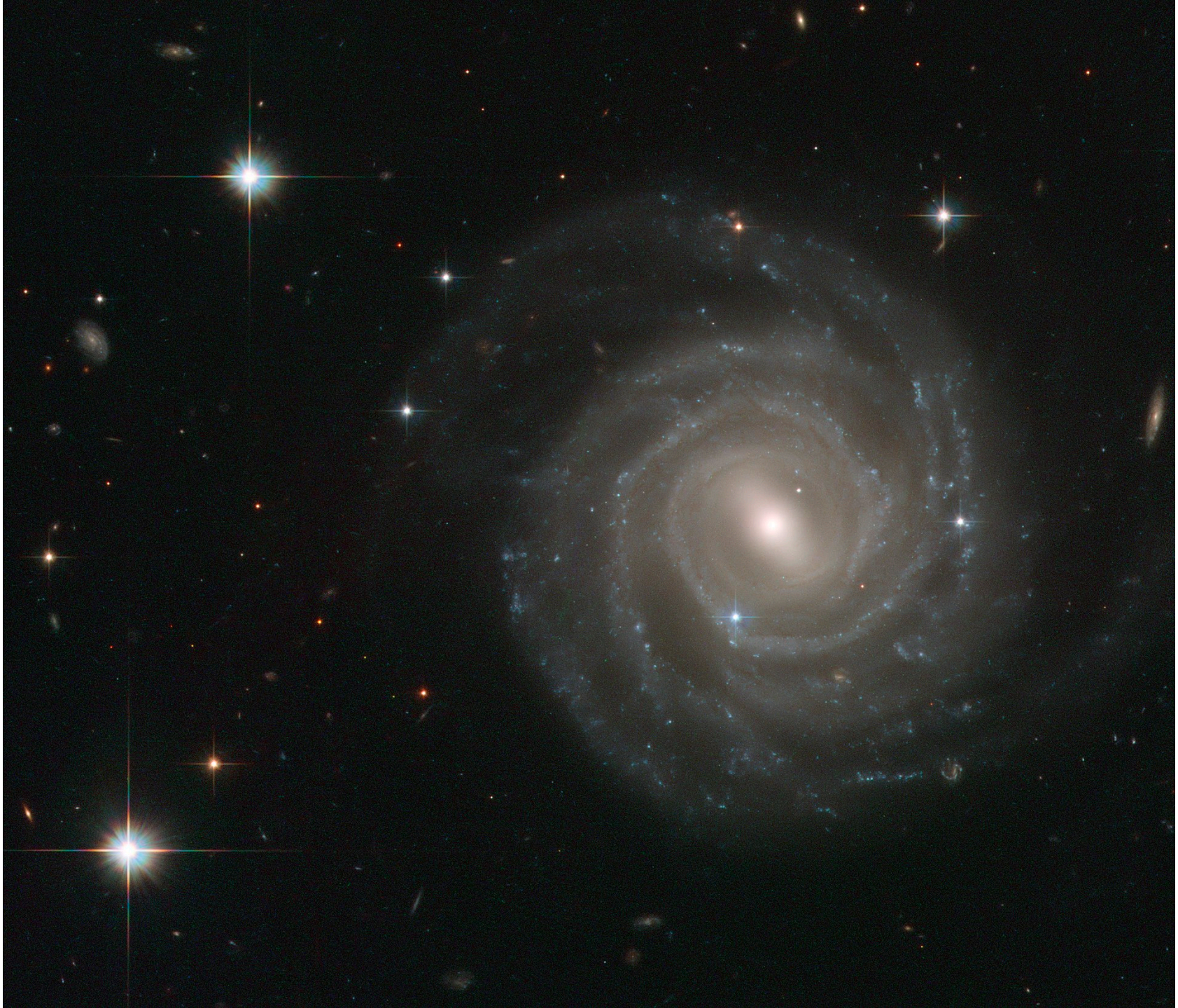
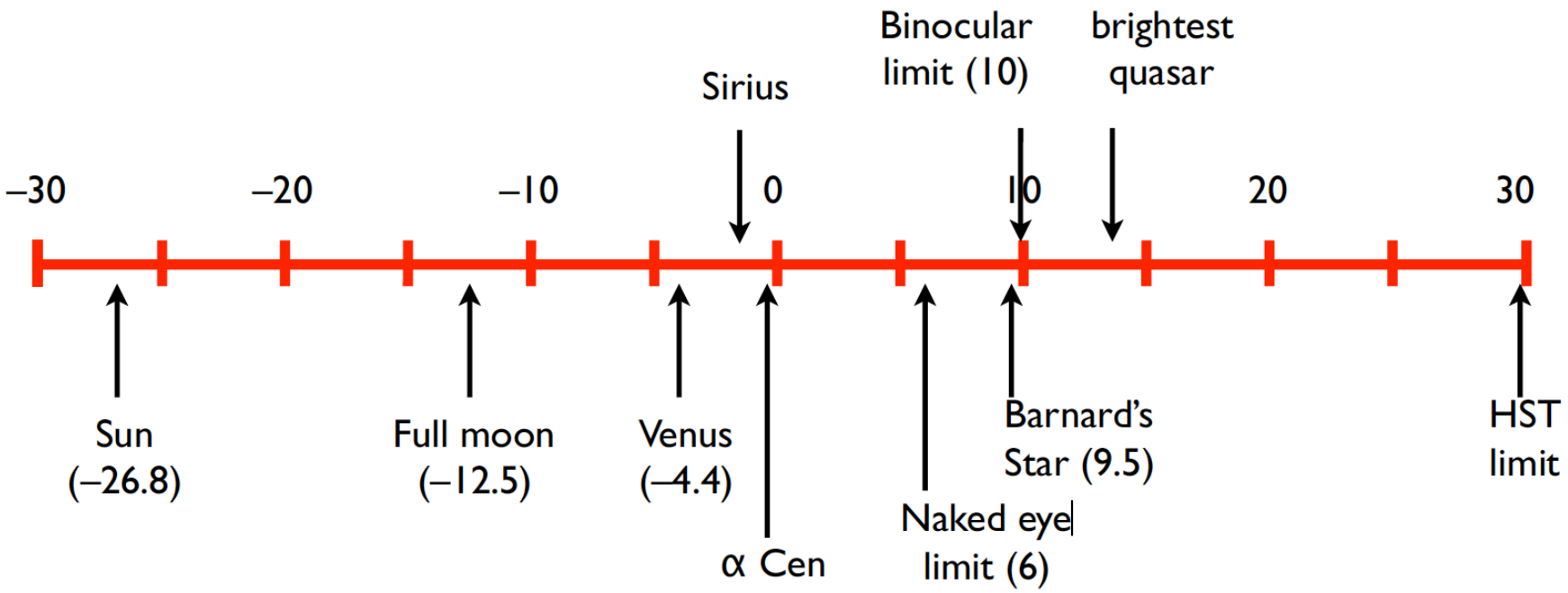

Stars:
The Building Blocks
of the Universe



What parameters of a star would you want to measure?

- Brightness: easy; luminosity requires distance
- Radius: direct measurement hard; Luminosity+Temperature
- Age: hard to measure
- Distance: hard before April 2018
- Temperature: easy
- Density: if you know M+R
- Mass: hard to measure! (sometimes easy in some binaries)
- Magnetic field!:
- Proper motion: easy (follows from distance)
- Composition: easy or hard
- Rotation rate: easy or hard

Magnitudes (how bright are stars)

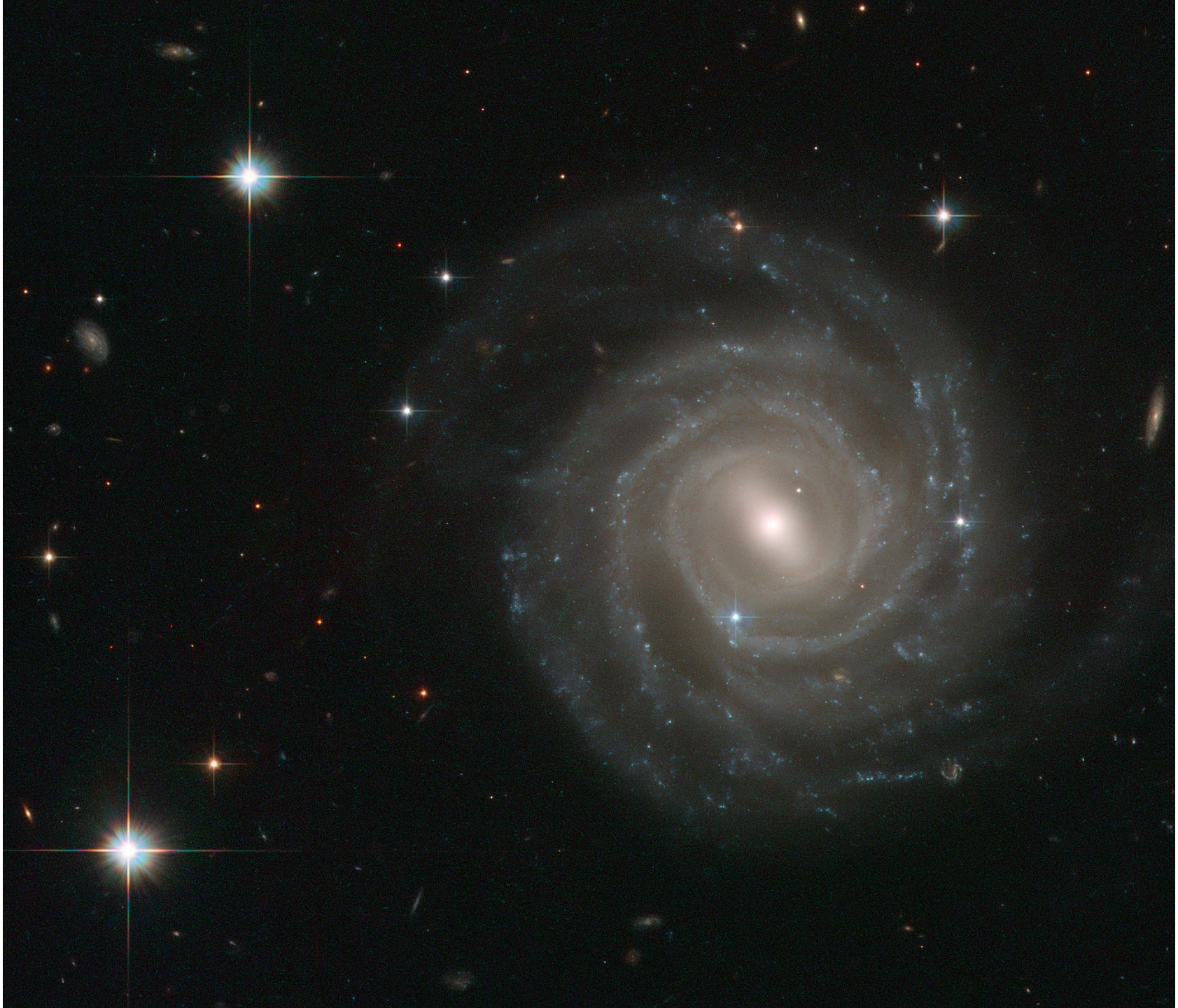


- Brightness: how bright are they at Earth
- Luminosity: how much energy are they emitting?

