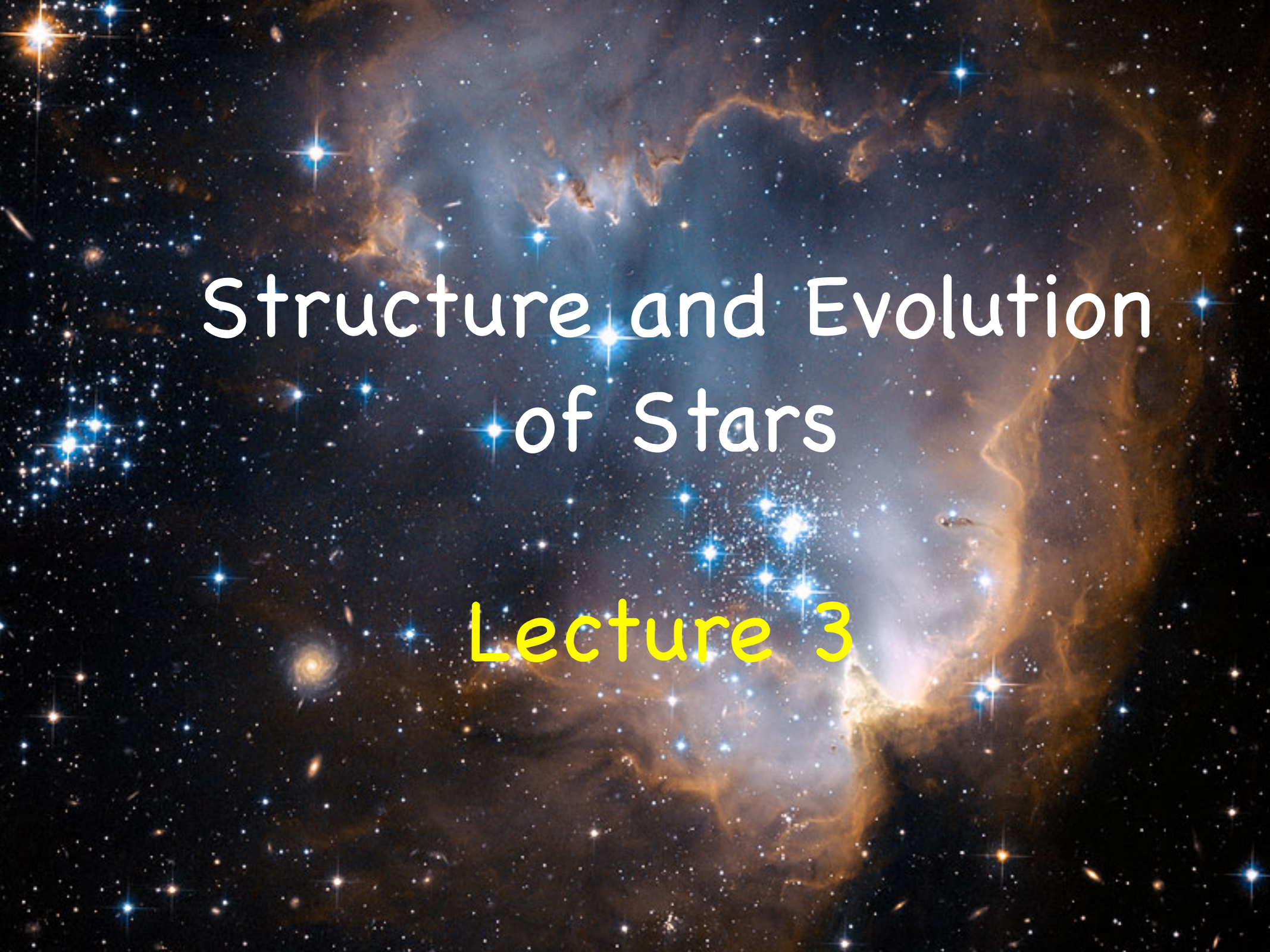
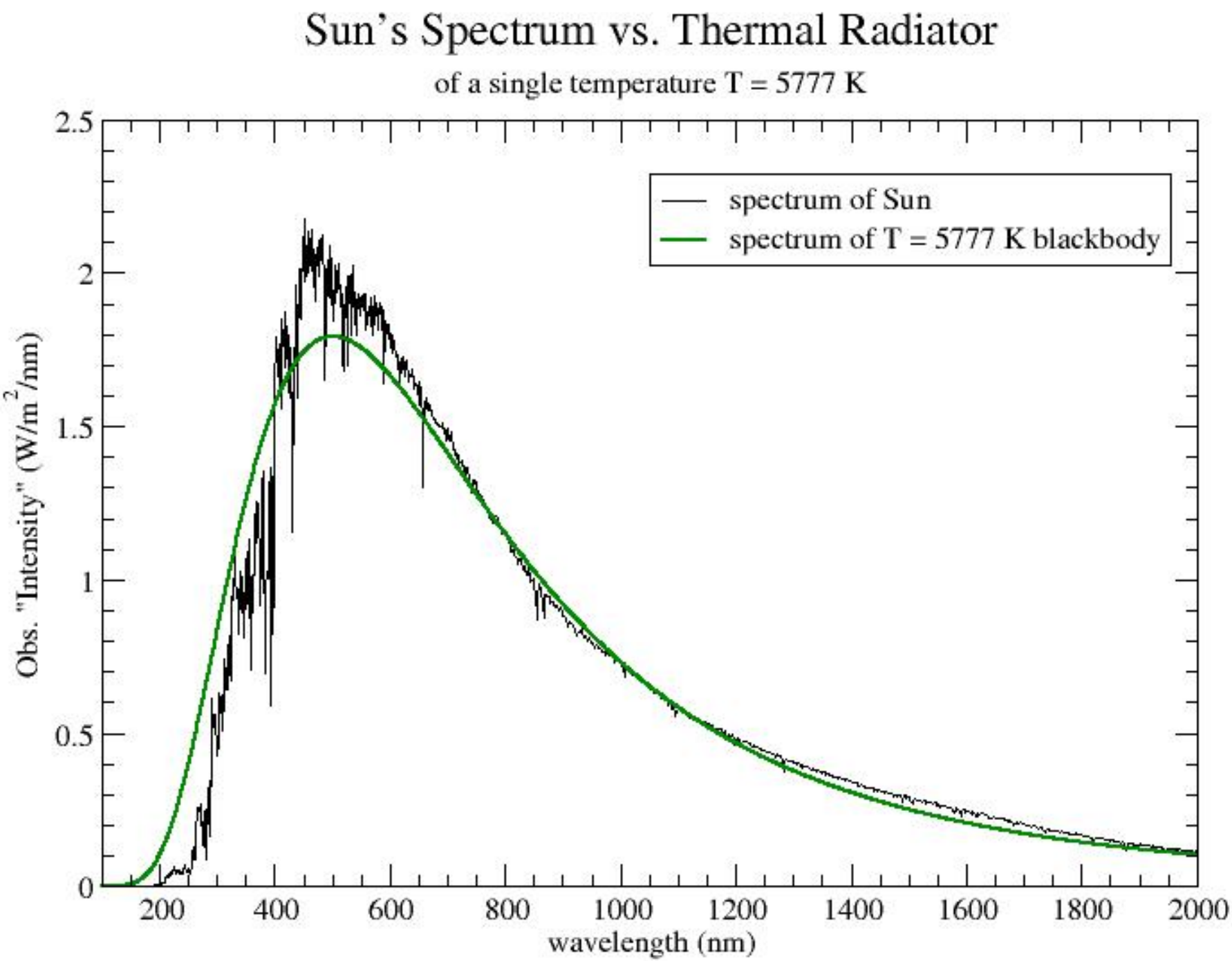
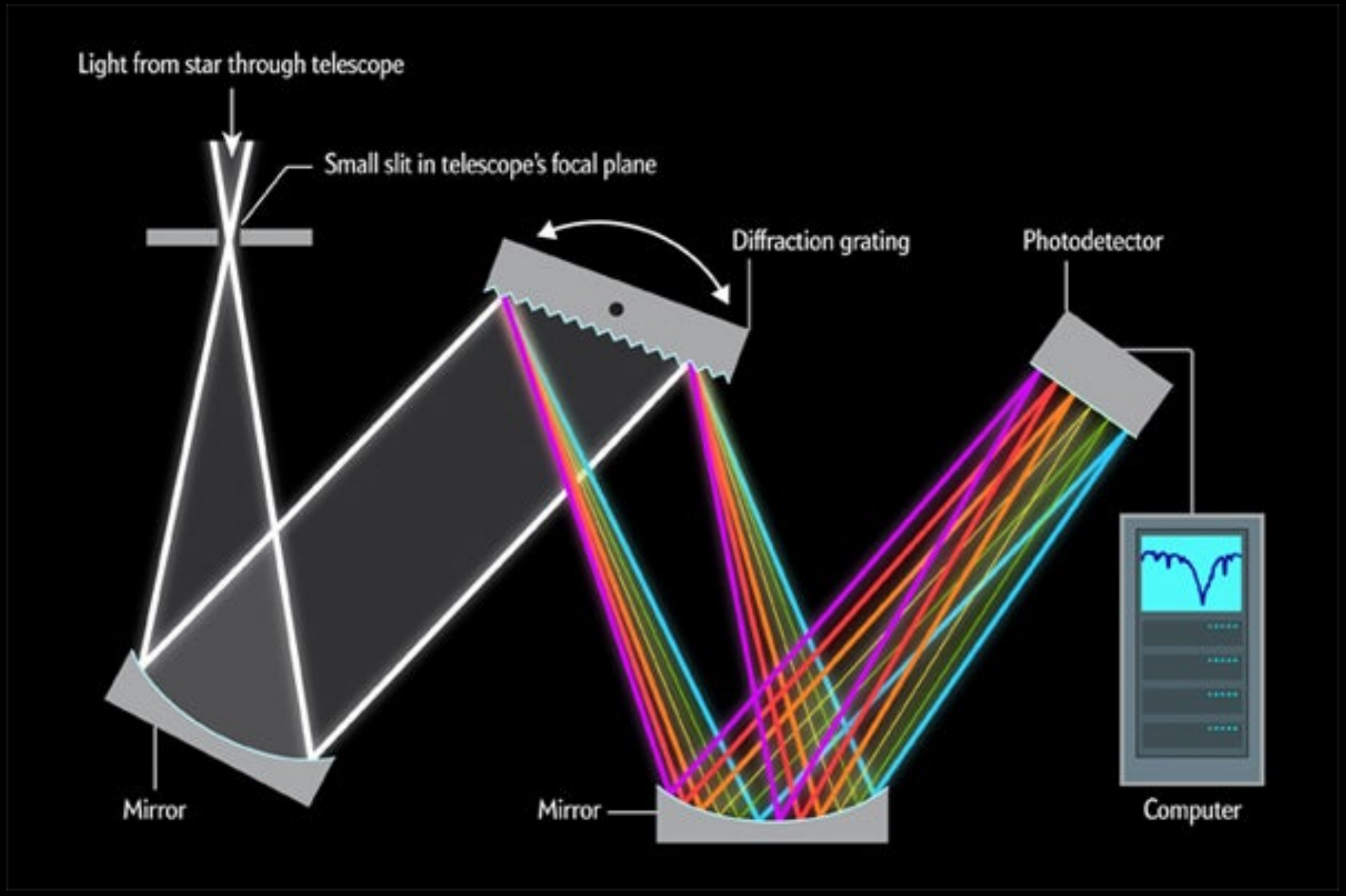
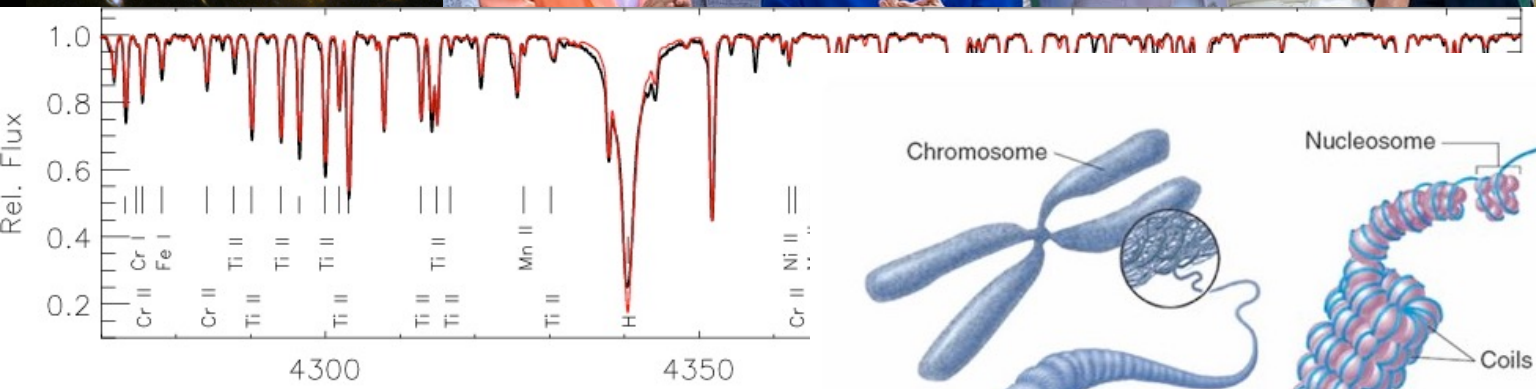
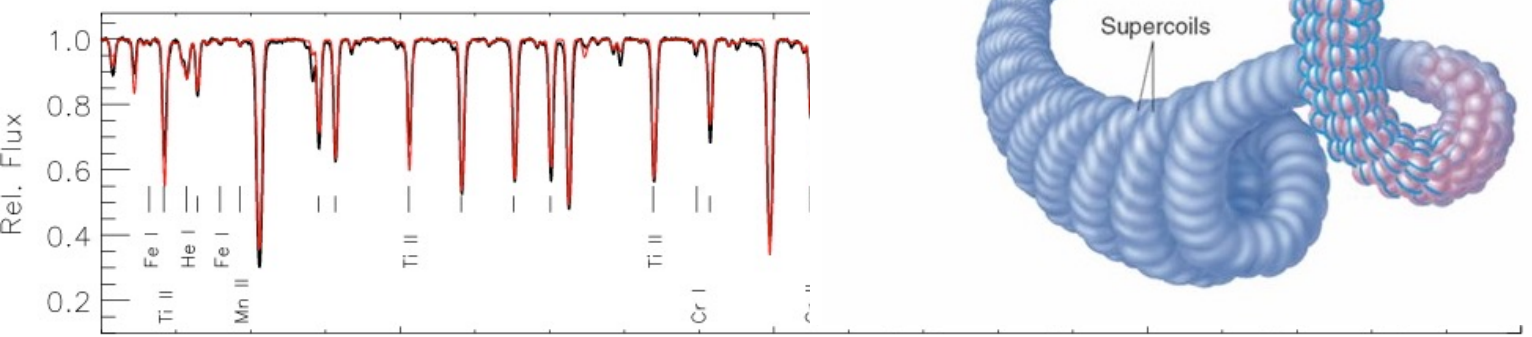
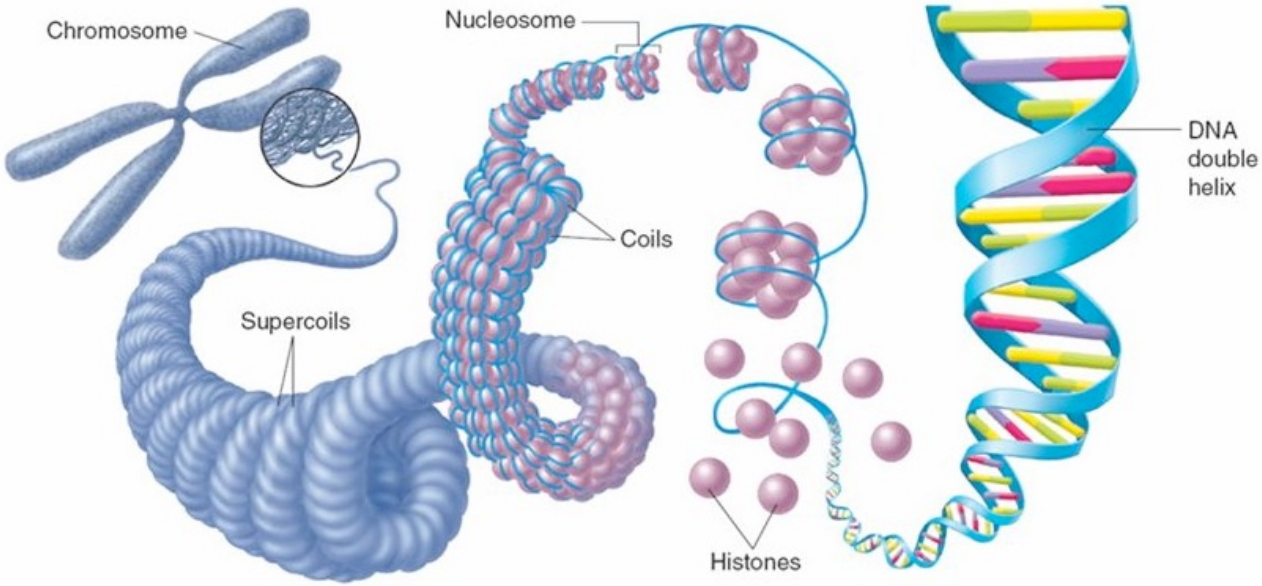

