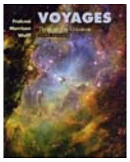


Chapter 16

Analyzing Starlight

16.1 The Brightness of Stars

Luminosity:

Pronunciation: "lü-m&-'nä-s&-tE

Function: *noun*

Inflected Form(s): *plural* **–ties**

1 a : the quality or state of being luminous **b :** something luminous

2 a : the relative quantity of light **b :** relative brightness of something

3 : the relative quantity of radiation emitted by a celestial source (such as a star)

16.1 The Brightness of Stars

Luminosity refers to the inherent brightness of a star, but not how bright a star appears in the night sky.

Why do some stars appear brighter than others in the sky?

Answer: Either because:

a) More luminous (different "wattage");
b) Closer to us (remember the inverse-square law?); or
c) Both

16.1 The Brightness of Stars

Remember the inverse-square law from chapter 4?

16.1 The Brightness of Stars

How about the magnitude scale from chapter 1?

16.1 The Brightness of Stars

Magnitude:

Pronunciation: 'mag-n&-"tüd, -"tyüd
Function: *noun*

1 a: great size or extent b (1) : spatial quality

2: the importance, quality, or caliber of something

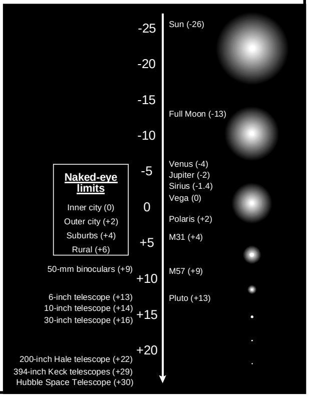
3: a number representing the *apparent* brightness of a celestial body on a logarithmic scale in which an *increase* of one unit corresponds to a *decrease* in the brightness of light by a factor of 2.512

4: a numerical quantitative measure expressed usually as a multiple of a standard unit

16.1 The Brightness of Stars

Magnitude:

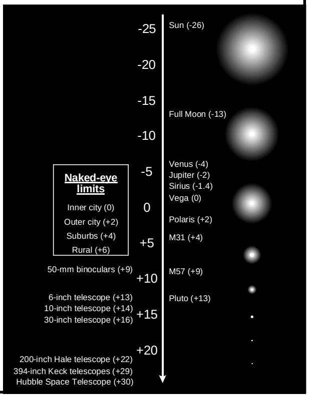
- Hipparchus
  - Brightest = 1st magnitude
  - Faintest = 6th magnitude
  - Brightness factor = 100
  - 1st mag star appears 100 times brighter than 6th mag star



16.1 The Brightness of Stars

Magnitude:

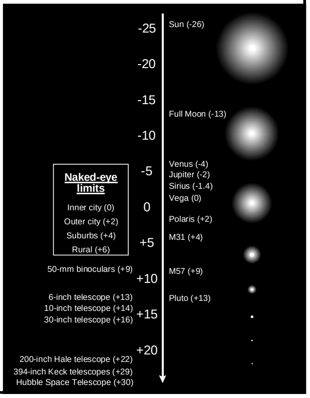
- If so, then how much brighter does a 1st magnitude star appear than a 2nd magnitude star?
- Answer: 2.512, since
  2.512 x 2.512 x 2.512 x 2.512 x 2.512 = 100



16.1 The Brightness of Stars

Magnitude:

- Since Hipparchus' time, the scale has been expanded
  - Sun: mag -26
  - Moon: mag -13
  - Venus: mag -4
  - Sirius: mag -1.4
  - Rigel: mag +0.1
  - Naked-eye limit: mag +6
  - Binoculars: mag +9



16.1 The Brightness of Stars

Magnitude versus Luminosity:

- Previous slide said:
  - Sirius: mag -1.4
  - Rigel: mag +0.1
- Appendix 11 (page 724)
  - Luminosity?
  - Sirius: 24 (times more luminous than the Sun)
  - Rigel: 60,000 (times more luminous than the Sun)
- So, which is
  - Brighter?
  - More luminous?
  - Why?