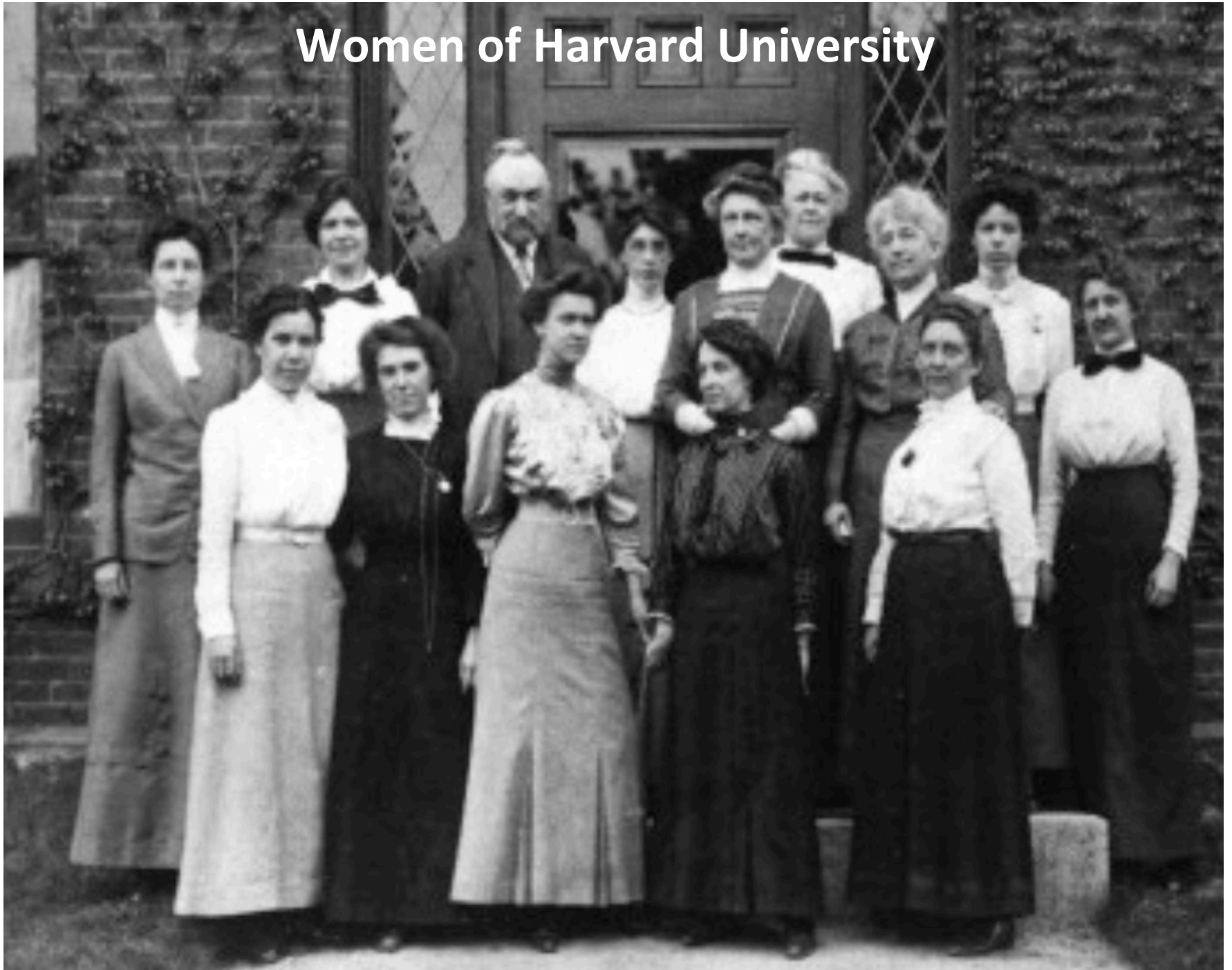
star	apparent mag
Sirius	–1.50
Canopus	–0.73
Alpha Centauri	+0.10
Vega	+0.04
Arcturus	0
Capella	+0.05
Rigel	+0.08
Procyon	+0.34
Betelgeuse	+0.41
Achernar	+0.47

Sky is 2D!