Structure and Evolution
of Stars
Lecture 3

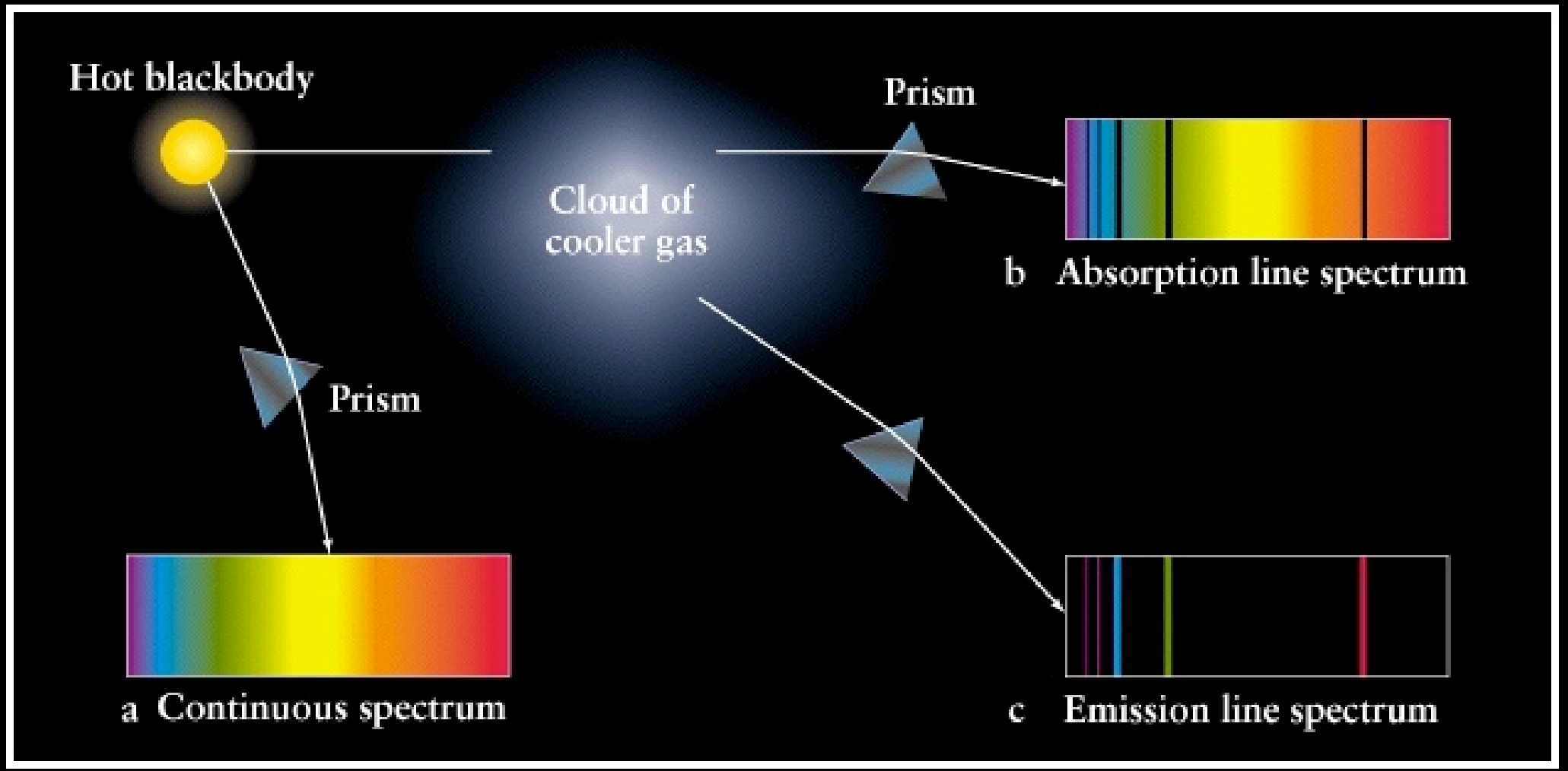

Sun's Spectrum vs. Thermal Radiator
of a single temperature T = 5777 K
spectrum of Sun
spectrum of T = 5777 K blackbody
Obs. "Intensity" (W/m 2 /nm)
wavelength (nm)
0
0.5
1
1.5
2
2.5
200
400
600
800
1000
1200
1400
1600
1800
2000

