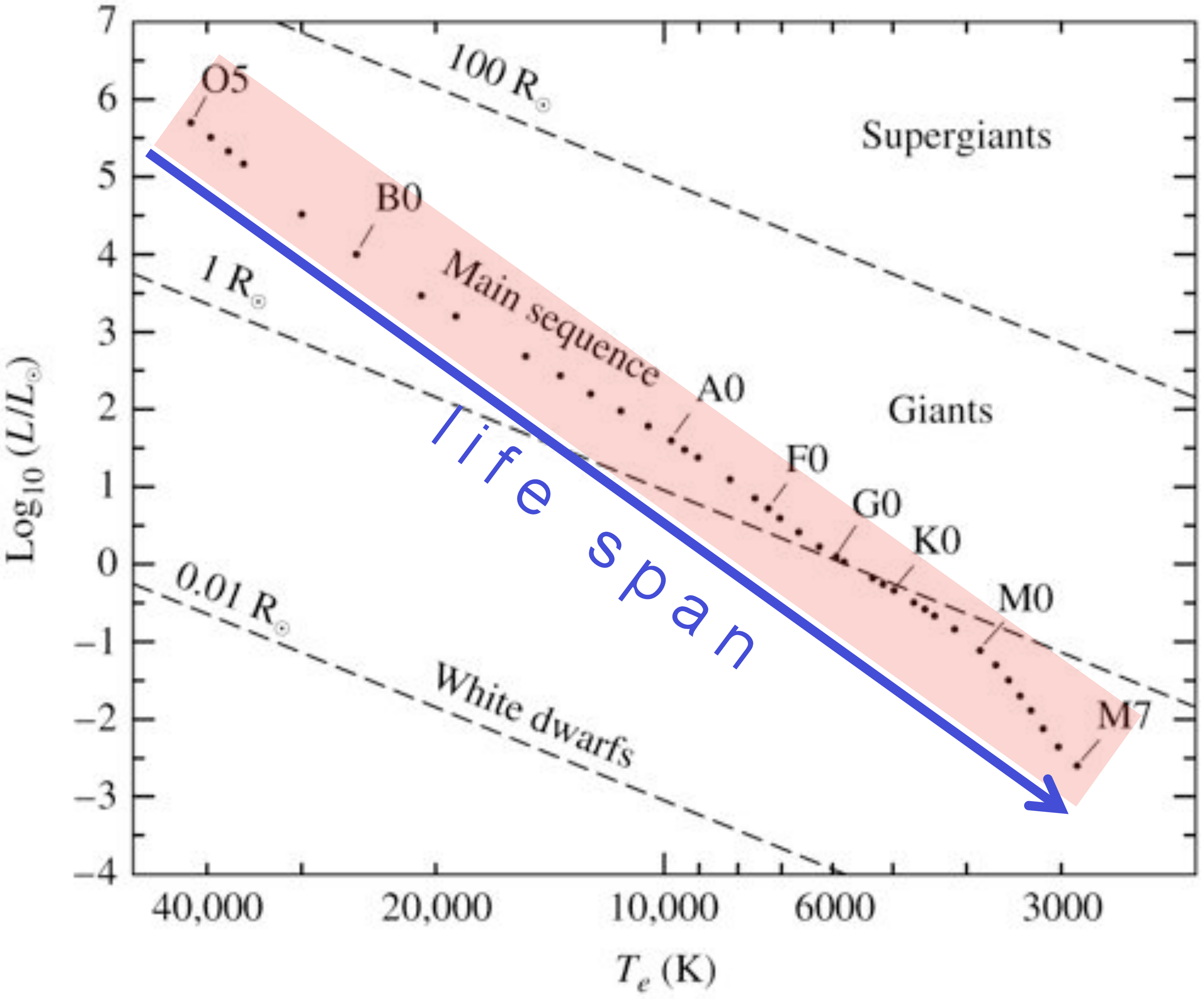


abs. magn. → luminosity

color → temperature

(Carroll & Ostlie: Figure 8.14)