Distance is usually uncertain

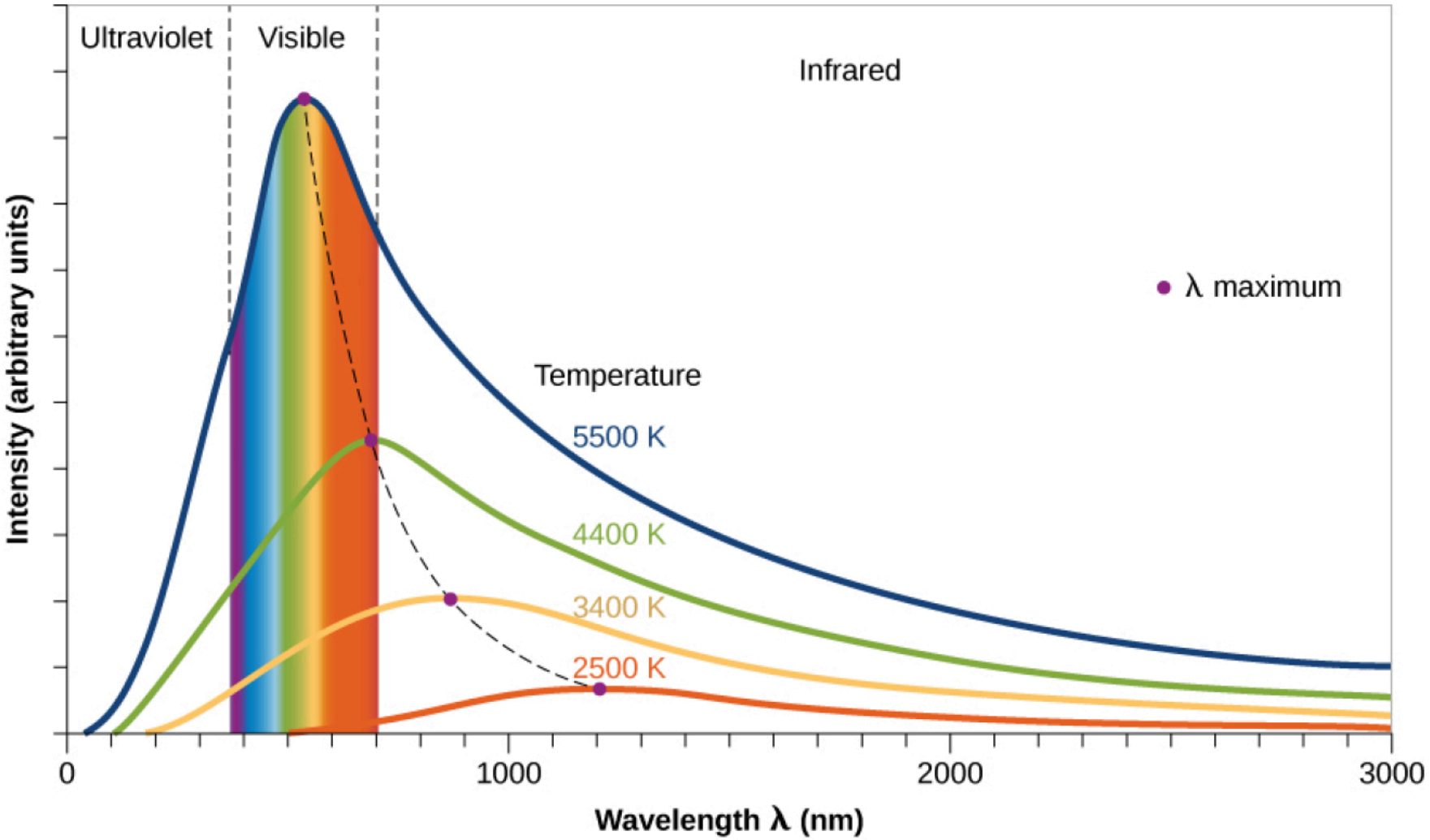


Women of Harvard University

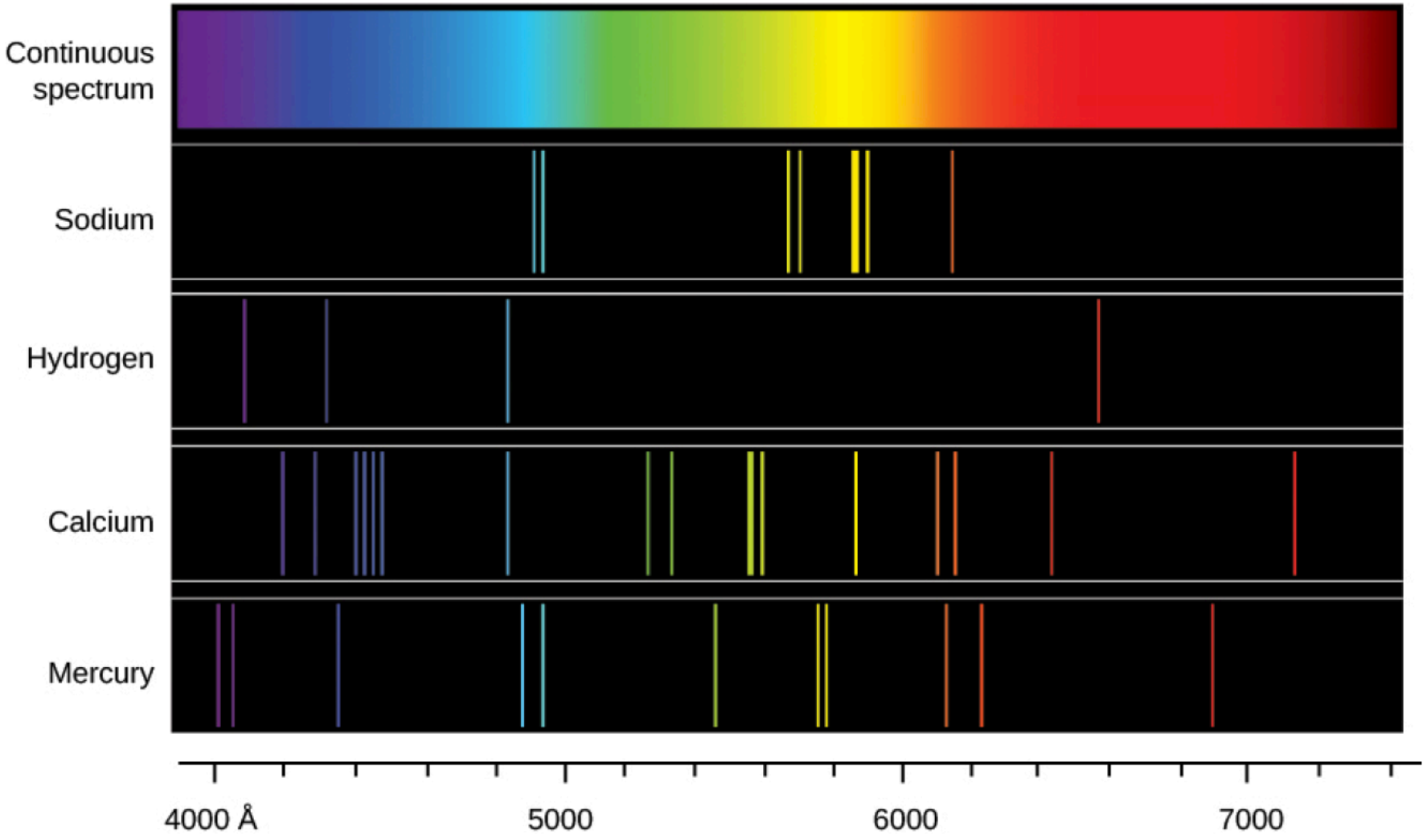


Blackbody emission: hotter things emit at higher energies (=shorter wavelengths)

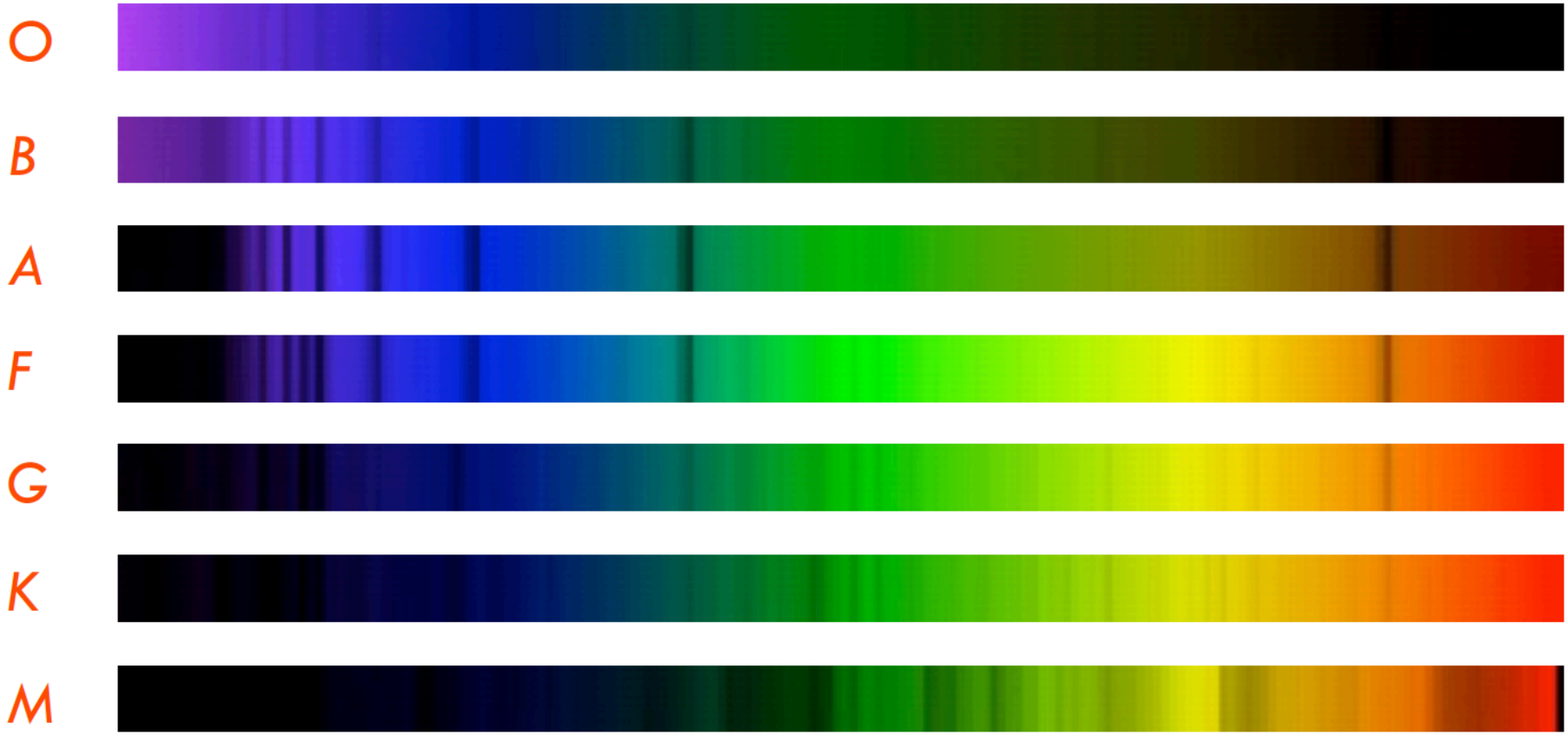
Peak of blackobody: $\lambda_{\max} \cdot T = 0.288\ \mathrm{cm} \cdot \mathrm{K}$