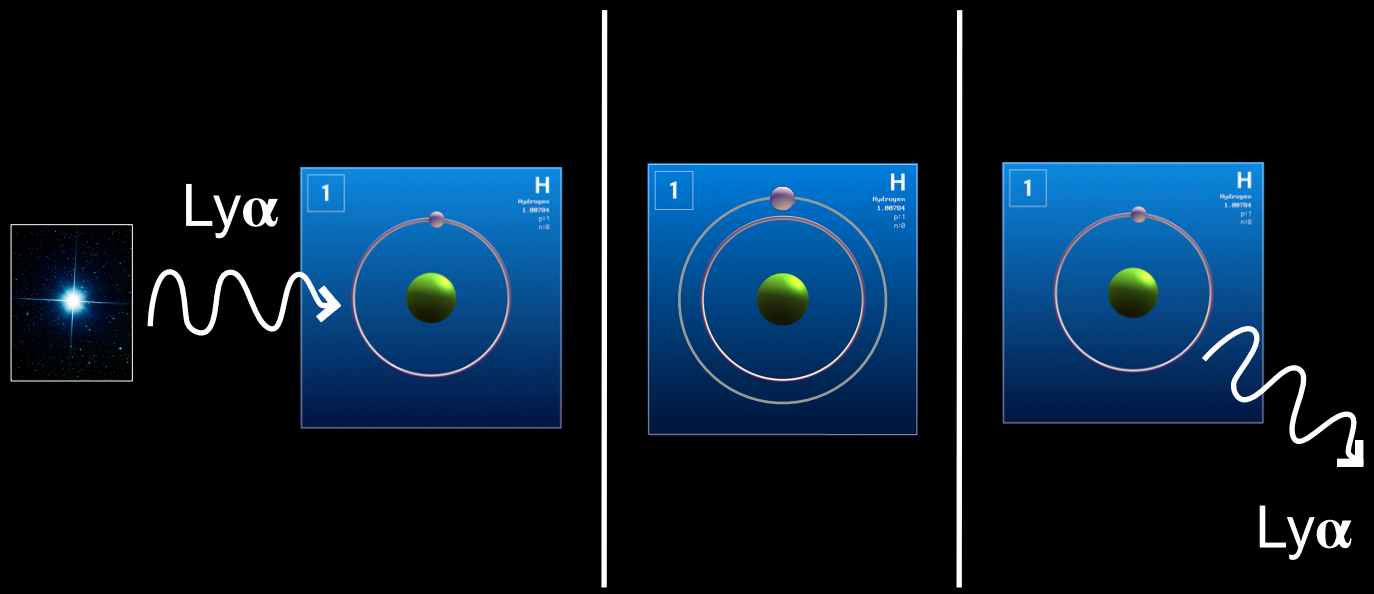

Light from star through telescope
Small slit in telescope's focal plane
Diffraction grating
Photodetector
Mirror
Mirror
Computer

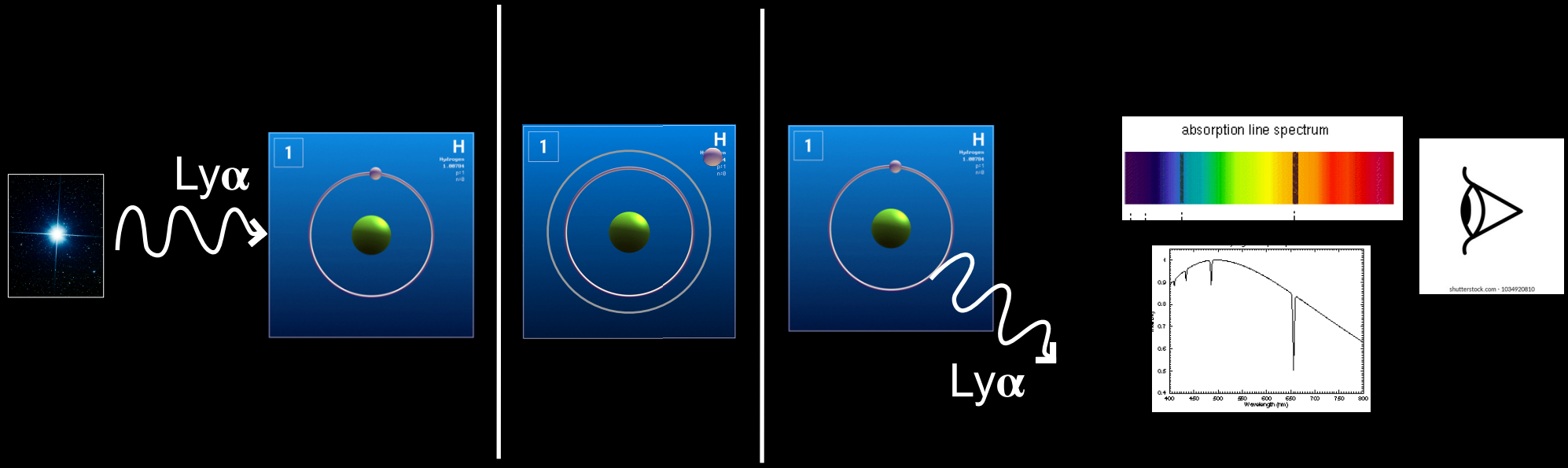

Rel. Flux
1.0
0.8
0.6
0.4
0.2
Cr II
Cr I
Fe I
Cr II
Ti II
Ti II
Ti II
Ti II
Ti II
Ti II
Mn II
Ti II
H
Cr II
Ni II
4300
4350

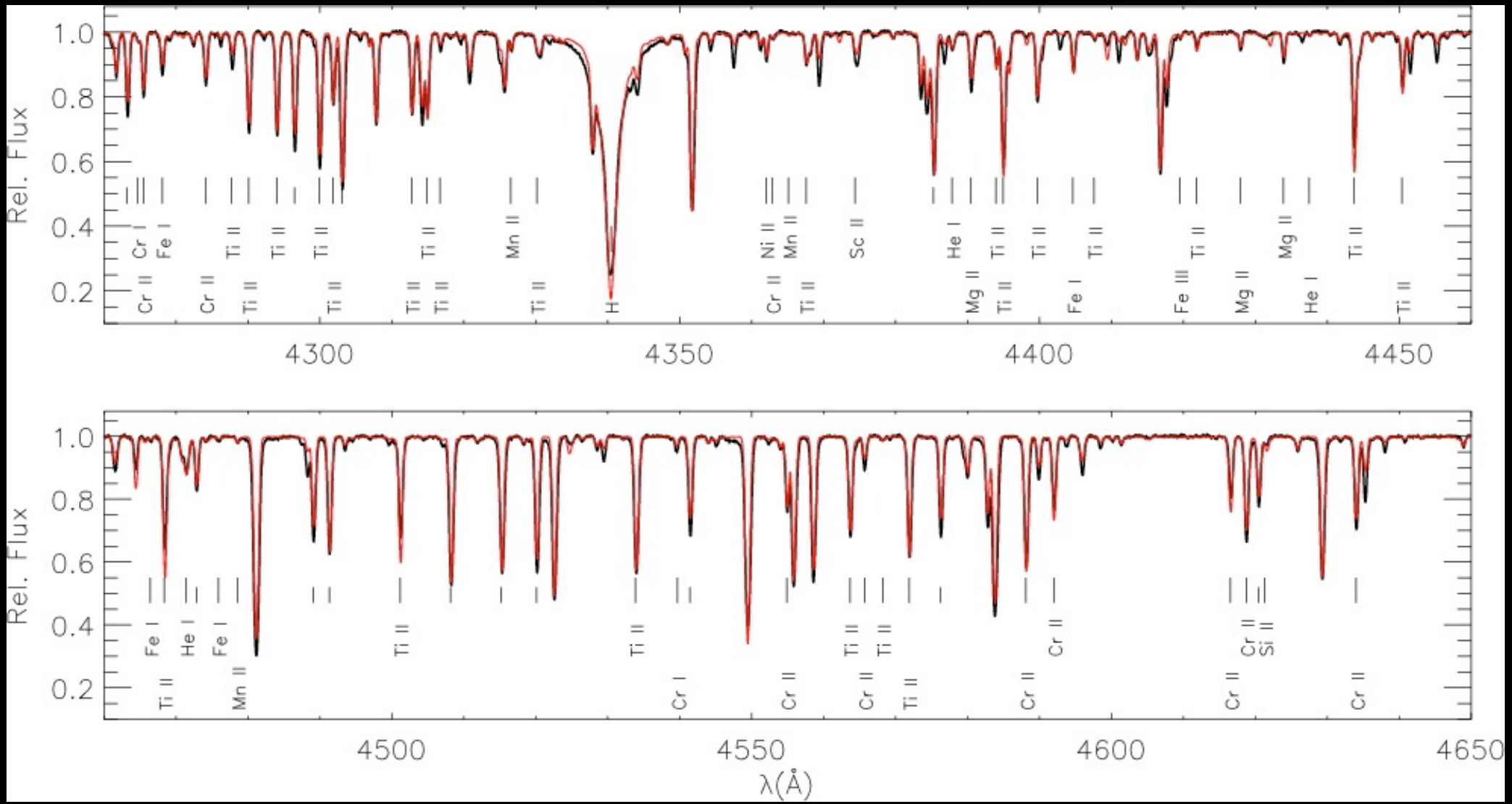

Rel. Flux
1.0
0.8
0.6
0.4
0.2
Ti II
Fe I
He I
Fe I
Mn II
Ti II
Ti II
Cr I


Chromosome
Nucleosome
DNA
double
helix
Coils
Supercoils
Histones

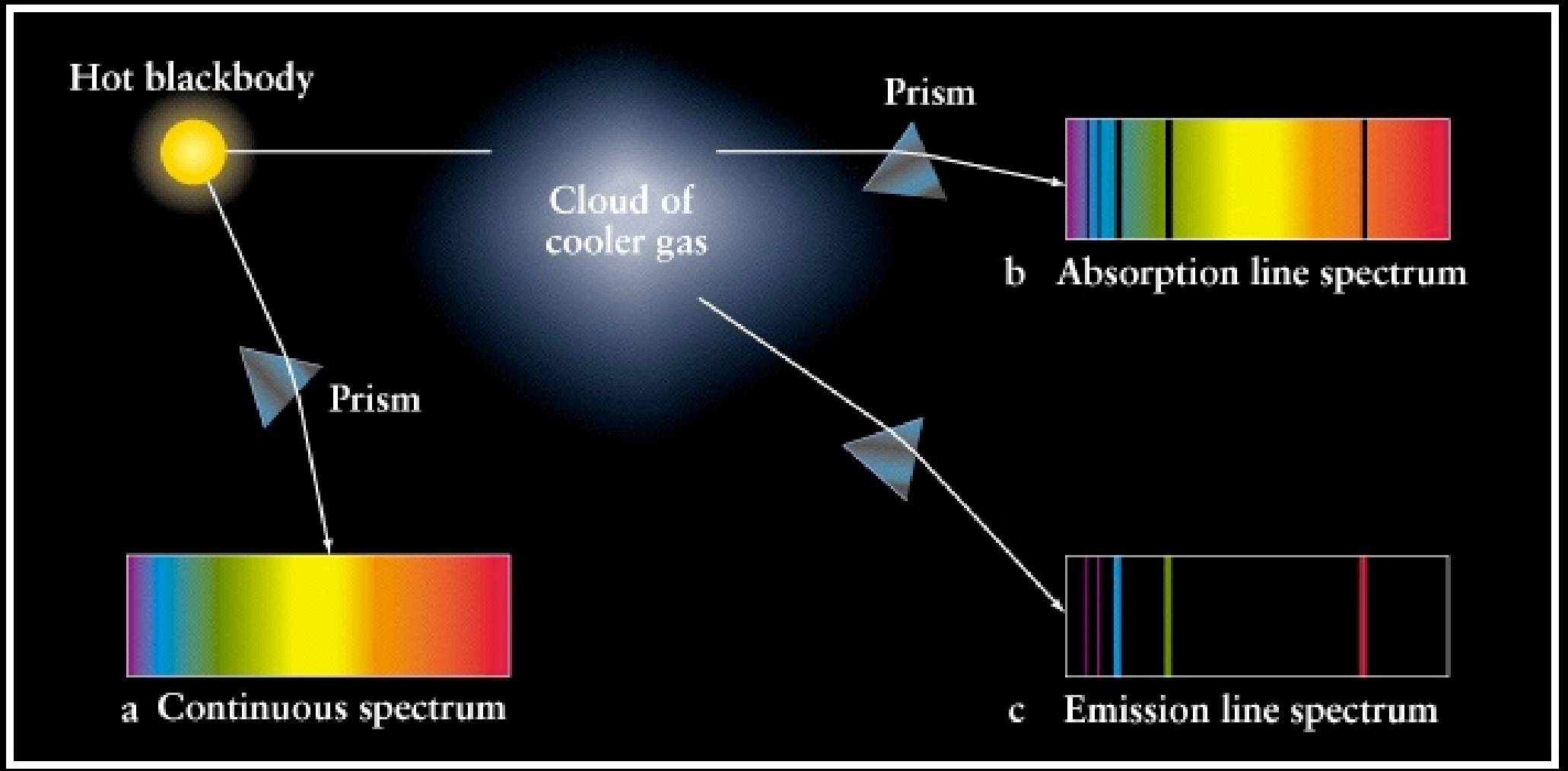

Hot blackbody
Prism
Cloud of
cooler gas
b Absorption line spectrum
Prism
a Continuous spectrum
c Emission line spectrum