16.1 The Brightness of Stars

Magnitude versus Luminosity:

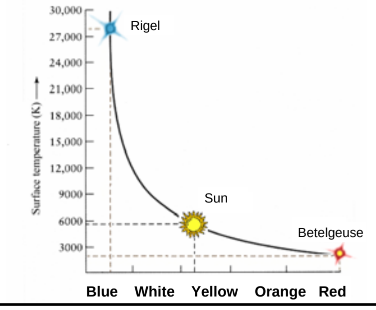
- Distances?
  - Sirius: 8.6 light years
  - Rigel: 772 light years
- Using the inverse-square law:
  - If Rigel were as close as Sirius, it would appear almost as bright as the Full Moon
  - If Sirius were as far as Rigel, it would be invisible through binoculars!

16.2 Colors of Stars

- Stars are not all the same color because they do not all have the same temperature.

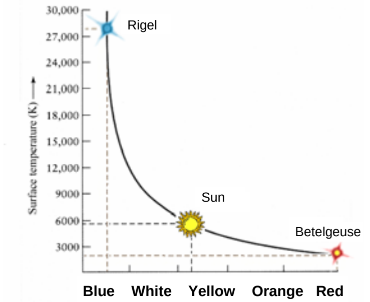
16.2 Colors of Stars

- Stars are not all the same color because they do not all have the same temperature. For instance…



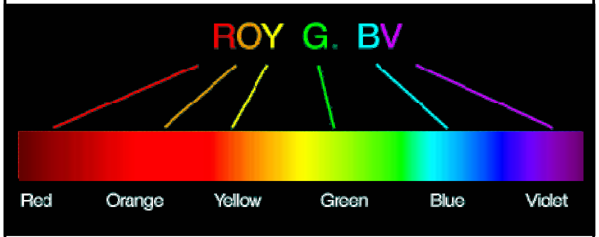
16.2 Colors of Stars

- Numerical values (sometimes called the **B-V Color Index**) more precisely define the exact colors of stars.



16.3 The Spectra of Stars

- Spectrum = rainbow
  - Continuous spectrum

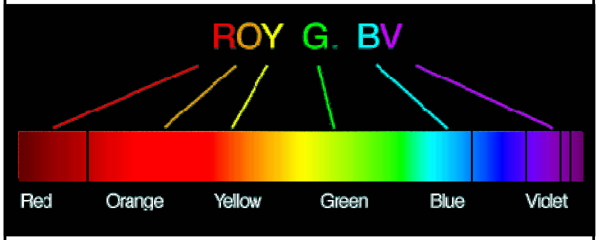


16.3 The Spectra of Stars

- 1802: William Wollaston discovered that the spectrum of sunlight had a series of superimposed dark lines
- 1814: Joseph Fraunhofer found some 600 dark lines
- 1864, Sir William Huggins matched some of these dark lines in spectra from other stars with terrestrial substances, demonstrating that stars are made of the same materials of everyday material rather than exotic substances.

16.3 The Spectra of Stars

- Dark-line spectrum (hydrogen shown)



16.3 The Spectra of Stars

- By observing spectra, astronomers realized that most stars fell into one of several broad categories based on distinct patterns in their spectral lines.
- At first, stars were cataloged alphabetically according to how prominent their hydrogen lines appeared.
- Original spectral classification:
  - A: **darkest**
  - B: a little less dark
  - C : a little less dark
  - D : a little less dark
  - E : a little less dark
  - F : a little less dark

16.3 The Spectra of Stars

- Astronomers thought this corresponded to temperature. They were wrong.
- Hydrogen lines are strongest in stars with intermediate temperatures
  - Almost invisible in very hot stars and cool stars
  - Hot stars show strong helium lines
  - Cool stars show lines associated with metals (titanium oxide)
  - Figure 16.5 (page 363)

16.3 The Spectra of Stars

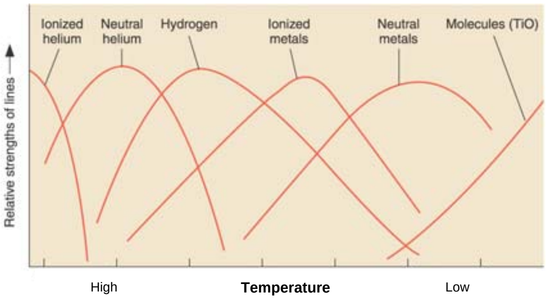
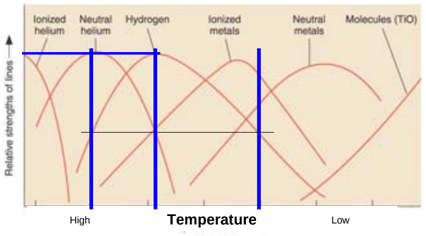