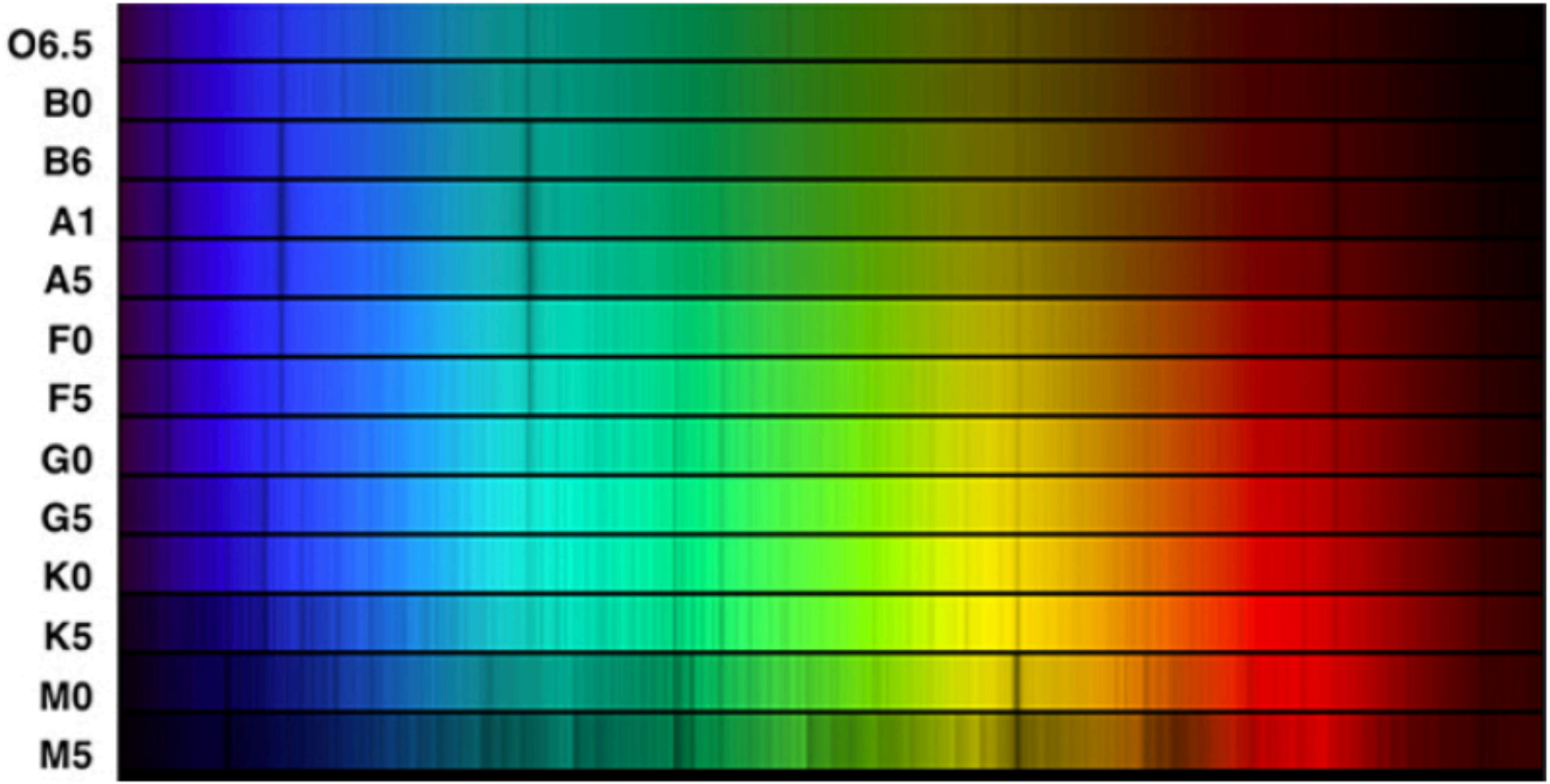


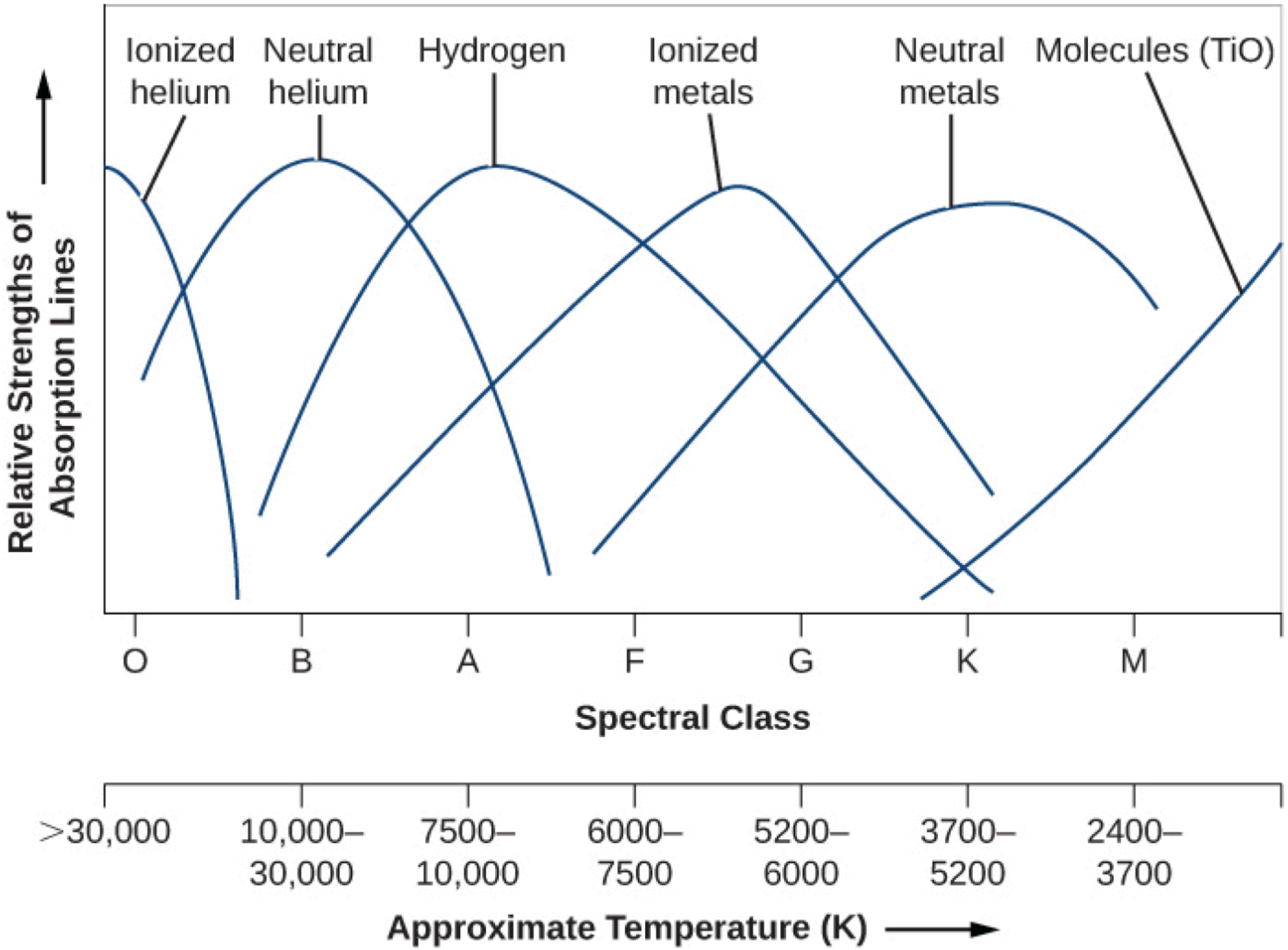
Star Color	Approximate Temperature	Example
Blue	25,000 K	Spica
White	10,000 K	Vega
Yellow	6000 K	Sun
Orange	4000 K	Aldebaran


Continuous spectrum
Sodium
Hydrogen
Calcium
Mercury
4000 Å
5000
6000
7000

Spectral Type




O6.5
B0
B6
A1
A5
F0
F5
G0
G5
K0
K5
M0
M5


Ionized helium
Neutral helium
Hydrogen
Ionized metals
Neutral metals
Molecules (TiO)
Relative Strengths of Absorption Lines
O
B
A
F
G
K
M
Spectral Class
>30,000
10,000–30,000
7500–10,000
6000–7500
5200–6000
3700–5200
2400–3700
Approximate Temperature (K)

Type	Colour	Main characteristics
O	Blue	Ionised helium and metals; weak hydrogen
B	Blue	Neutral helium, ionised metals, stronger hydrogen
A	Blue	Hydrogen dominant,singly-ionised metals
F	Blue to white	Hydrogen weaker, neutral and singly-ionised metals
G	White to yellow	Singly-ionised calcium, hydrogen weaker, neutral metals
K	Orange to red	Neutral metals, molecular lines begin to appear
M	Red	Titanium oxide molecular lines dominate, neutral metals

The Abundance of Elements in the Sun

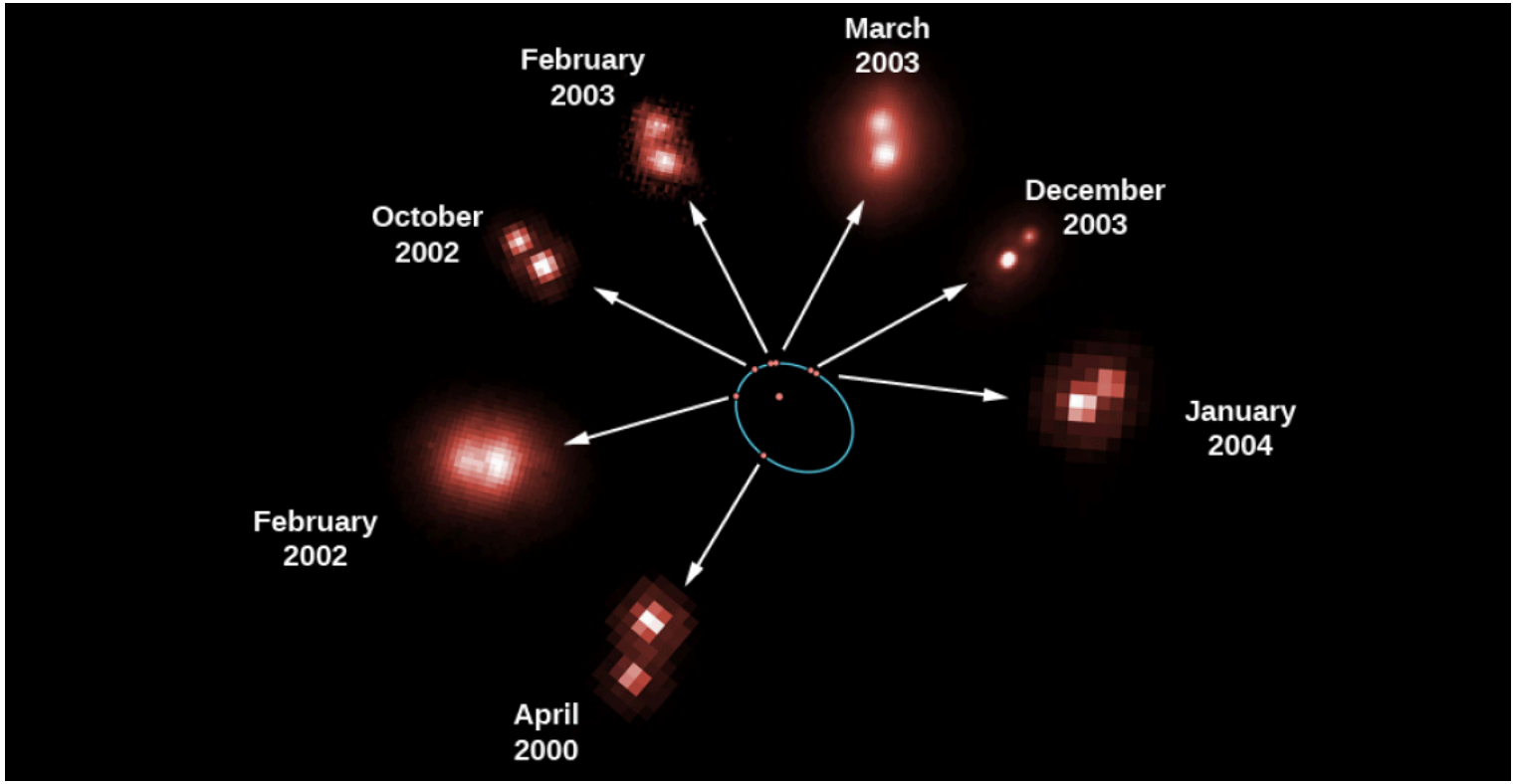
Element	Percentage by Number of Atoms	Percentage By Mass
Hydrogen	92.0	73.4
Helium	7.8	25.0
Carbon	0.02	0.20
Nitrogen	0.008	0.09
Oxygen	0.06	0.80
Neon	0.01	0.16
Magnesium	0.003	0.06
Silicon	0.004	0.09
Sulfur	0.002	0.05
Iron	0.003	0.14