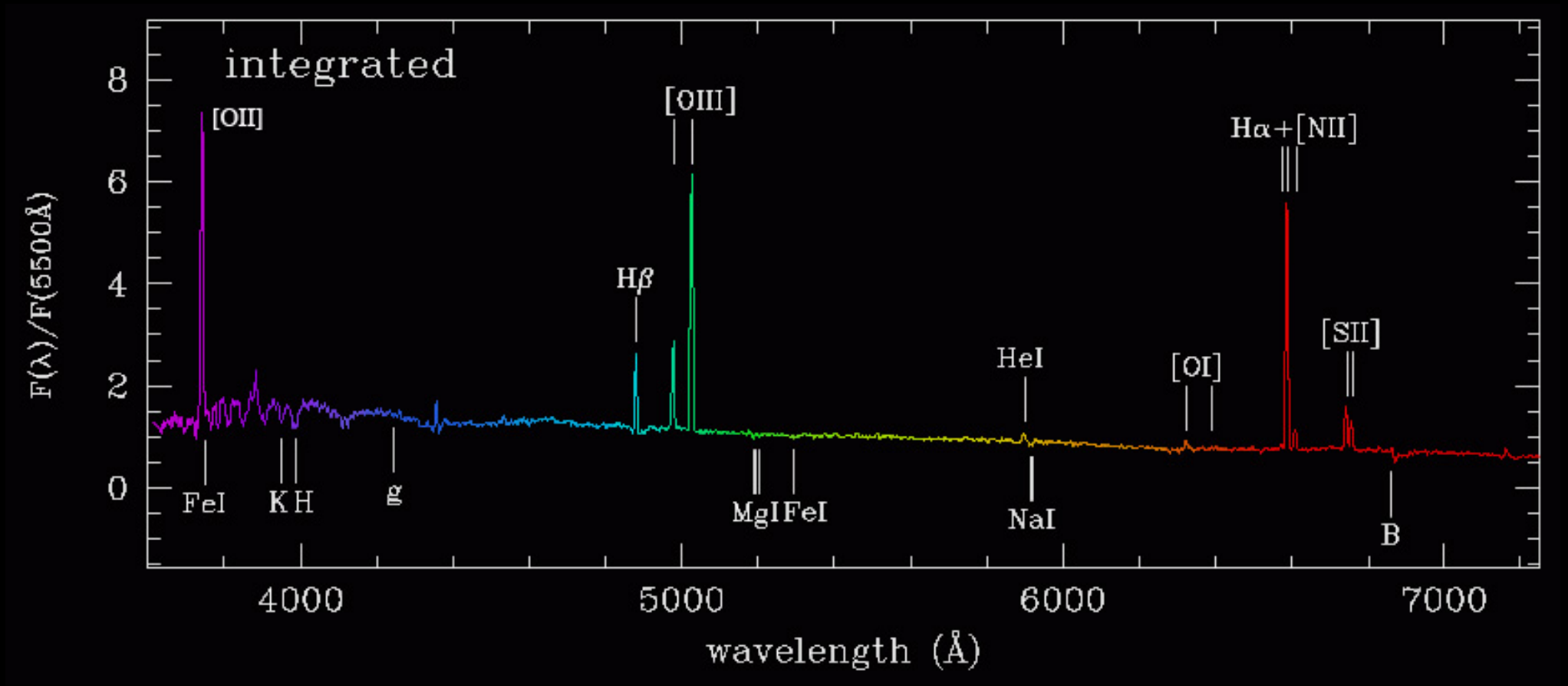

Lyα
1
H
1
H
1
H
Lyα

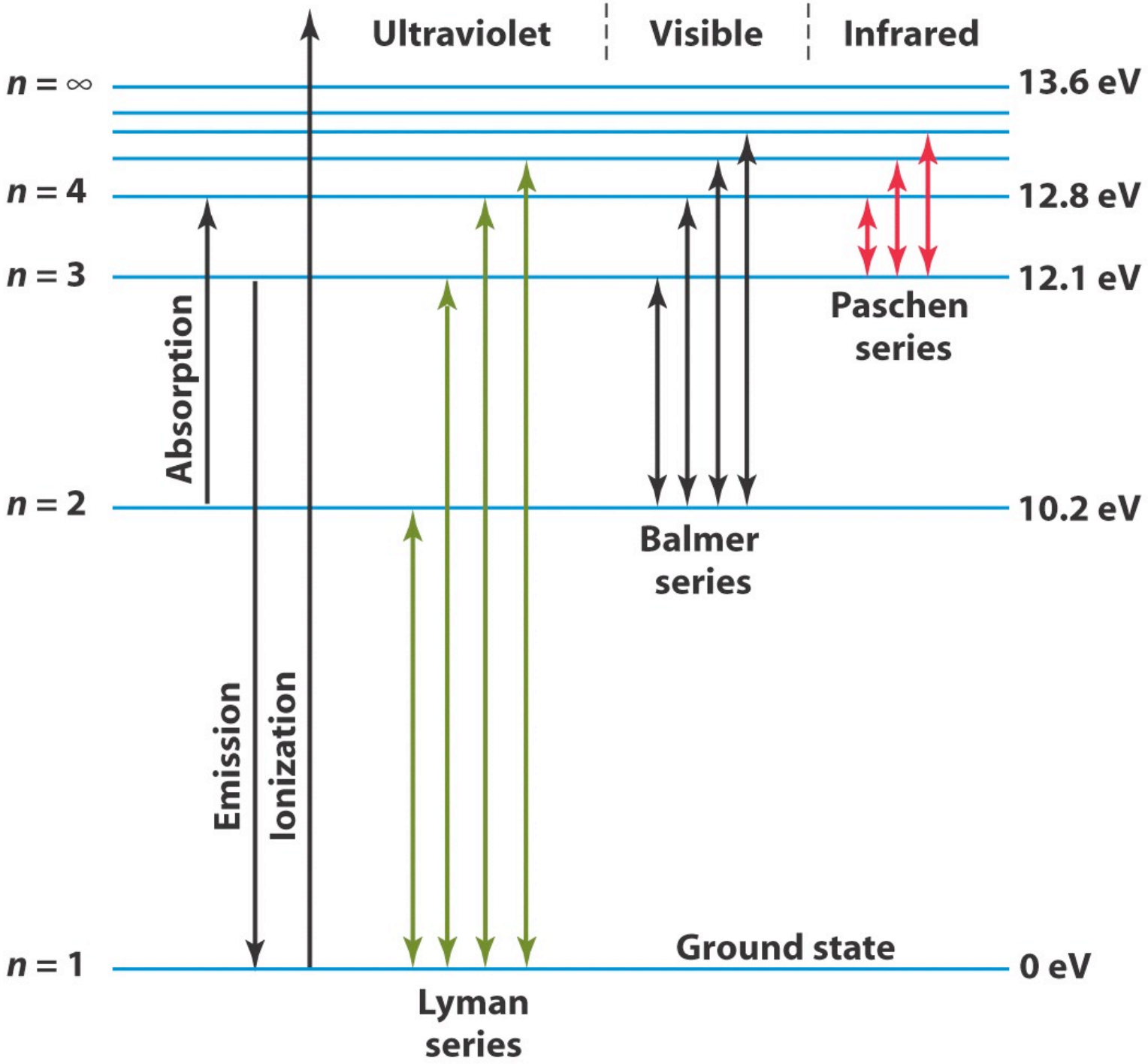

Lyα
1
H
1
H
1
H
Lyα
absorption line spectrum
shutterstock.com · 1034920810



High resolution spectrum of Vega

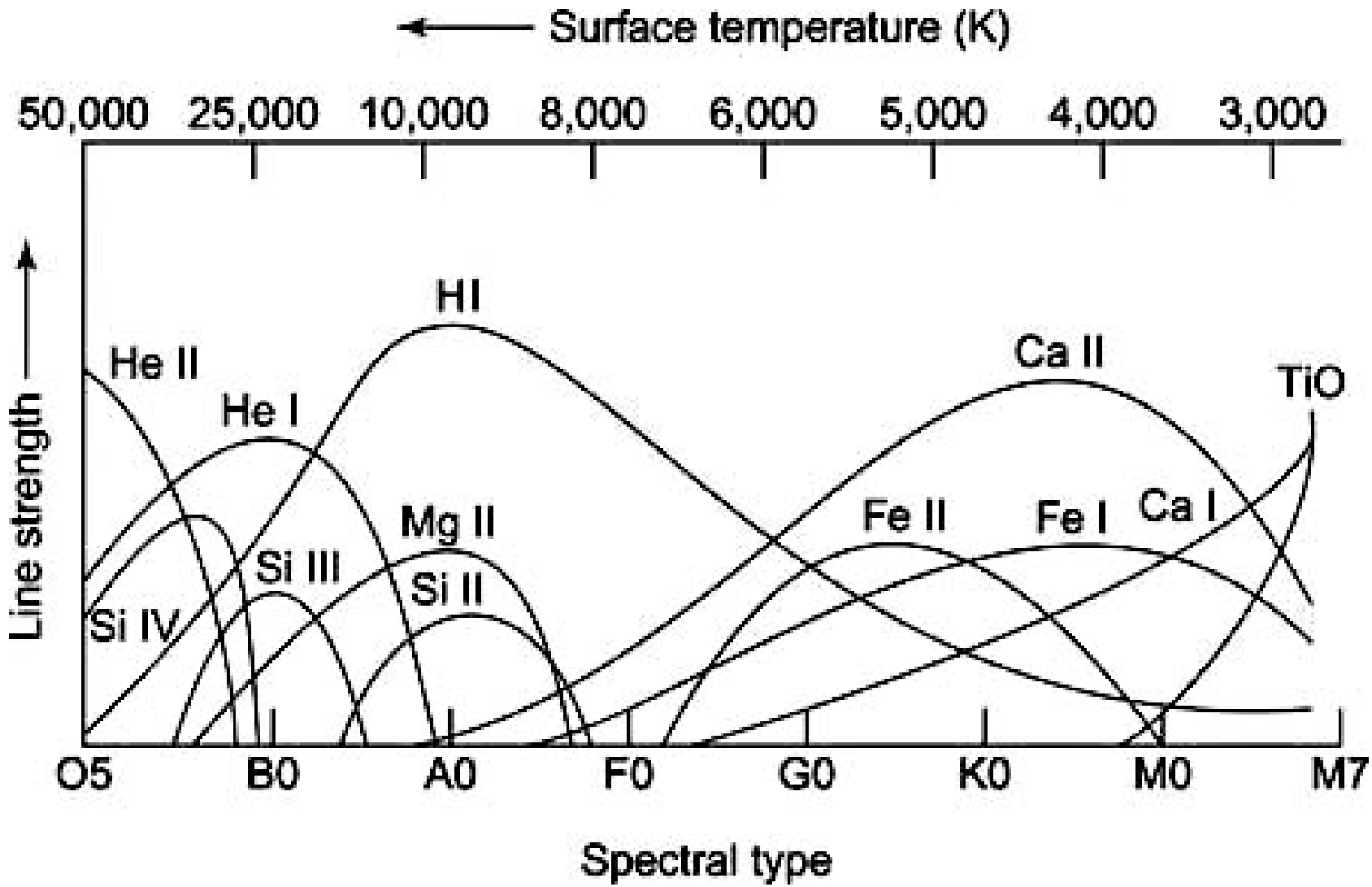

Hot blackbody
Prism
Cloud of
cooler gas
b Absorption line spectrum
Prism
a Continuous spectrum
c Emission line spectrum

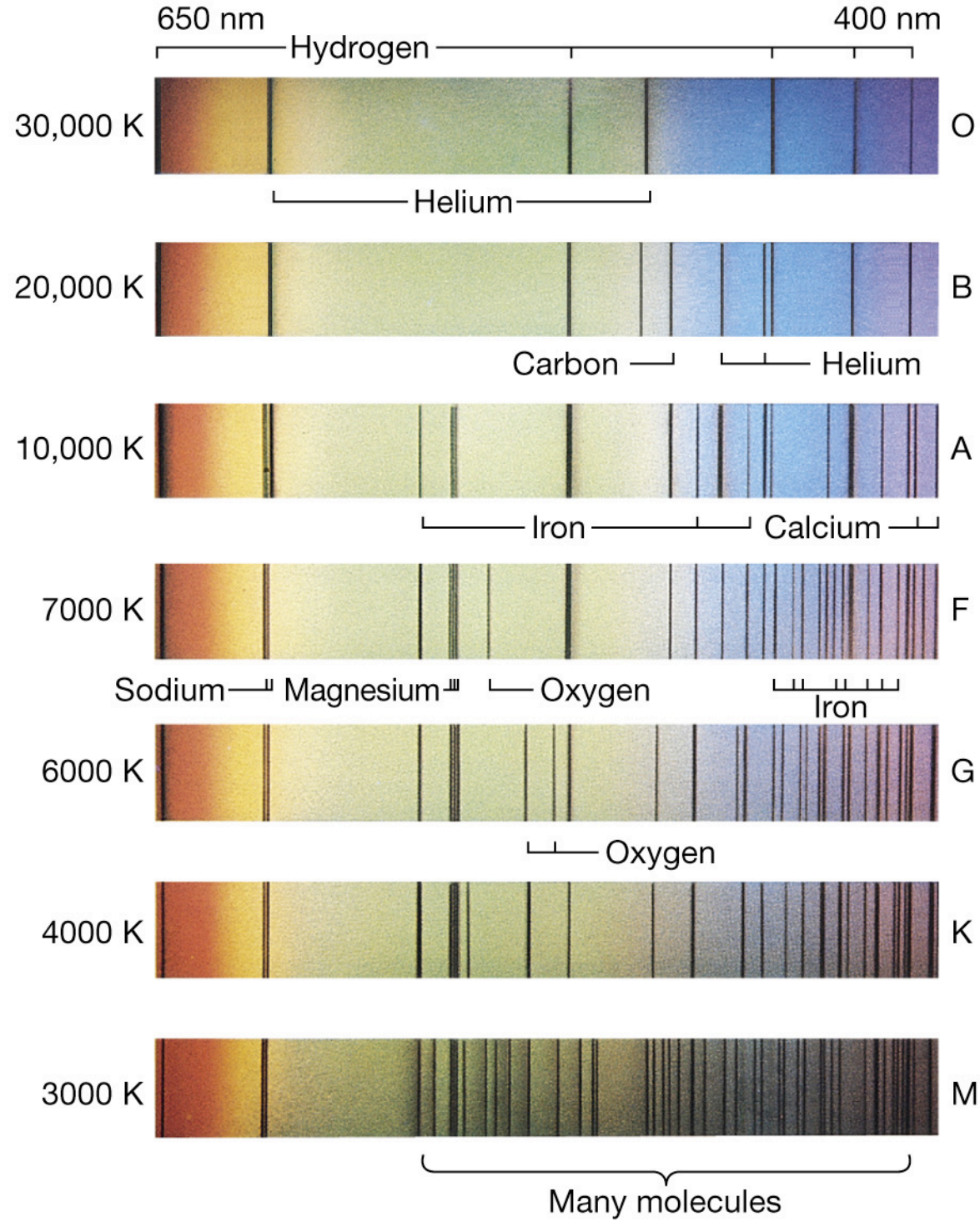

