Spectral types and colors

a) Values for the Sun

Spectral Type = G2 V

Color = yellow-white (qualitatively), B/V = 0.55 (flux ratio). (B-V=0.65 actual color index).

b) Range of values for other stars

Spectral types range from 0 to M

Colors range from red to blue (qualitatively), B/V ranges from 0.2-1.3.

(B-V = -0.4 - 2.1)

c) How it's measured

Spectral Types: spectroscopy, measure absorption line strengths

Colors: use multi-color photometry (ie. record images or counts through color filters).

d) Theory behind interpretation of measurement.

Spectral Types: no theory, just an arbitrary classification scheme. (However, the spectral types have been arranged in order of decreasing surface temperature.)

Colors: qualitative colors are explained with the physiology of the eye (different cone cells in the retina respond to different frequencies of light). Quantitative colors, namely B/V, are measured with photometry. The ``theory” behind photometry is that counts in linear light detectors are proportional to the flux of light. Also, that color filters allow a narrow range of frequencies to pass so that counts are proportional to light we call “blue”, “red”, “UV”, etc.

Table 17-2
Stellar Spectral Classes

TABLE 17.2 Stellar Spectral Classes

Spectral Class	Approximate Surface Temperature (K)	Noteworthy Absorption Lines	Familiar Examples
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	Mintaka (O9)
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2), Barnard's Star (M5)

Radius

a) Values for the Sun

Rsun = $7x10^5$ km

b) Range of values for other stars

0.05 Rsun - ~500 Rsun (on main sequence)

0.005 – 1000 Rsun (off main sequence, including white dwarfs and supergiants)

c) How it's measured

Directly: by imaging and finding distance through parallaxj (or another means).

Indirectly: by finding the luminosity (which requires apparent brightness and a distance to be measured with photometry and parallax), and measuring the temperature (which requires spectroscopy).

d) Theory behind interpretation of measurement.

Direct: angle subtended (in radians) = diameter/distance

Indirect: $L = 4\pi R^2 \sigma T^4$

Luminosity Class

a) Values for the Sun

V (dwarf)

b) Range of values for other stars

V, IV, III, II, Ib,Ia (dwarf to bright supergiant)

c) How it's measured

Spectroscopy is used to carefully measure the widths of absorption lines. The wider the line, the smaller the star. The small stars are class V dwarfs, the biggest are bright supergiants. Thus, luminosity class indicates radius as well as luminosity.

d) Theory behind interpretation of measurement.

A compact star will have a higher surface gravity than a big star. This causes greater pressure broadening of the absorption lines.

Mass

a) Values for the Sun

Msun = 2x10^30 kg

b) Range of values for other stars

0.08 Msun - ~50 Msun 0.08 M is the limit of H fusion. Brown dwarfs can be lower.

Higher mass (100-150 Msun) stars are suspected to exist, but none have been measured directly (they are rare).

c) How it's measured

Observations of binary stars. Example: for eclipsing binaries, get the period from the light curve (photometry), get the mass ratios and the true speeds from the doppler effect (spectra).

Or, for visual binaries (those where two stars can be resolved), one can get the relative masses from the relative sizes of the orbits.

$$m_1/m_2 = r_2/r_1 \quad \text{or} \quad m_1/m_2 = v_2/v_1$$

d) Theory behind interpretation of measurement.

Kepler's 3rd law (with Newton's modification):

$$P^2=4\pi R^3/G(m_1+m_2)$$

Radial velocity / transverse velocity

a) Values for the Sun

Vr = 0 (on average), Vt ~ 1°/day or 1,315,000 "/year, but this is really a reflex motion caused by the motion of the Earth around the Sun.
The motion of the Sun relative to our galaxy's center is about 200 km/s.

b) Range of values for other stars

Speeds of stars relative to the Sun range from 0 to about 300 km/s.

c) How it's measured

For *Vr*: Use spectrograph to get a spectrum of the star. Measure the doppler shifting of absorption lines to get the radial velocity.

For *Vt*: Take images of the star at many different times. Measure how many arcseconds the star moves per year relative to background stars. (One must correct for parallax, which also makes a star "move").

d) Theory behind interpretation of measurement.

For *Vr*: the radial motion of the star causes a Doppler shift according to (observed wavelength – rest wavelength)/rest wavelength = v/c.

For *Vt*: simple geometry.

Composition

a) Values for the Sun

Mostly Hydrogen (71% by mass, 91.2% by number)

Helium is next abundant (27.1% by mass, 8.7% by number)

All other elements are "metals" (1.9% by mass, 0.1% by number)

b) Range of values for other stars

.The ratio of H/He is very similar. But metal content differs. Old stars have less metals and young stars have more metals. Quantified as [Fe/H], which is called "metallicity".

c) How it's measured

Spectroscopy – look at absorption line strengths and line shapes.

d) Theory behind interpretation of measurement.

At a given temp, the greater the line strength the greater the abundance. Atomic physics and radiative transfer tells us what line strength to expect.

Another limit to abundances comes from the physics of nuclear fusion at the core. For a given temperature and density, the energy derived from the p-p chain will be greater if more hydrogen is present. (You can't say that the core gas is only 50% hydrogen and get the same luminosity.)

Distance to far away stars

(Spectroscopic parallax)

a) Values for the Sun

NA. *(The distance to the sun is 10^{-5} LY*

b) Range of values for other stars

The distance range over which spectroscopic parallax is most useful for determining distances is 1000 LY – 40,000 LY.

c) How it's measured

For single stars: Spectroscopy is used to identify the spectral type of a star, including its luminosity class. From this, one estimates the stars luminosity (L or *M*). The difference between the apparent brightness, *m*, and *M* gives a distance.

For a cluster of stars: two-color photometry can be done on a cluster of stars to obtain color index (B-V or B/V) and apparent brightness, *m*, for each star. A plot of *m* vs B-V will exhibit a Main Sequence just like a real H-R diagram (a plot of *M* vs B-V). The vertical offset of the cluster's main sequence from the main sequence on *M* vs B-V gives us (*m*-*M*) and thus a distance for the entire cluster. (This is called main-sequence fitting.)

d) Theory behind interpretation of measurement.

$m-M = 5 \log (D/10pc)$. Where D is the distance in pc.

H-R Diagram

a) Values for the Sun

The Sun's position on the H-R Diagram is Spectral Type = G2, L=1Lsun. The Spectral Type can be replaced by surface temperature (5800 K), or color index (B/V=0.55, B-V=0.65).

The Luminosity, L, can be replaced by absolute magnitude, M=+4.83.

b) Range of values for other stars

(See an H-R diagram.) The surface temperatures range from 3000-30000 K, and the luminosities range from about 0.0001 – 100,000 Lsun.

c) How it's measured

Spectroscopy is used to identify the spectral type, or surface temp. of a star. Two-color photometry can give the color index of the star. The luminosity can be found, for example, by getting a distance and a flux (or apparent magnitude).

d) Theory behind interpretation of measurement.

The placement of a star on the H-R diagram tells us about the stars mass and its stage in evolution. Stars on the Main Sequence (MS) are fusing H to He in their core, and this is the longest stage in their evolution. The MS is really the “mass-luminosity” relation in disguise, with the top left of the MS being high mass stars and the bottom right being low mass stars. The mass-luminosity relationship is $L \sim M^4$