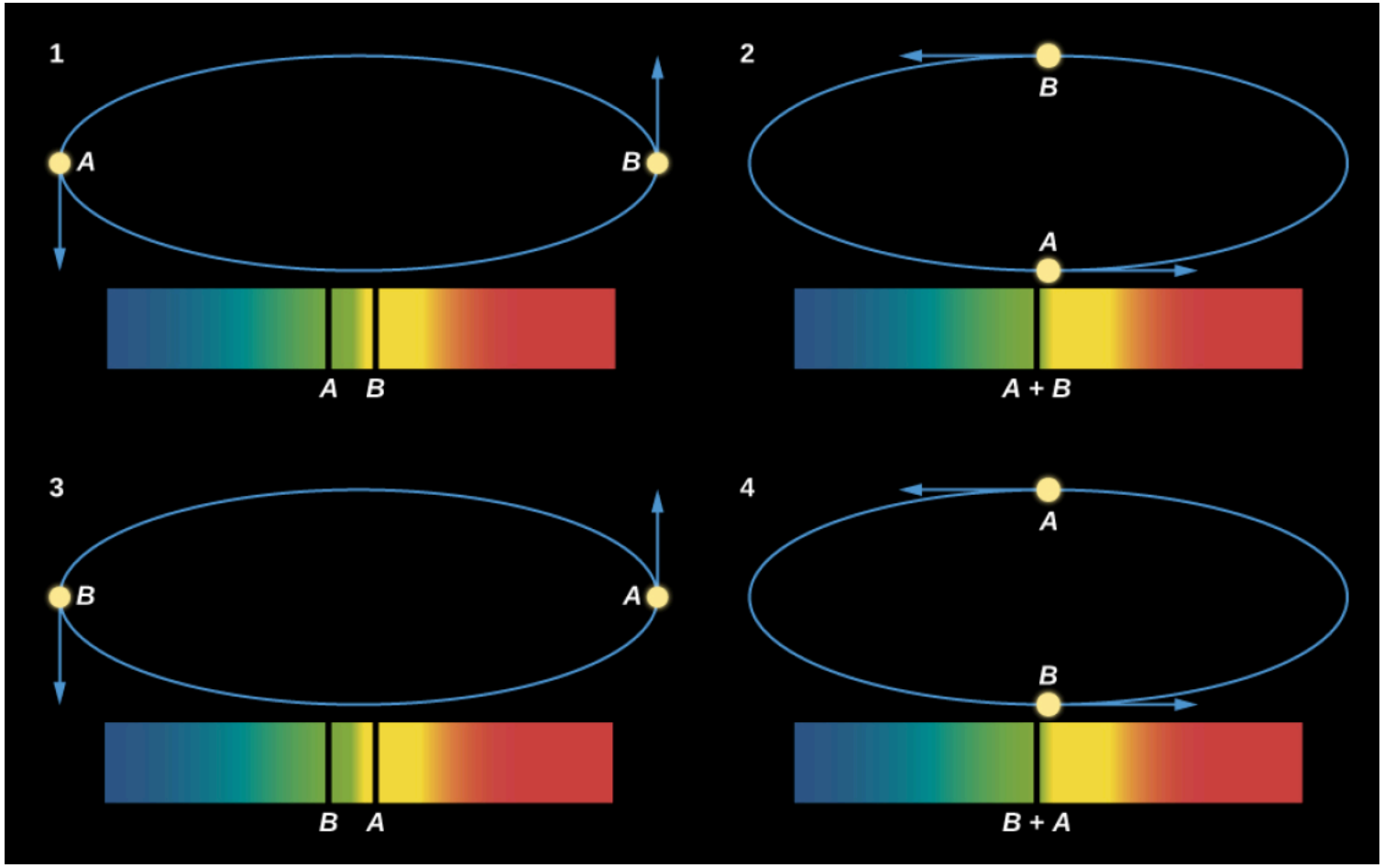
Stars within 21 Light-Years of the Sun

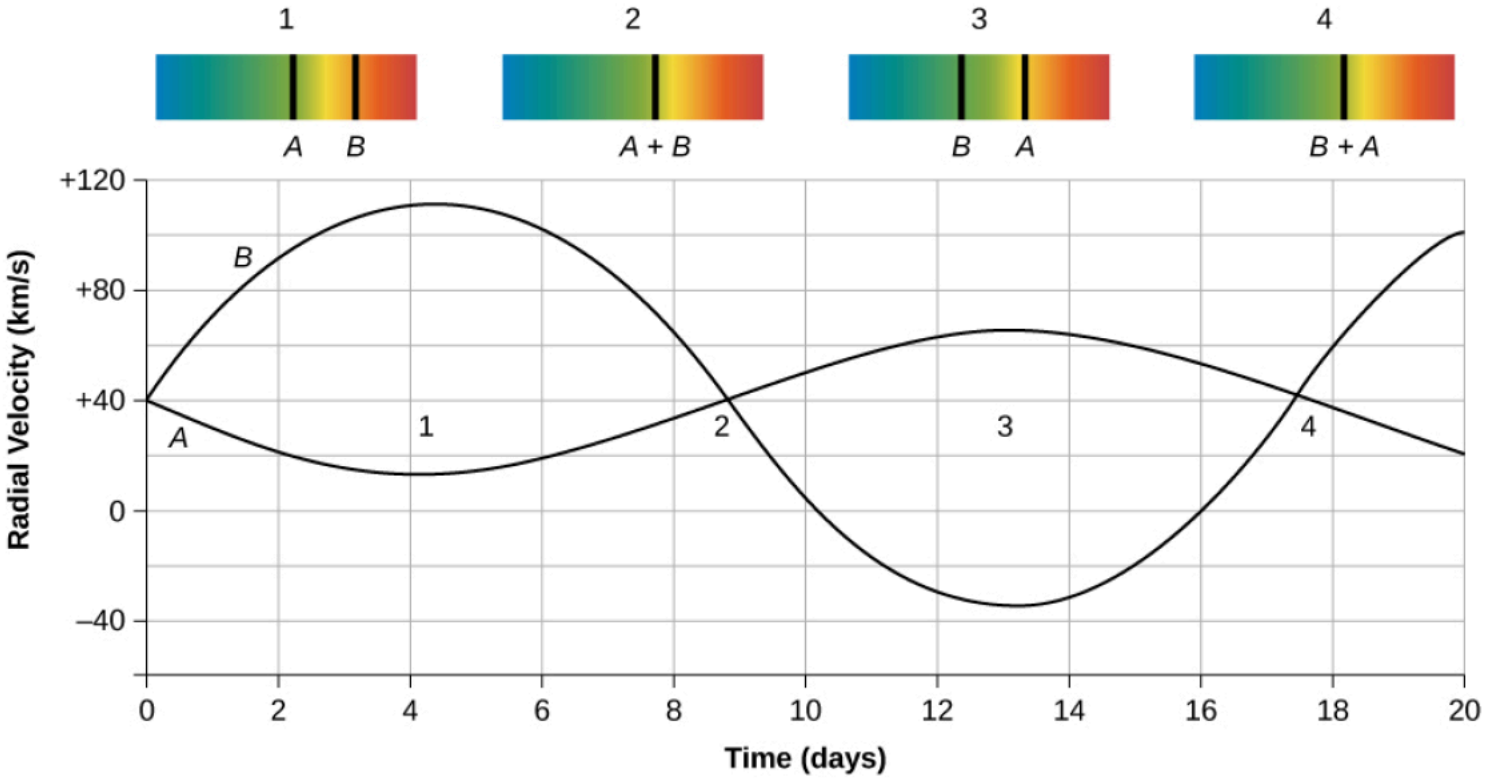
Spectral Type	Number of Stars
A	2
F	1
G	7
K	17
M	94
White dwarfs	8
Brown dwarfs	33

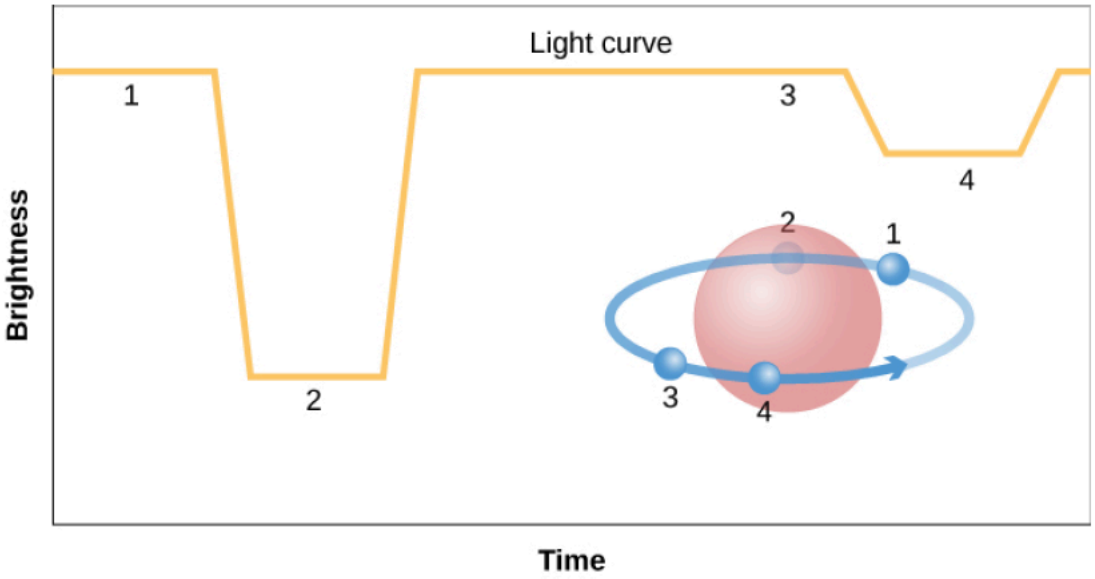
Measuring the Characteristics of Stars

Characteristic	Technique
Surface temperature	1. Determine the color (very rough). 2. Measure the spectrum and get the spectral type.
Chemical composition	Determine which lines are present in the spectrum.
Luminosity	Measure the apparent brightness and compensate for distance.
Radial velocity	Measure the Doppler shift in the spectrum.
Rotation	Measure the width of spectral lines.
Mass	Measure the period and radial velocity curves of spectroscopic binary stars.
Diameter	1. Measure the way a star's light is blocked by the Moon. 2. Measure the light curves and Doppler shifts for eclipsing binary stars.