integrated
[OII]
[OIII]
Hα+[NII]
Hβ
HeI
[OI]
[SII]
FeI
K H
g
MgI FeI
NaI
B
F(λ)/F(5500Å)
wavelength (Å)
0
2
4
6
8
4000
5000
6000
7000

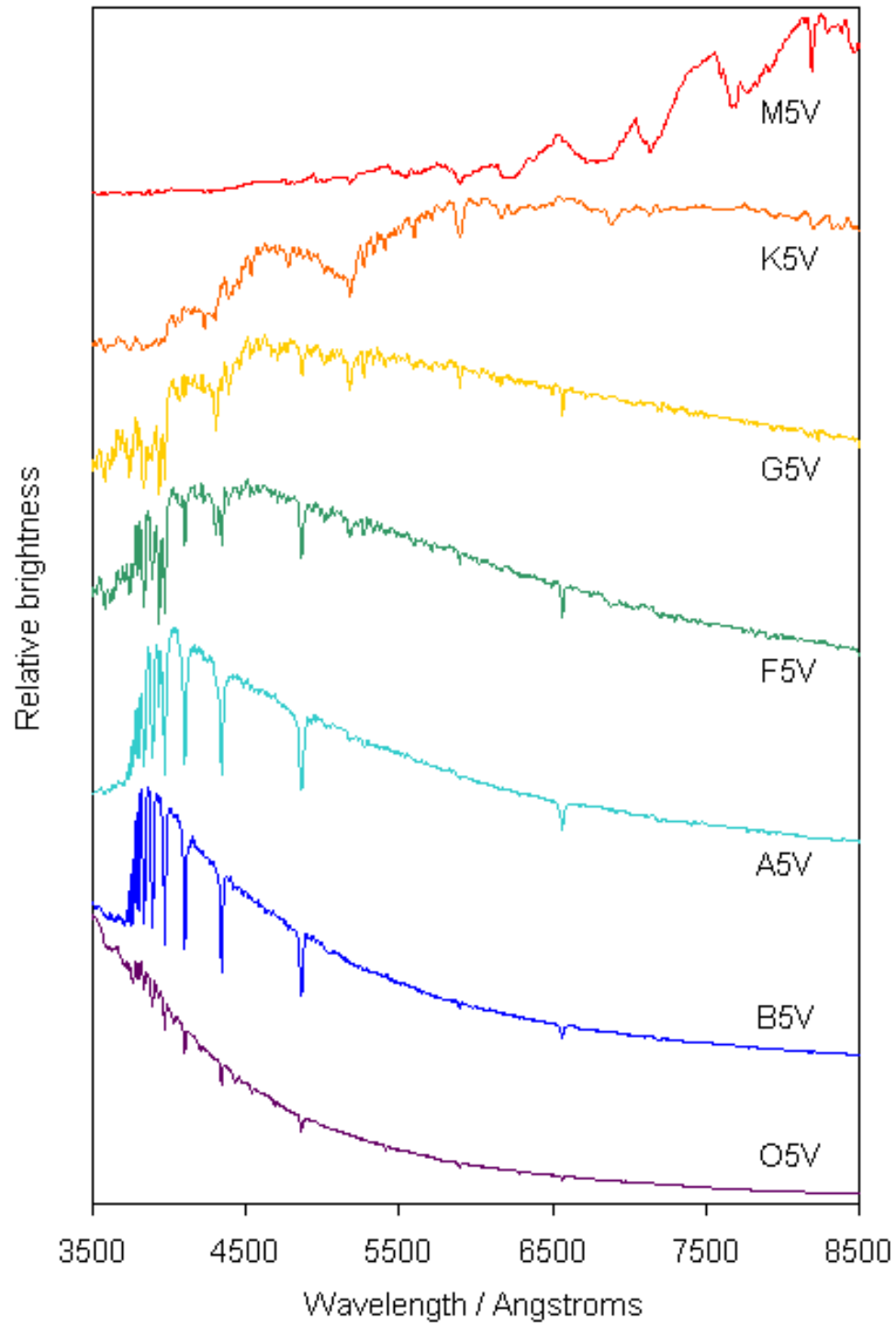

Ultraviolet
Visible
Infrared
n = ∞
n = 4
n = 3
n = 2
n = 1
13.6 eV
12.8 eV
12.1 eV
10.2 eV
0 eV
Absorption
Emission
Ionization
Paschen series
Balmer series
Lyman series
Ground state

IONIZATION POTENTIALS[a]