Figure 16.5 (page 363)

16.3 The Spectra of Stars

- Work by Annie Cannon (p. 364) forced astronomers to reorder their classification
  - Also combined several together to create seven classes
- Ordered from highest temperature to lowest, the seven main stellar types are O, B, A, F, G, K, and M
  - Although the nomenclature is rooted in long-obsolete ideas about stellar evolution, the terminology remains
- Astronomers use mnemonics to remember the order of the classification scheme
  - ***O**h **B**e **A** **F**ine [**G**uy/**G**irl] **K**iss **M**e*

16.3 The Spectra of Stars



Example: The spectrum of a star with hydrogen lines about half as strong as an A-type star.

From this, the star could be either a Type-B or Type-G.

If the spectrum also contains helium lines, it is a Type-B; if it contains ionized metals, it's a Type-G.

16.3 The Spectra of Stars

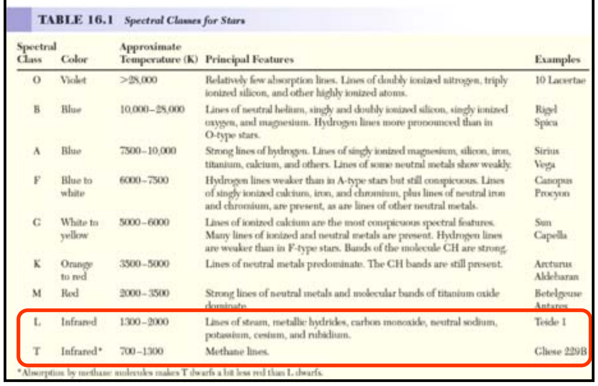


TABLE 16.1 *Spectral Classes for Stars*

Spectral Class	Color	Approximate Temperature (K)	Principal Features	Examples
O	Violet	>28,000	Relatively few absorption lines. Lines of doubly ionized nitrogen, triply ionized silicon, and other highly ionized atoms.	10 Lacertae
B	Blue	10,000–28,000	Lines of neutral helium, singly and doubly ionized silicon, singly ionized oxygen, and magnesium. Hydrogen lines more pronounced than in O-type stars.	Rigel Spica
A	Blue	7500–10,000	Strong lines of hydrogen. Lines of singly ionized magnesium, silicon, iron, titanium, calcium, and others. Lines of some neutral metals show weakly.	Sirius Vega
F	Blue to white	6000–7500	Hydrogen lines weaker than in A-type stars but still conspicuous. Lines of singly ionized calcium, iron, and chromium, plus lines of neutral iron and chromium, are present, as are lines of other neutral metals.	Canopus Procyon
G	White to yellow	5000–6000	Lines of ionized calcium are the most conspicuous spectral features. Many lines of ionized and neutral metals are present. Hydrogen lines are weaker than in F-type stars. Bands of the molecule CH are strong.	Sun Capella
K	Orange to red	3500–5000	Lines of neutral metals predominate. The CH bands are still present.	Arcturus Aldebaran
M	Red	2000–3500	Strong lines of neutral metals and molecular bands of titanium oxide dominate.	Betelgeuse Antares
L	Infrared	1300–2000	Lines of steam, metallic hydrides, carbon monoxide, neutral sodium, potassium, cesium, and rubidium.	Teide 1
T	Infrared*	700–1300	Methane lines.	Gliese 229B

*Absorption by methane molecules makes T dwarfs a bit less red than L dwarfs.