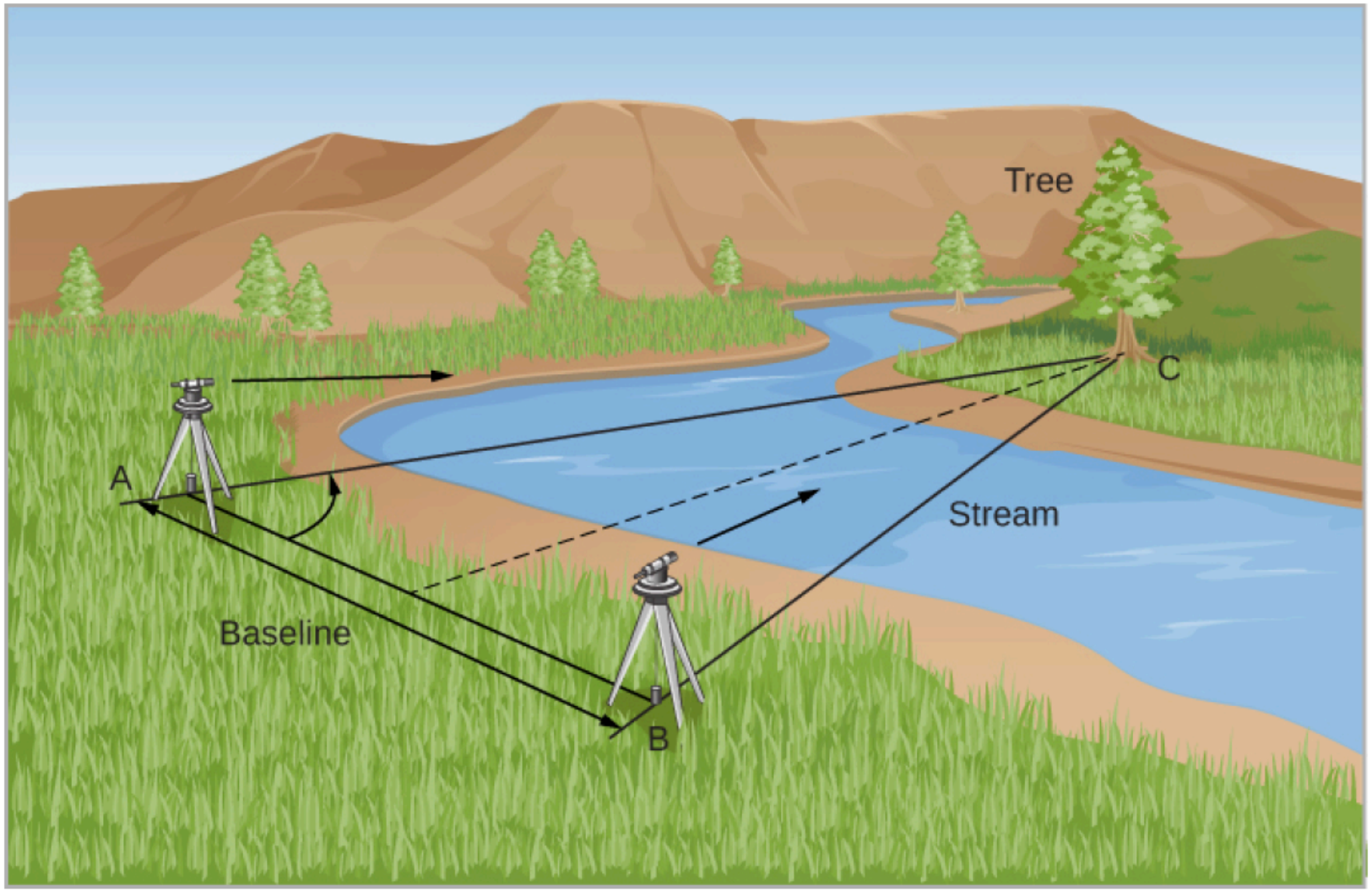

March
2003
February
2003
October
2002
December
2003
January
2004
February
2002
April
2000


1
A
B
A B
2
B
A
A + B
3
B
A
B A
4
A
B
B + A

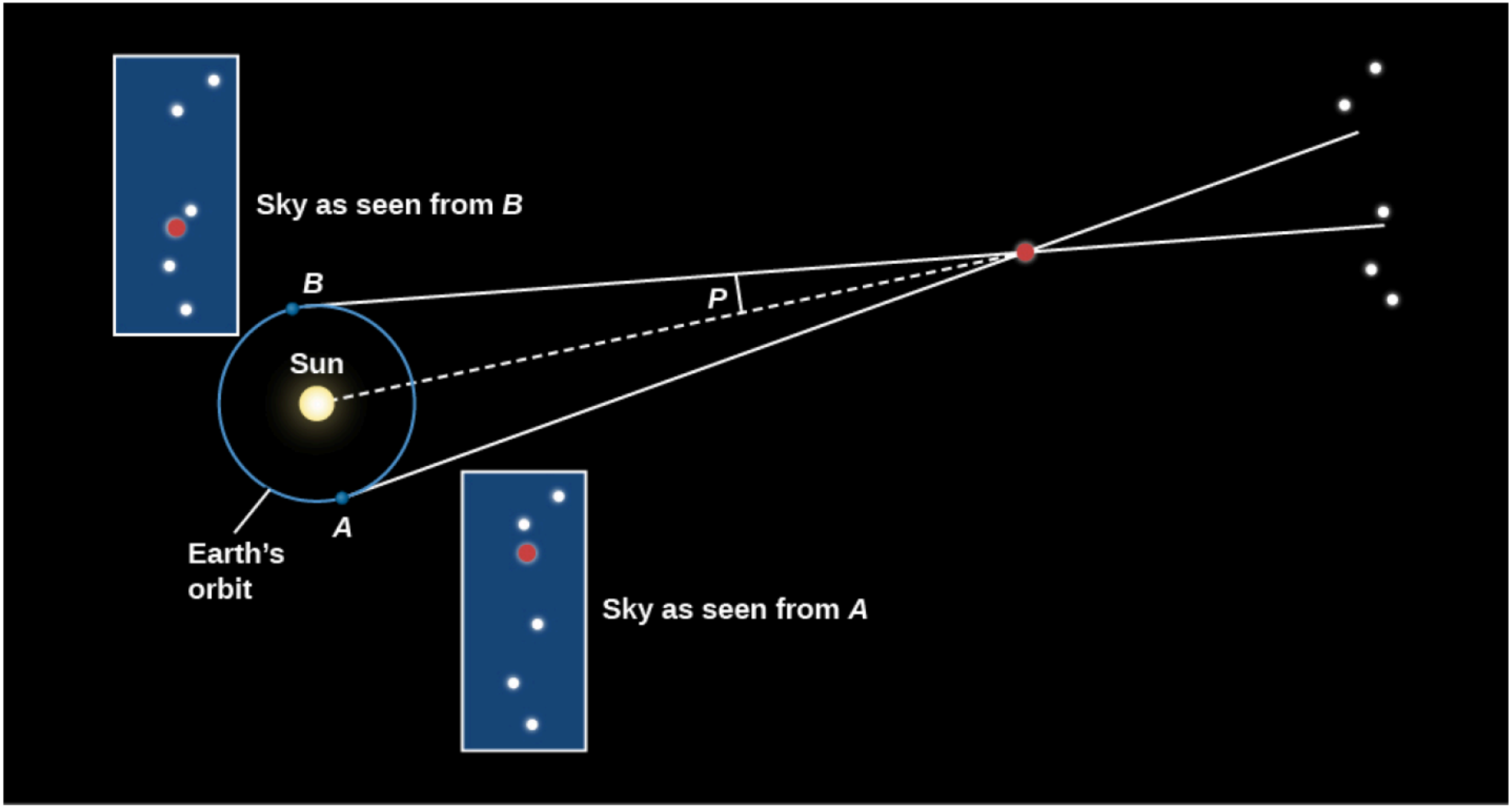

1
2
3
4
A B
A + B
B A
B + A
+120
+80
+40
0
–40
B
A
1
2
3
4
Radial Velocity (km/s)
0 2 4 6 8 10 12 14 16 18 20
Time (days)