Z	Element	Spectrum																			
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
1	H	13.598																				
2	He	24.587	54.416																			
3	Li	5.392	75.638	122.451																		
4	Be	9.322	18.211	153.893	217.713																	
5	B	8.298	25.154	37.930	259.368	340.217																
6	C	11.260	24.383	47.887	64.492	392.077	489.981															
7	N	14.534	29.601	47.448	77.472	97.888	552.057	667.029														
8	O	13.618	35.116	54.934	77.412	113.896	138.116	739.315	871.387													
9	F	17.422	34.970	62.707	87.138	114.240	157.161	185.182	953.886	1103.089												
10	Ne	21.564	40.962	63.45	97.11	126.21	157.93	207.27	239.09	1195.797	1362.164											
11	Na	5.139	47.286	71.64	98.91	138.39	172.15	208.47	264.18	299.87	1465.091	1648.659										
12	Mg	7.646	15.035	80.143	109.24	141.26	186.50	224.94	265.90	327.95	367.53	1761.802	1962.613									
13	Al	5.986	18.828	28.447	119.99	153.71	190.47	241.43	284.59	330.21	398.57	442.07	2085.983	2304.080								
14	Si	8.151	16.345	33.492	45.141	166.77	205.05	246.52	303.17	351.10	401.43	476.06	523.50	2437.676	2673.108							
15	P	10.486	19.725	30.18	51.37	65.023	230.43	263.22	309.41	371.73	424.50	479.57	560.41	611.85	2816.943	3069.762						
16	S	10.360	23.33	34.83	47.30	72.68	88.049	280.93	328.23	379.10	447.09	504.78	564.65	651.63	707.14	3223.836	3494.099					
17	Cl	12.967	23.81	39.61	53.46	67.8	98.03	114.193	348.28	400.05	455.62	529.26	591.97	656.69	749.74	809.39	3658.425	3946.193				
18	Ar	15.759	27.629	40.74	59.81	75.02	91.007	124.319	143.456	422.44	478.68	538.95	618.24	686.09	755.73	854.75	918	4120.778	4426.114			
19	K	4.341	31.625	45.72	60.91	82.66	100.0	117.56	154.86	175.814	503.44	564.13	629.09	714.02	787.13	861.77	968	1034	4610.955	4933.931		
20	Ca	6.113	11.871	50.908	67.10	84.41	108.78	127.7	147.24	188.54	211.270	591.25	656.39	726.03	816.61	895.12	974	1087	1157	5129.045	5469.738	
21	Sc	6.54	12.80	24.76	73.47	91.66	111.1	138.0	158.7	180.02	225.32	249.832	685.89	755.47	829.79	926.00						
22	Ti	6.82	13.58	27.491	43.266	99.22	119.36	140.8	168.5	193.2	215.91	265.23	291.497	787.33	861.33	940.36						
23	V	6.74	14.65	29.310	46.707	65.23	128.12	150.17	173.7	205.8	230.5	255.04	308.25	336.267	895.58	974.02						
24	Cr	6.766	16.50	30.96	49.1	69.3	90.56	161.1	184.7	209.3	244.4	270.8	298.0	355	384.30	1010.64						
25	Mn	7.435	15.640	33.667	51.2	72.4	95	119.27	196.46	221.8	248.3	286.0	314.4	343.6	404	435.3	1136.2					
26	Fe	7.870	16.18	30.651	54.8	75.0	99	125	151.06	235.04	262.1	290.4	330.8	361.0	392.2	457	489.5	1266.1				
27	Co	7.86	17.06	33.50	51.3	79.5	102	129	157	186.13	276	305	336	379	411	444	512	546.8	1403.0			
28	Ni	7.635	18.168	35.17	54.9	75.5	108	133	162	193	224.5	321.2	352	384	430	464	499	571	607.2	1547		
29	Cu	7.726	20.292	36.83	55.2	79.9	103	139	166	199	232	266	368.8	401	435	484	520	557	633	671	1698	
30	Zn	9.394	17.964	39.722	59.4	82.6	108	134	174	203	238	274	310.8	419.7	454	490	542	579	619	698	738	1856
31	Ga	5.999	20.51	30.71	64																	
32	Ge	7.899	15.934	34.22	45.71	93.5																
33	As	9.81	18.633	28.351	50.13	62.63	127.6															
34	Se	9.752	21.19	30.820	42.944	68.3	81.70	155.4														
35	Br	11.814	21.8	36	47.3	59.7	88.6	103.0	192.8													
36	Kr	13.999	24.359	36.95	52.5	64.7	78.5	111.0	126	230.39												
37	Rb	4.177	27.28	40	52.6	71.0	84.4	99.2	136	150	277.1											
38	Sr	5.695	11.030	43.6	57	71.6	90.8	106	122.3	162	177	324.1										
39	Y	6.38	12.24	20.52	61.8	77.0	93.0	116	129	146.52	191	206	374.0									
40	Zr	6.84	13.13	22.99	34.34	81.5																
41	Nb	6.88	14.32	25.04	38.3	50.55	102.6	125														
42	Mo	7.099	16.15	27.16	46.4	61.2	68	126.8	153													
43	Te	7.28	15.26	29.54																		
44	Ru	7.37	16.76	28.47																		
45	Rh	7.46	18.08	31.06																		
46	Pd	8.34	19.43	32.93																		
47	Ag	7.576	21.49	34.83																		


Surface temperature (K)
50,000
25,000
10,000
8,000
6,000
5,000
4,000
3,000
Line strength
He II
He I
H I
Ca II
TiO
Mg II
Si III
Si II
Si IV
Fe II
Fe I
Ca I
O5
B0
A0
F0
G0
K0
M0
M7
Spectral type

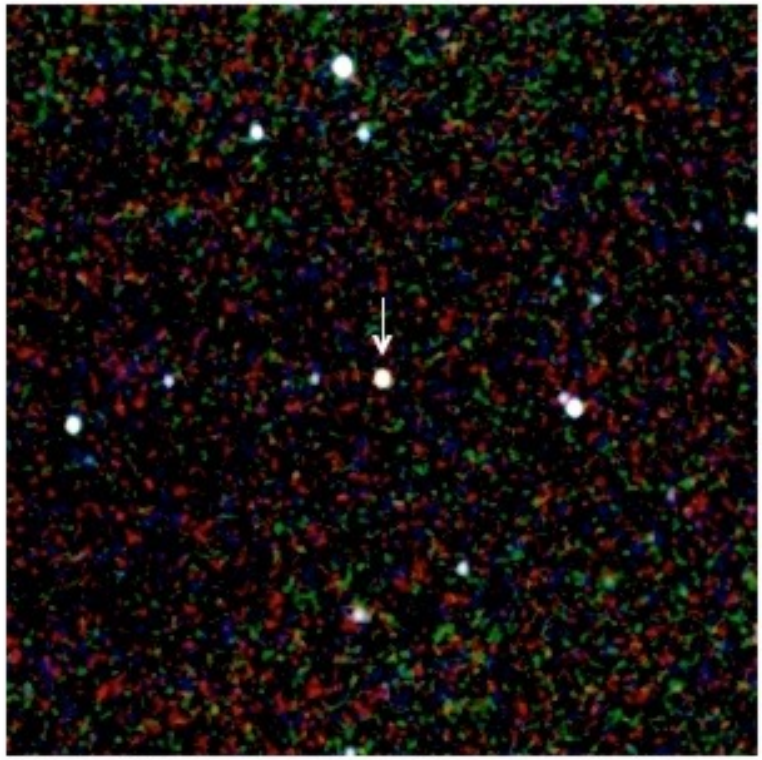



M5V
K5V
G5V
F5V
A5V
B5V
O5V
Relative brightness
3500
4500
5500
6500
7500
8500
Wavelength / Angstroms

2MASS J1146+2230

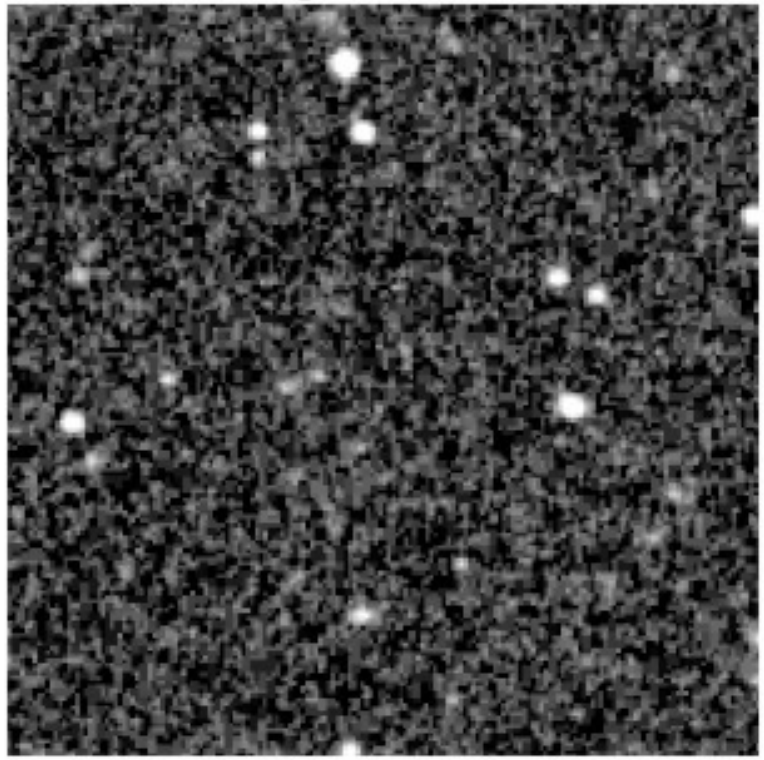
An L–type dwarf in the constellation Leo