16.3 The Spectra of Stars

Spectral Subclasses

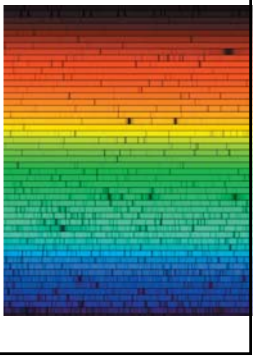
- There are ten subclasses within each spectral class
- Numbered 0 to 9
  - 0 is the hottest in the class, 9 is the coolest
  - Examples: B0 to B9, then A0 to A9, etc.
  - Our Sun is a spectral class G2

16.3 The Spectra of Stars

Spectral Classes L and T

- 1995: Astronomers discover objects even cooler than M9 stars
- Not really stars, but not planets either
- Dubbed “brown dwarfs,” since they do emit energy but they are not stars
  - Some call them “failed stars”
- Mass < 7.2% of our Sun ($0.072M_{Sun}$)
  - Not hot enough for hydrogen atoms to fuse into helium
- Shine mostly in the infrared part of the spectrum
- Labeled spectral class L (hotter) and T (cooler)

16.4 Spectroscopy: Key to the Universe

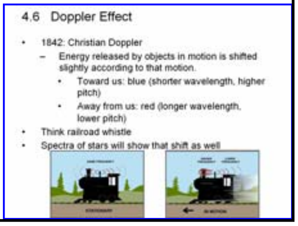


- Stars vary in color, temperature, as well as diameter
- Stellar spectra can distinguish so-called “giant” stars from average size stars like our Sun
  - Spectra show the abundance of elements in a star’s atmosphere
  - Giant stars show lower densities of atoms than smaller stars with similar temperatures
    - Complexity of spectrum make it difficult to sort out

16.4 Spectroscopy: Key to the Universe

To add to the confusion…***radial motion***

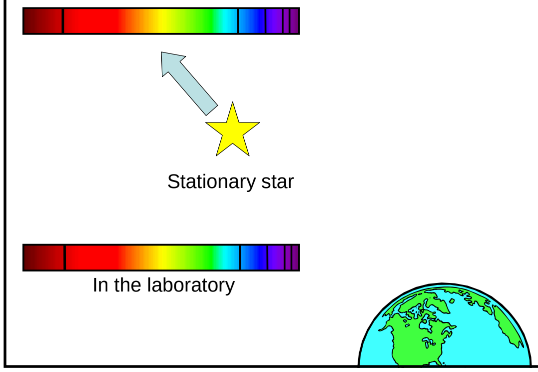
- When we measure the spectrum of a star, we measure the wavelength of each of its lines
  - If a star is not moving, then the wavelengths of the dark lines correspond to what we can measure in a laboratory
  - If the star is approaching us or moving away from us, those wavelengths will shift
  - Doppler Effect (ch. 4)



4.6 Doppler Effect

- 1842: Christian Doppler
  - Energy released by objects in motion is shifted slightly according to that motion.
    - Toward us: blue (shorter wavelength, higher pitch)
    - Away from us: red (longer wavelength, lower pitch)
- Think railroad whistle
- Spectra of stars will show that shift as well

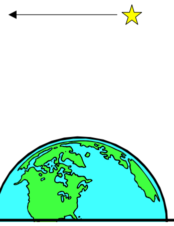
16.4 Spectroscopy: Key to the Universe



16.4 Spectroscopy: Key to the Universe

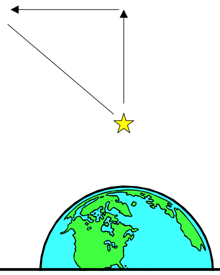
To add to the confusion…***proper motion***

- Stars are rarely moving exactly toward or away from us.
  - They also move side to side



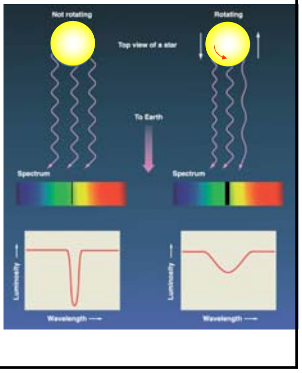
16.4 Spectroscopy: Key to the Universe

- We usually see a combination of radial velocity and proper motion



16.4 Spectroscopy: Key to the Universe

- Rotation
  - Stars are so far away, they only appear as points of light, so how do we know they are rotating?
  - Once again, their spectra tell the story
  - If a star is not rotating, its spectrum's absorption lines will be very thin



16.4 Spectroscopy: Key to the Universe

- Rotation
  - If, however, a star is rotating, the Doppler Effect will cause its absorption lines to broaden
    - Broadening due to part of the star moving toward us, part moving away
  - Results: Hot stars rotate more rapidly than cooler stars