Light curve
1
2
3
4
Brightness
Time
1
2
3
4

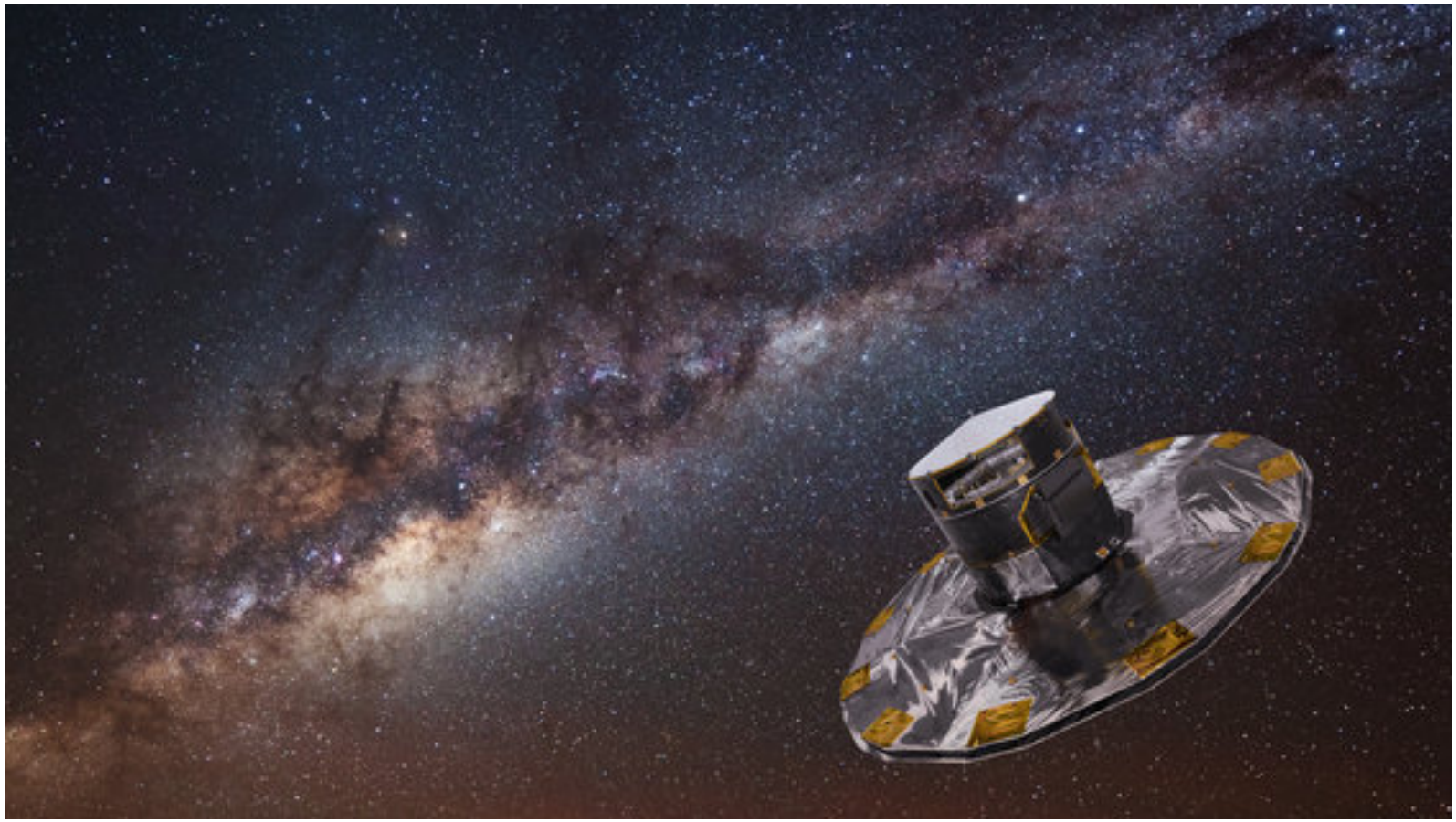
Distance: parallax

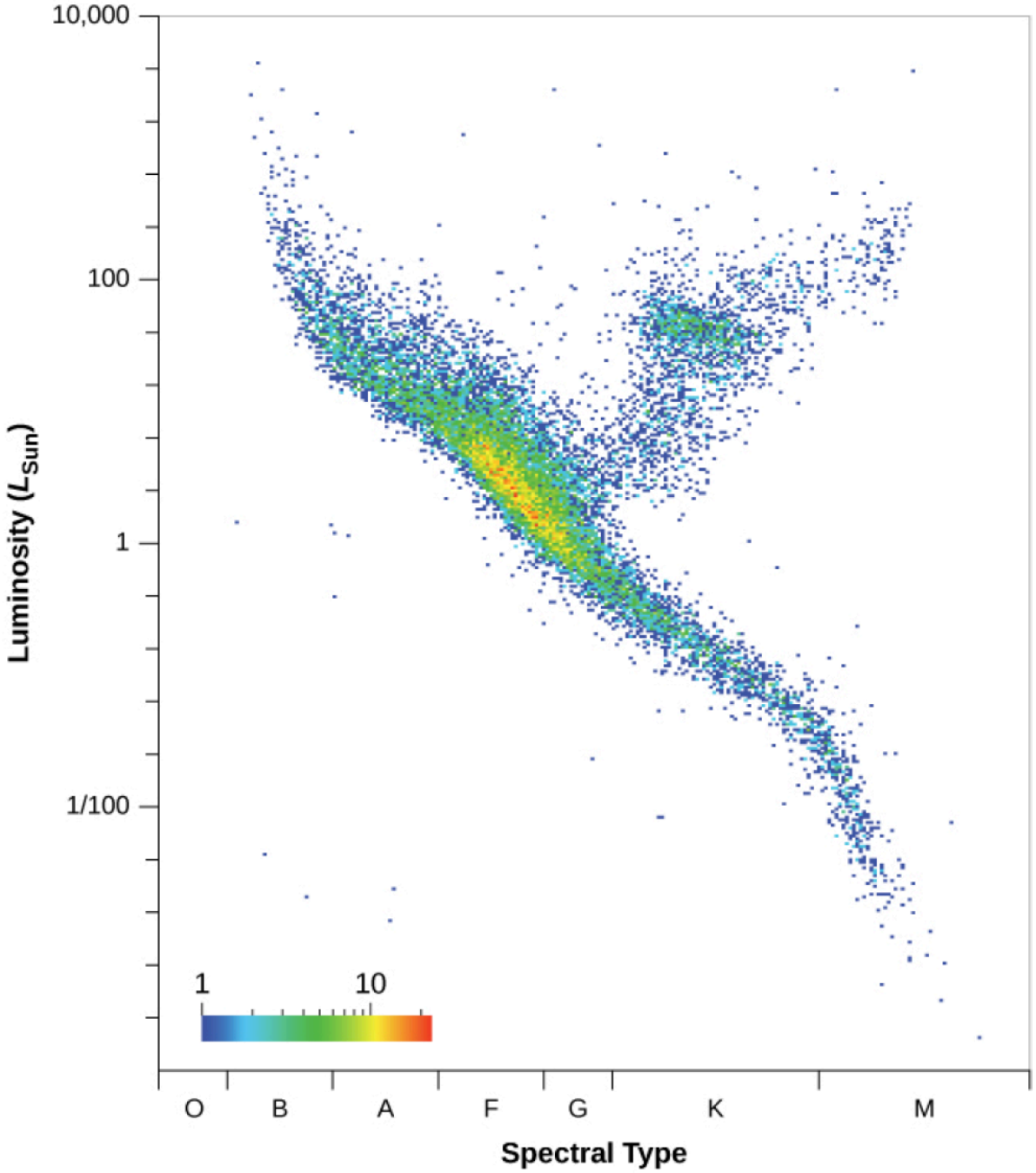


Distance: parallax

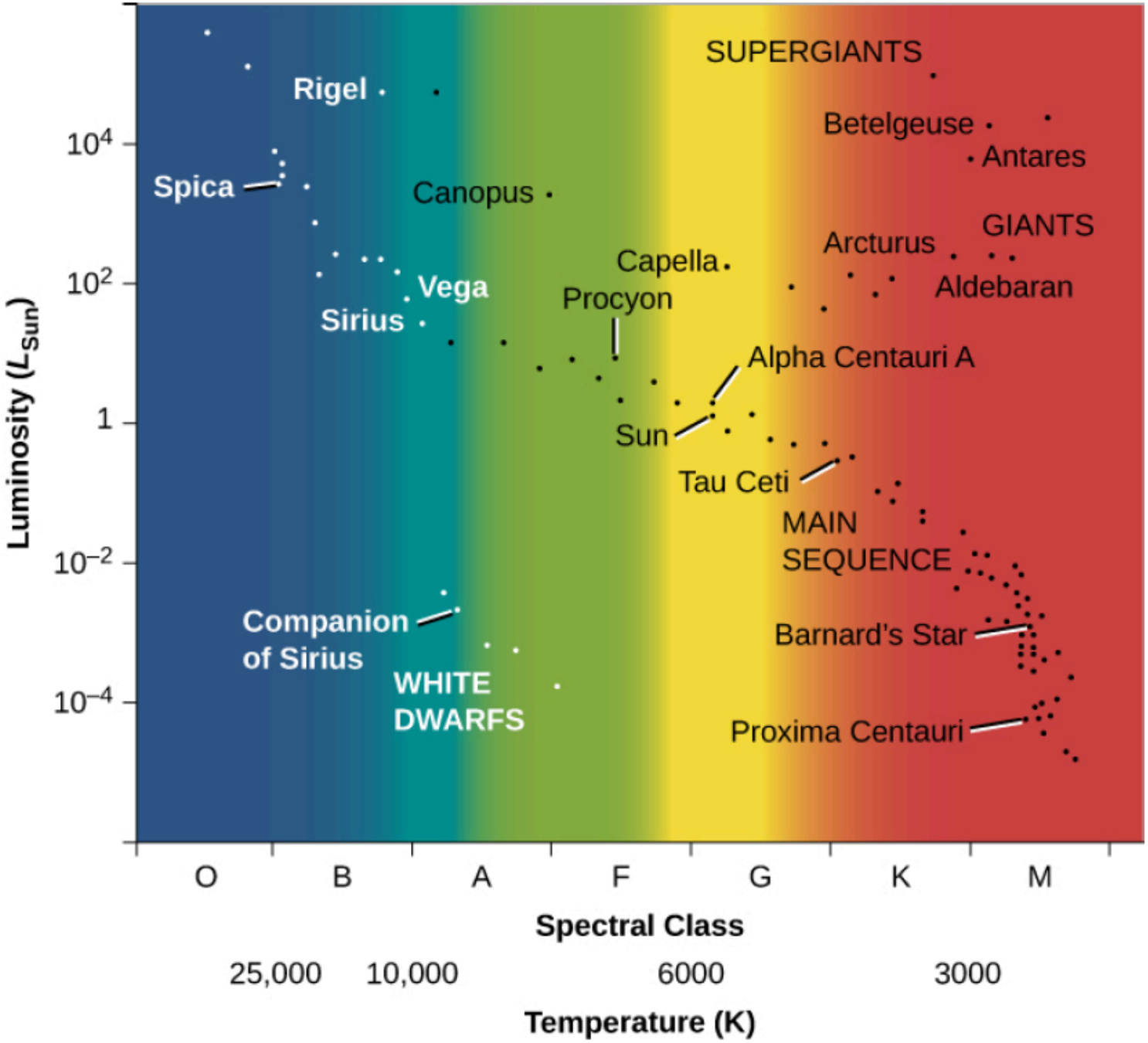


Gaia satellite:
distances to ~1 billion stars!