The near–infrared view



2MASS Atlas JHK$_s$ Composite Image

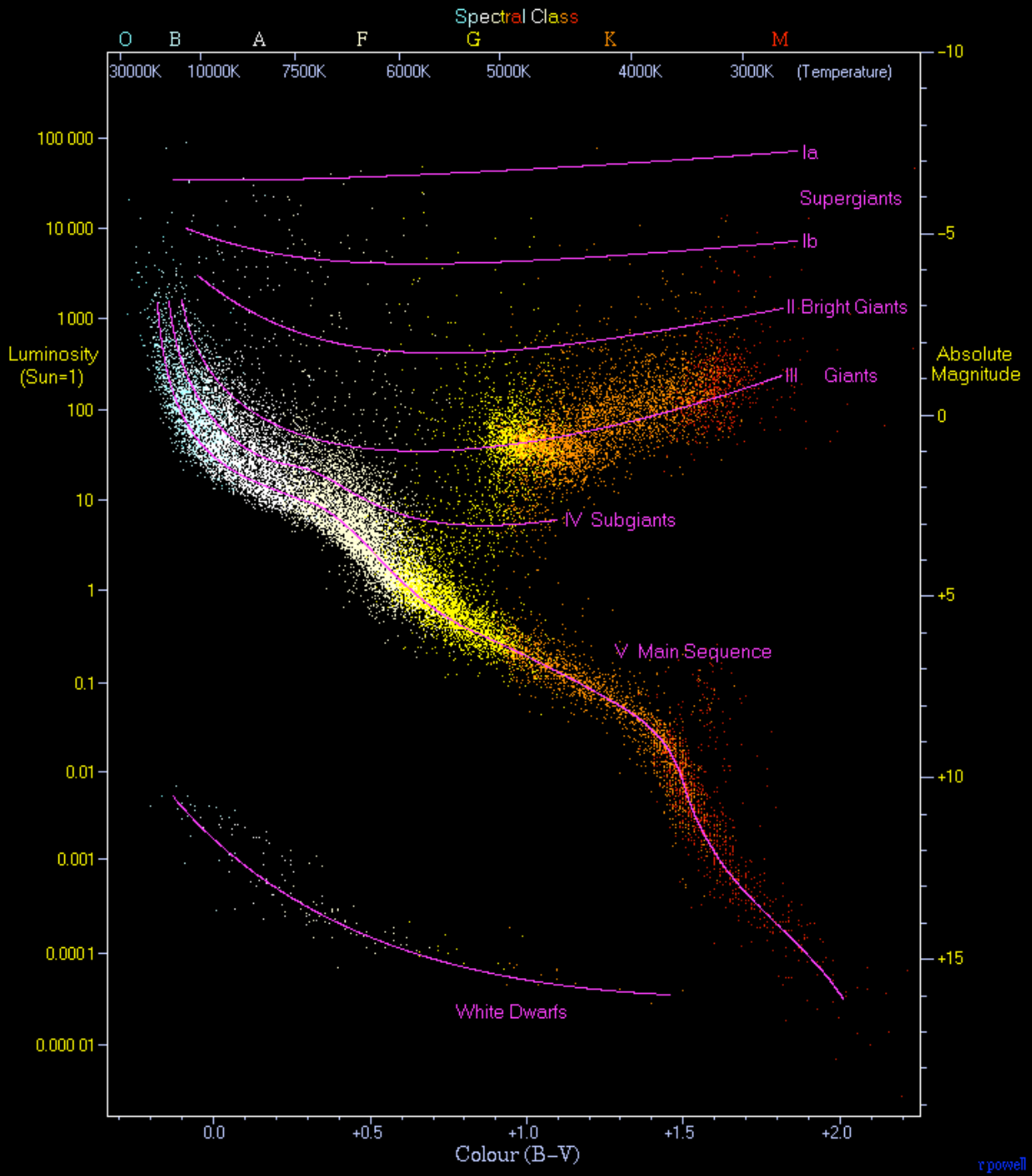
The optical view

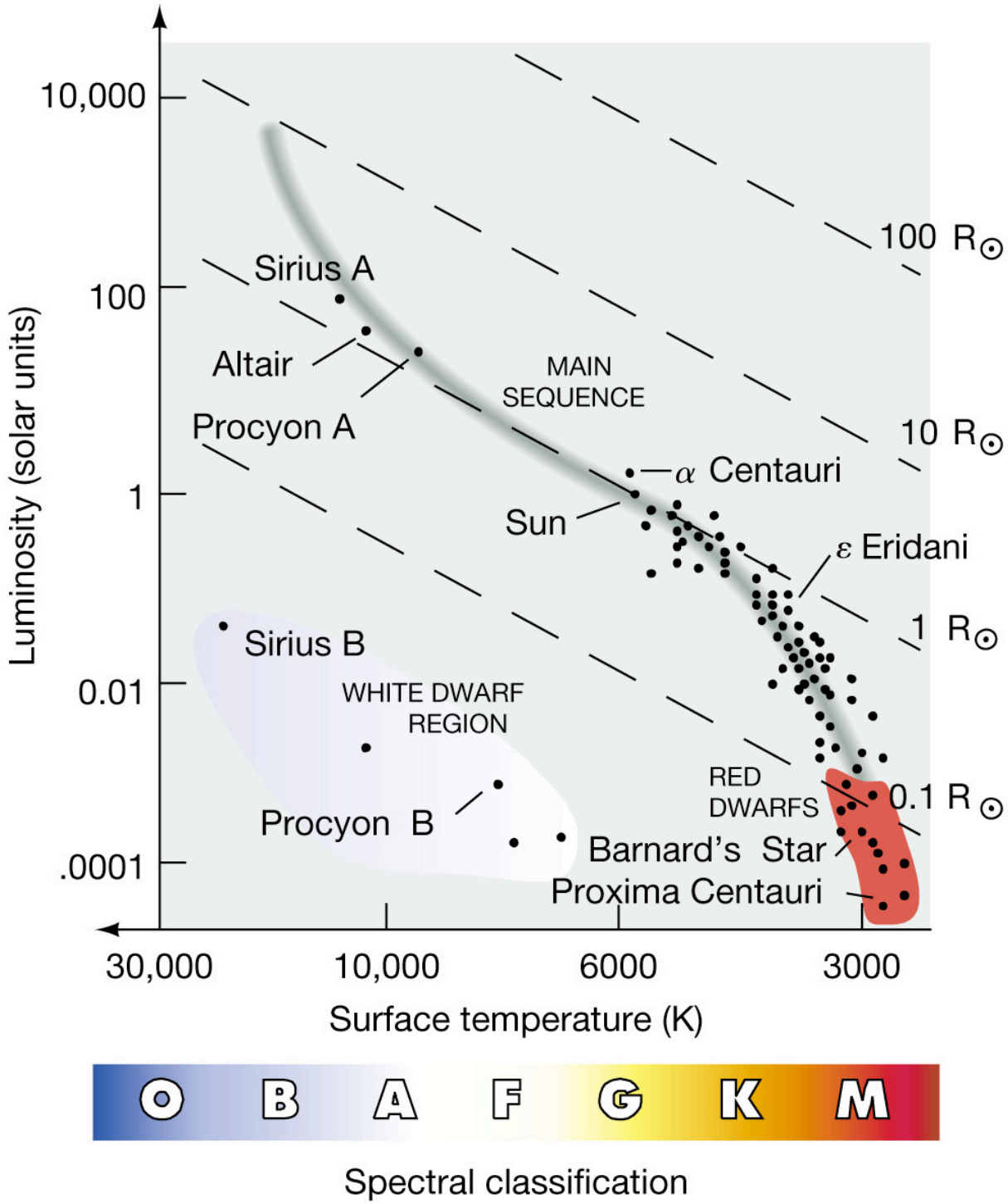


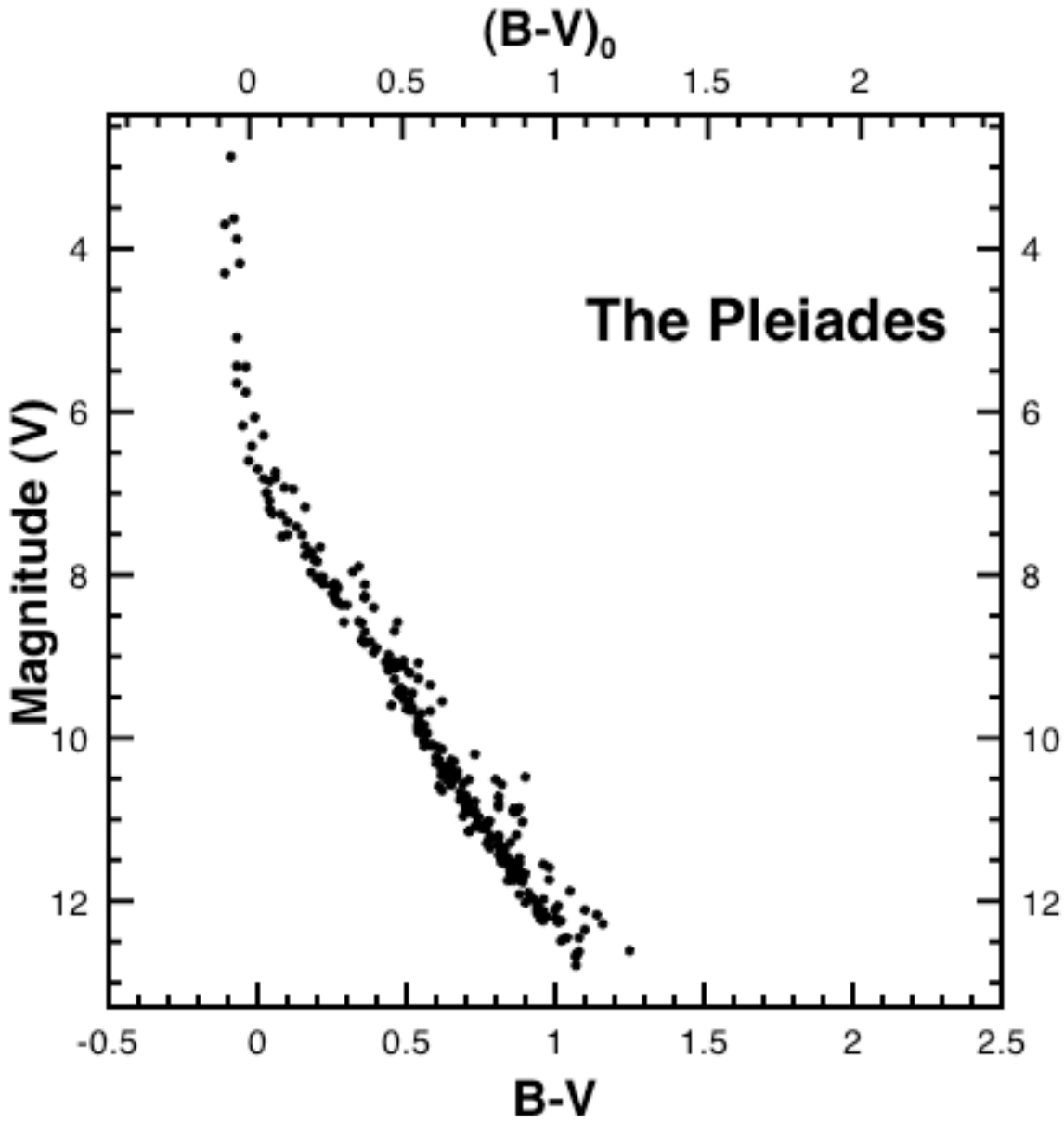
Palomar Digitized Sky Survey

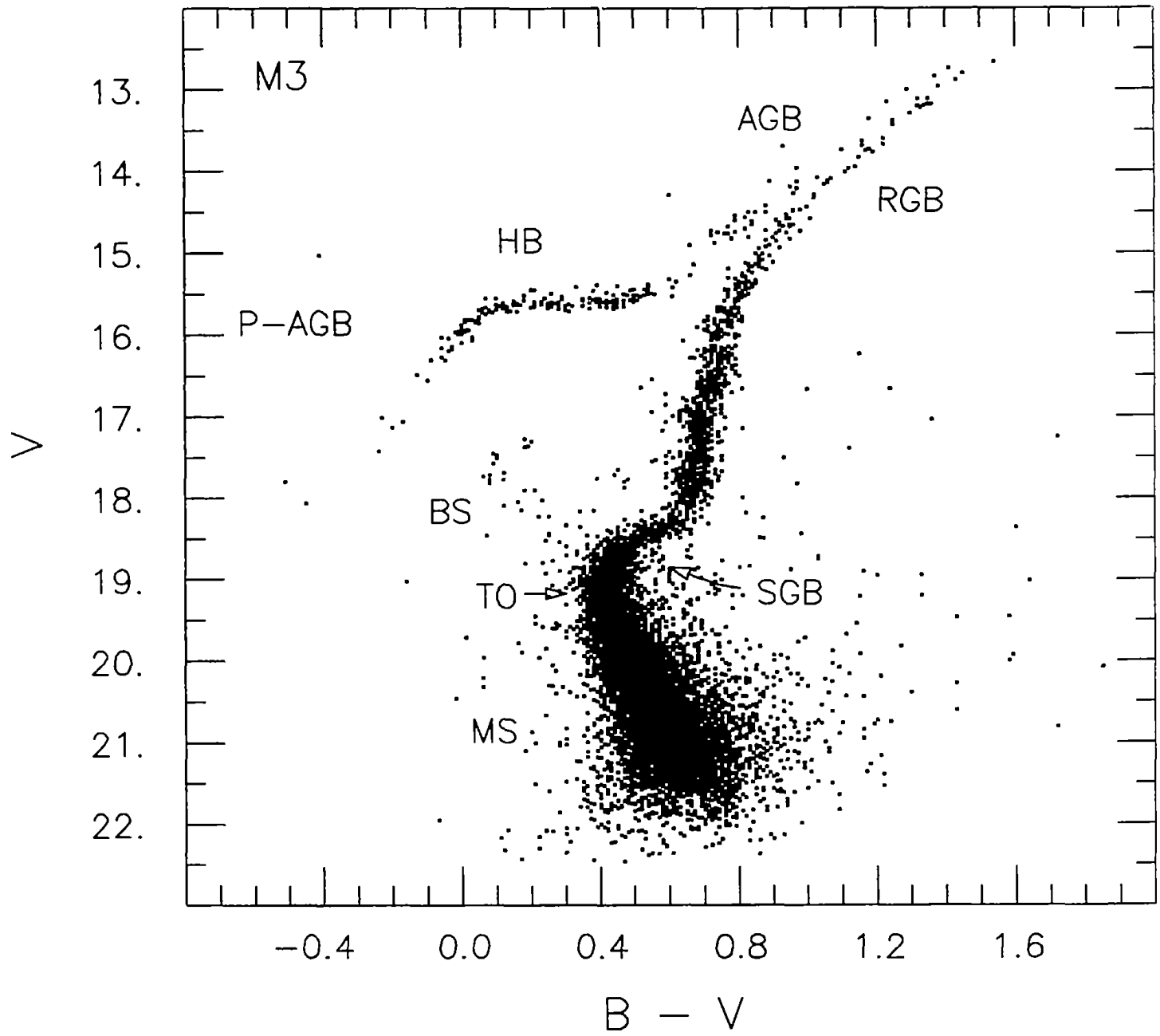
J.D. Kirkpatrick (IPAC/Caltech), I.N. Reid (Caltech), R.M. Cutri (IPAC/Caltech),
C.A. Beichman (IPAC/JPL/Caltech), J. Liebert (U of A), M.F. Skrutskie (UMass)