physical interpretation

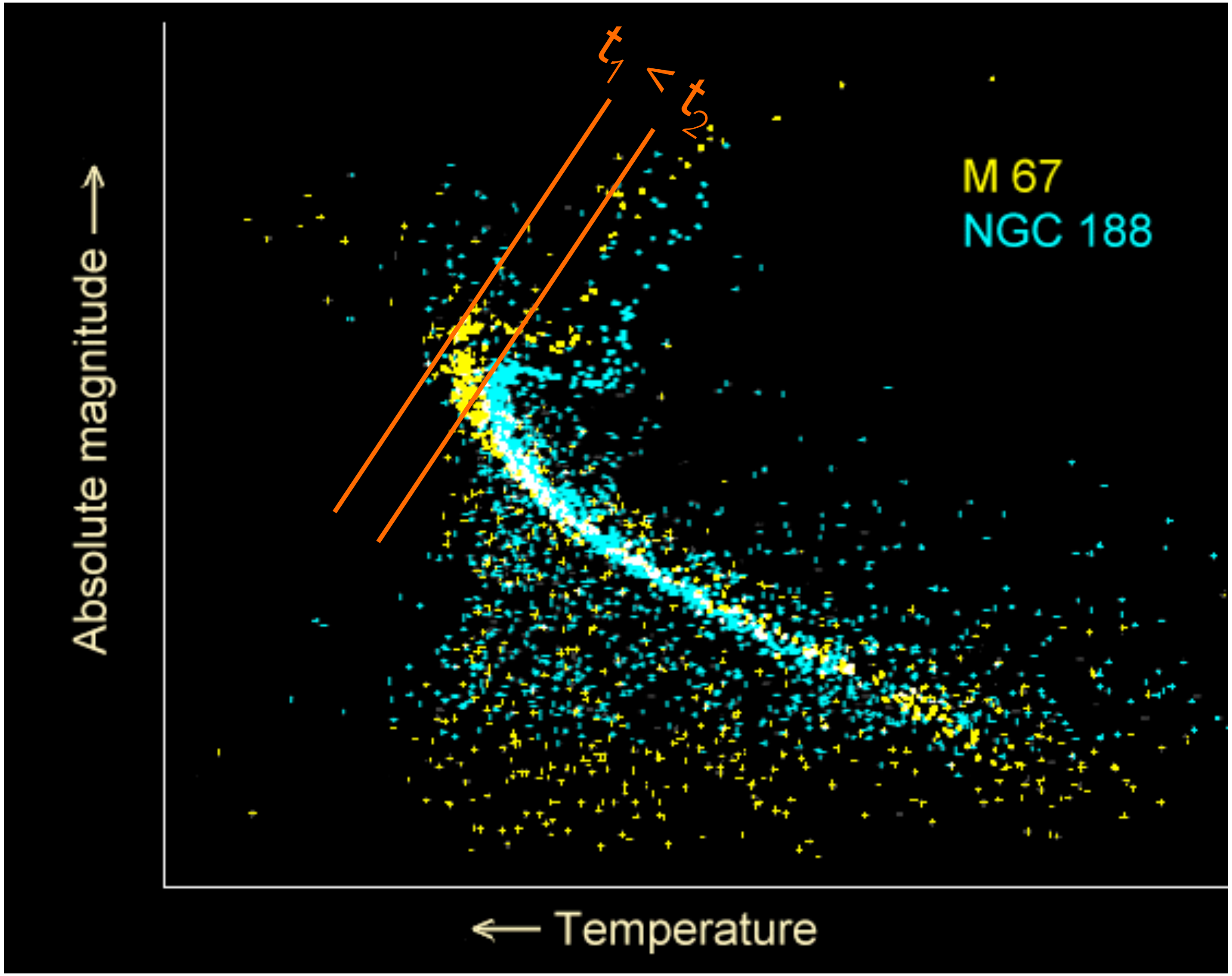


abs. magn. → luminosity

color → temperature

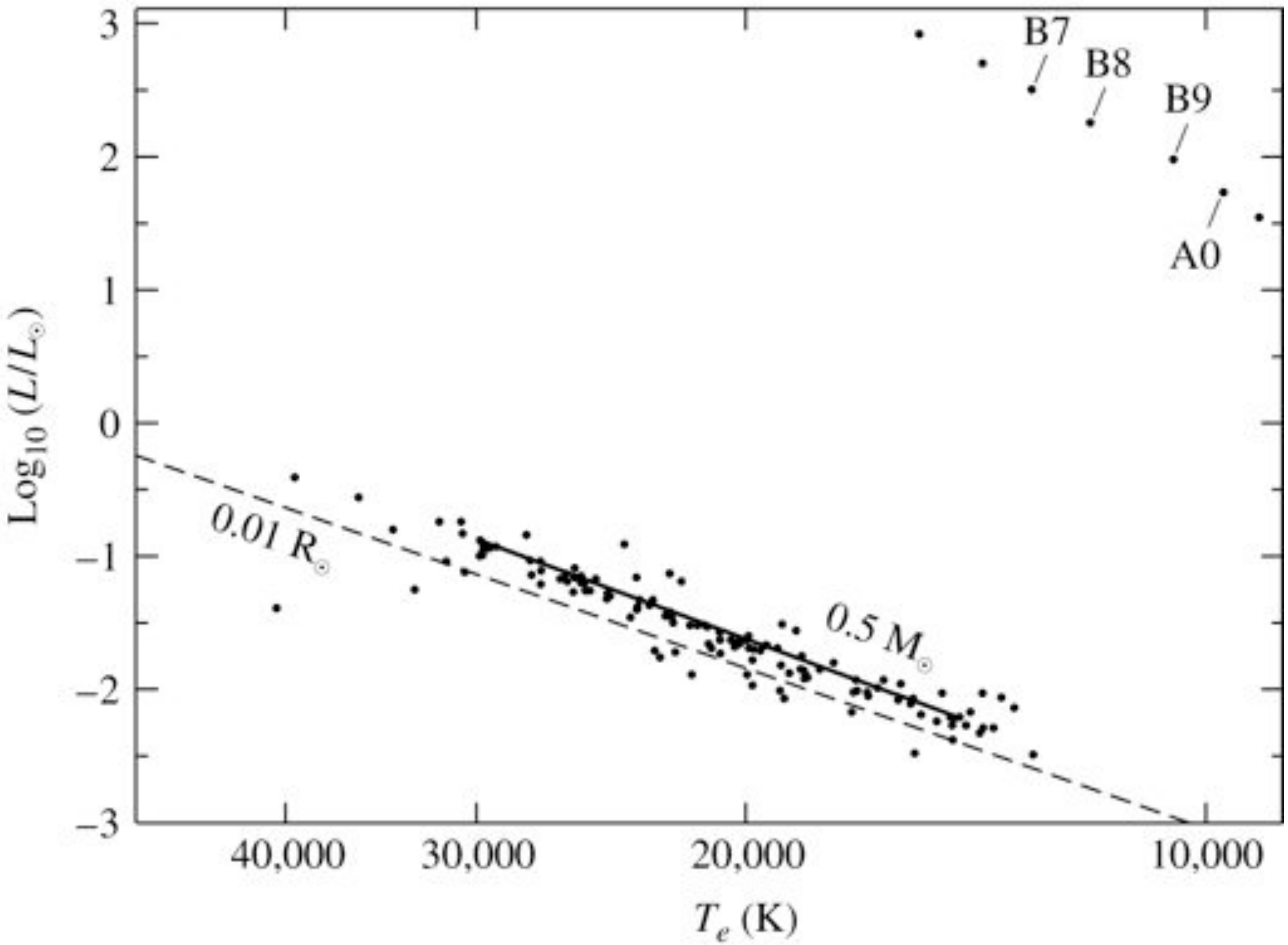
(Carroll & Ostlie: Figure 8.14)

application: age of cluster



(color magnitude diagram: copyright Creative Commons)

white dwarfs



(Carroll & Ostlie: Figure 16.3)