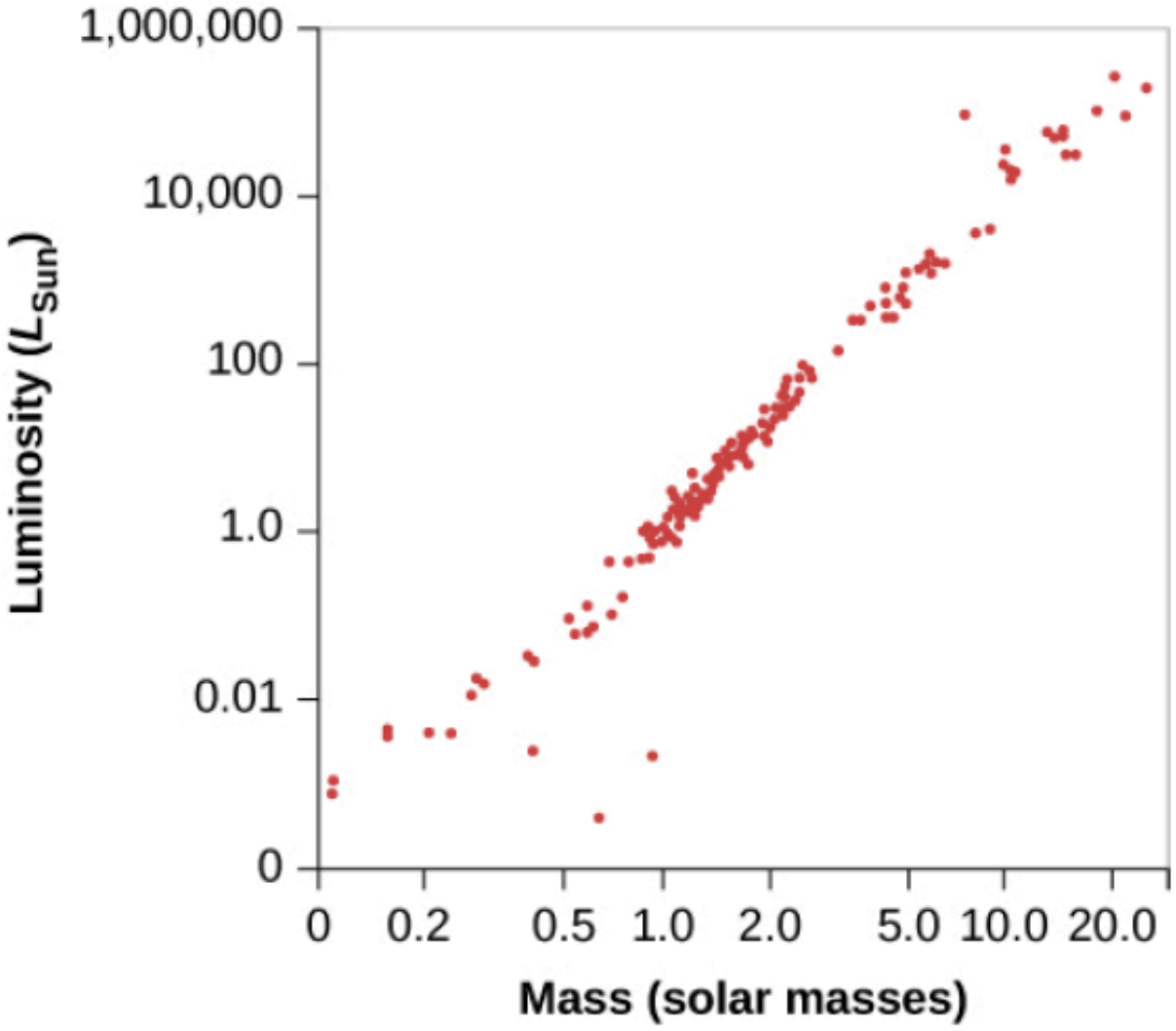


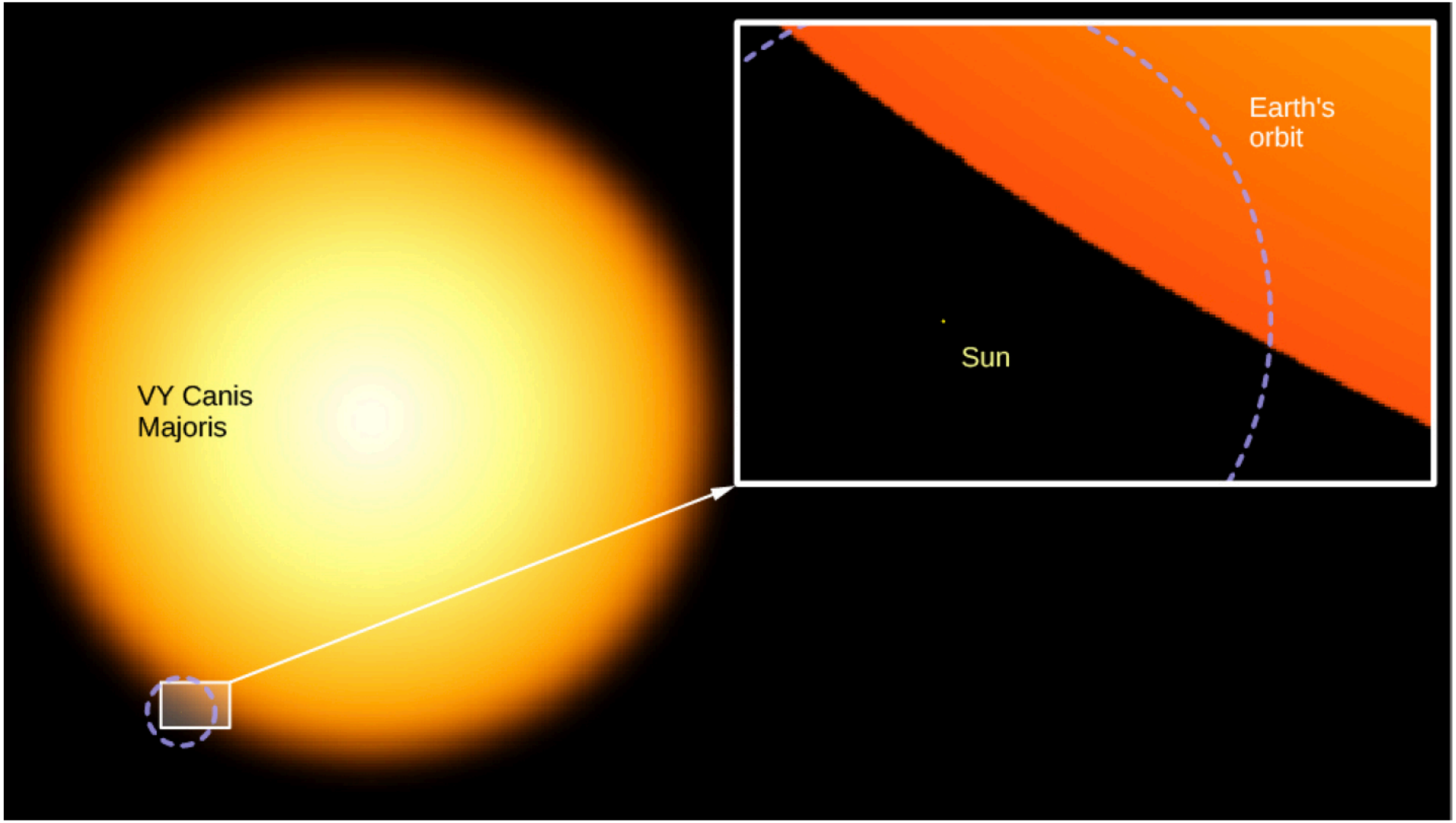
Before distances: use stars in a single cluster


SUPERGIANTS
Rigel
Betelgeuse
Antares
Spica
Canopus
GIANTS
Arcturus
Capella
Vega
Procyon
Aldebaran
Sirius
Alpha Centauri A
Sun
Tau Ceti
MAIN
SEQUENCE
Companion
of Sirius
Barnard's Star
WHITE
DWARFS
Proxima Centauri
Luminosity (L_{Sun})
10^4
10^2
1
10^{-2}
10^{-4}
O
B
A
F
G
K
M
Spectral Class
25,000
10,000
6000
3000
Temperature (K)

Characteristics of Main-Sequence Stars

Spectral Type	Mass (Sun = 1)	Luminosity (Sun = 1)	Temperature	Radius (Sun = 1)
O5	40	7×10^5	40,000 K	18
B0	16	2.7×10^5	28,000 K	7
A0	3.3	55	10,000 K	2.5
F0	1.7	5	7500 K	1.4
G0	1.1	1.4	6000 K	1.1
K0	0.8	0.35	5000 K	0.8
M0	0.4	0.05	3500 K	0.6


1,000,000
10,000
100
1.0
0.01
0
Luminosity (L_{Sun})
0
0.2
0.5
1.0
2.0
5.0
10.0
20.0
Mass (solar masses)


Earth's
orbit
Sun
VY Canis
Majoris

star	apparent mag	distance (pc)
Sirius	–1.50	2.6
Canopus	–0.73	96
Alpha Centauri	+0.10	1.3
Vega	+0.04	7.9
Arcturus	0	11.6
Capella	+0.05	13.1
Rigel	+0.08	184
Procyon	+0.34	3.5
Betelgeuse	+0.41	131
Achernar	+0.47	45

star	apparent mag	distance (pc)
Proxima Centauri	11.5	1.3
Alpha Centauri	0.1	1.3
Barnard's Star	9.5	1.8
Wolf 359	13.5	2.3
Lalande 21185	7.5	2.5
Sirius	–1.5	2.6
Luyten 726–8	12.5	2.7
Ross 154	10.6	2.9
Ross 248	12.2	3.2
Epsilon Eridani	3.7	3.3

Known star systems within 5.0 parsecs (16.3 light-years)

Designation		Distance[6] (light-years (±err))	Stellar class	Apparent magnitude (m_V[5] or m_J)	Absolute magnitude (M_V[5] or M_J)	Epoch J2000.	
System	Star					Right ascension[5]	Decl
Solar System	Sun	0.000 0158	G2V[5]	−26.74 #	4.85	N/A	
Alpha Centauri (Rigil Kentaurus)	Proxima Centauri (V645 Centauri)	4.2441 ±0.0011	M5.5Ve	11.09	15.53	$14^h\ 29^m\ 43.0^s$	−62
	α Centauri A (HD 128620)	4.3650 ±0.0068	G2V[5]	0.01 #	4.38	$14^h\ 39^m\ 36.5^s$	−60
	α Centauri B (HD 128621)		K1V[5]	1.34 #	5.71	$14^h\ 39^m\ 35.1^s$	−60
Barnard's Star (BD+04°3561a)		5.9577 ±0.0032	M4.0Ve	9.53	13.22	$17^h\ 57^m\ 48.5^s$	+04
Luhman 16 (WISE 1049–5319) §	Luhman 16A §	6.5029 ±0.0011	L8±1[12]	10.7 J	14.2 J	$10^h\ 49^m\ 15.57^s$	−53
	Luhman 16B §		T1±2[12]				
WISE 0855–0714 §		7.26 ±0.13[16]	Y2	25.0 J		$08^h\ 55^m\ 10.83^s$	−07
Wolf 359 (CN Leonis)		7.856 ±0.031	M6.0V[5]	13.44	16.55	$10^h\ 56^m\ 29.2^s$	+07
Lalande 21185 (BD+36°2147)		8.307 ±0.014	M2.0V[5]	7.47	10.44	$11^h\ 03^m\ 20.2^s$	+35

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	Luhman 16B §		T				
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Brown dwarfs: don’t burn H!