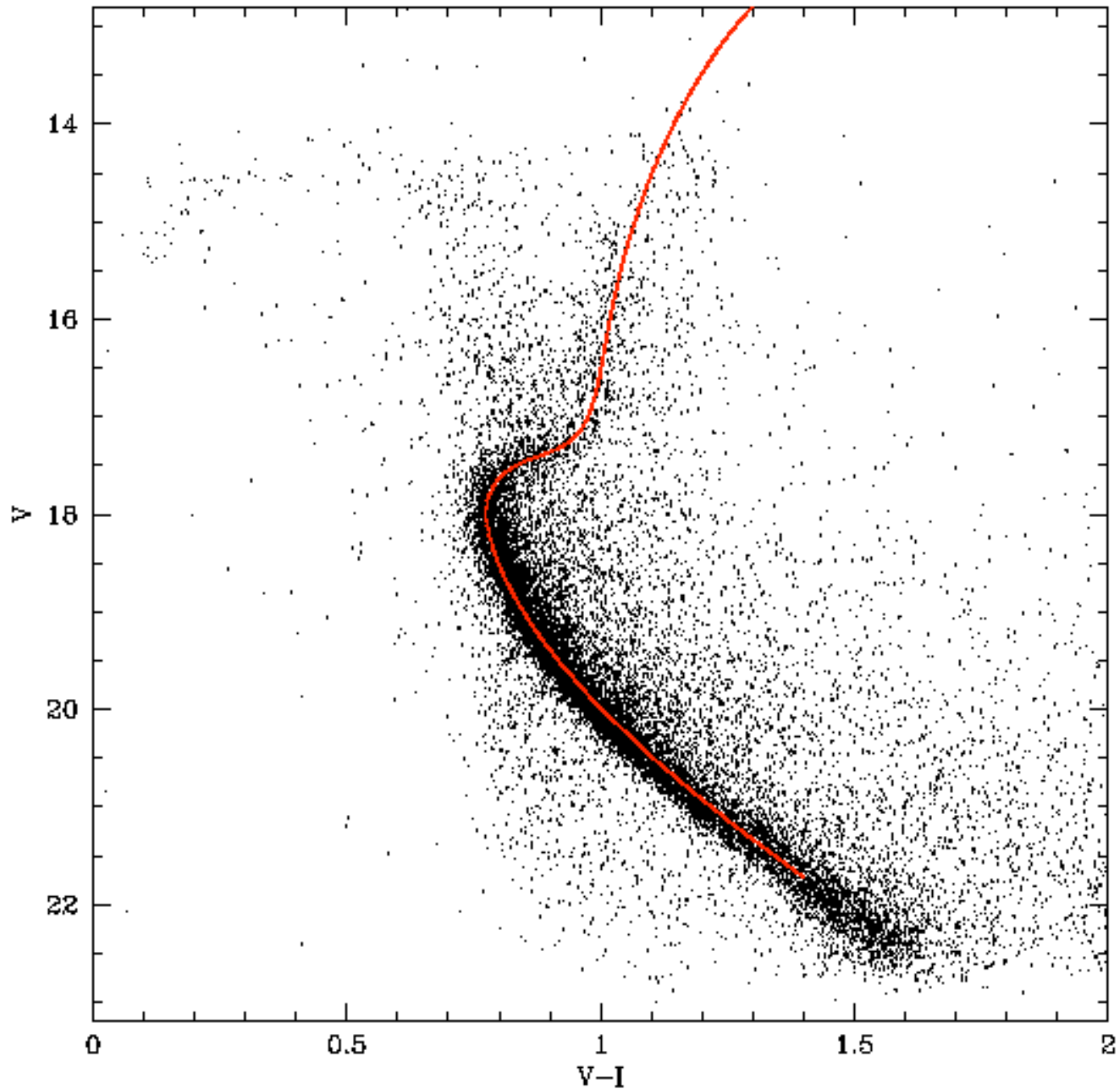
The 2MASS project is a collaboration between the University of Massachusetts and IPAC

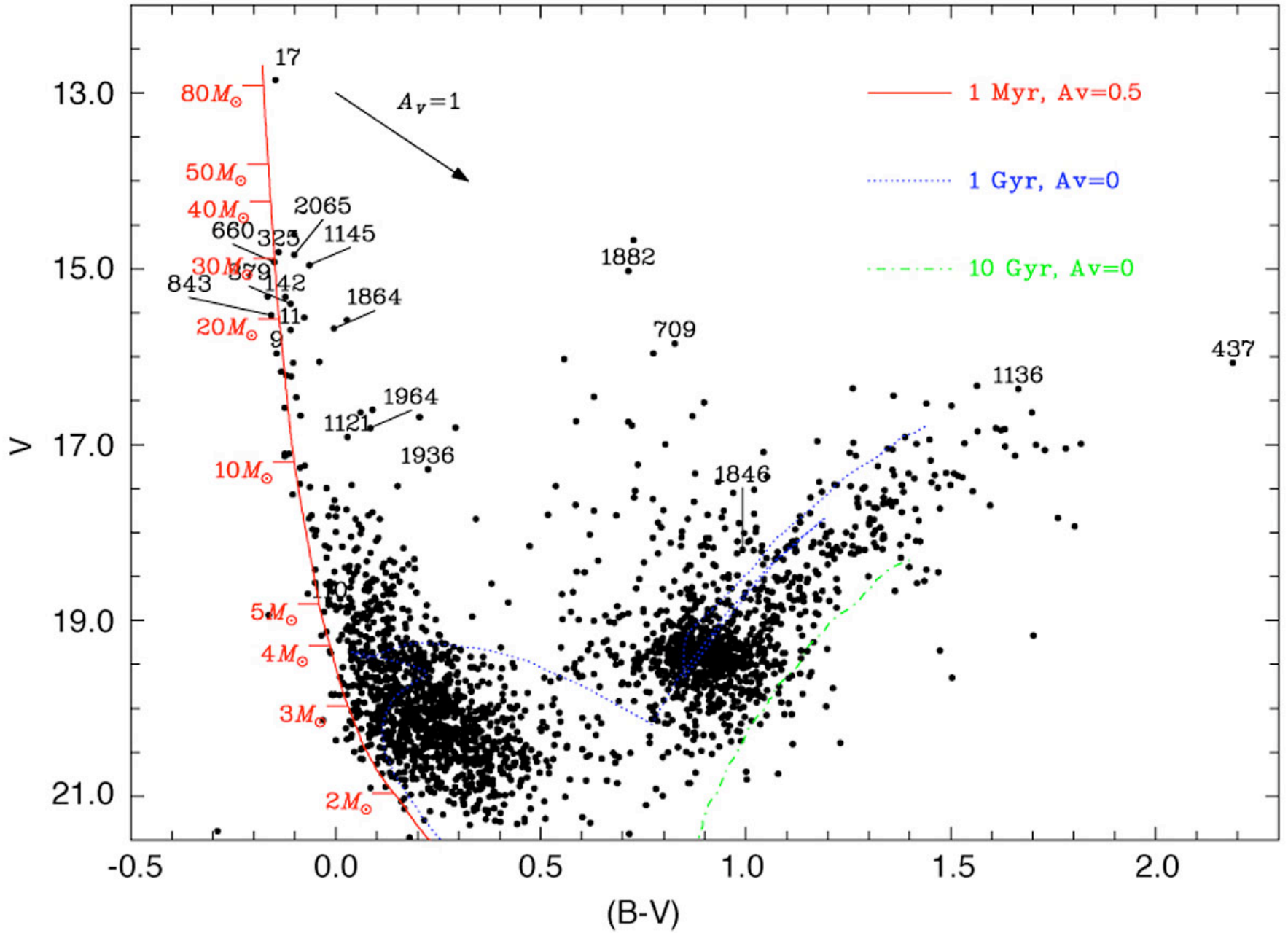

Spectral Class
O
B
A
F
G
K
M
30000K
10000K
7500K
6000K
5000K
4000K
3000K
(Temperature)
-10
100 000
10 000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.000 01
Luminosity
(Sun=1)
Absolute
Magnitude
-5
0
+5
+10
+15
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
0.0
+0.5
+1.0
+1.5
+2.0
Colour (B–V)
r powell


10,000
100
1
0.01
.0001
Luminosity (solar units)
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
Sirius A
Altair
Procyon A
MAIN SEQUENCE
α Centauri
Sun
ε Eridani
Sirius B
WHITE DWARF REGION
Procyon B
RED DWARFS
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification


(B-V)0
0
0.5
1
1.5
2
The Pleiades
Magnitude (V)
4
6
8
10
12
-0.5
0
0.5
1
1.5
2
2.5
B-V


M3
AGB
RGB
HB
P–AGB
BS
TO
SGB
MS
V
13.
14.
15.
16.
17.
18.
19.
20.
21.
22.
−0.4
0.0
0.4
0.8
1.2
1.6
B − V


14
16
18
20
22
V
0
0.5
1
1.5
2
V−I


17
80$M_\odot$
50$M_\odot$
40$M_\odot$
30$M_\odot$
20$M_\odot$
10$M_\odot$
5$M_\odot$
4$M_\odot$
3$M_\odot$
2$M_\odot$
A_v=1
2065
660
325
1145
379
142
843
11
9
1864
1882
709
437
1136
1964
1121
1936
1846
10
1 Myr, Av=0.5
1 Gyr, Av=0
10 Gyr, Av=0
13.0
15.0
17.0
19.0
21.0
V
-0.5
0.0
0.5
1.0
1.5
2.0
(B-V)