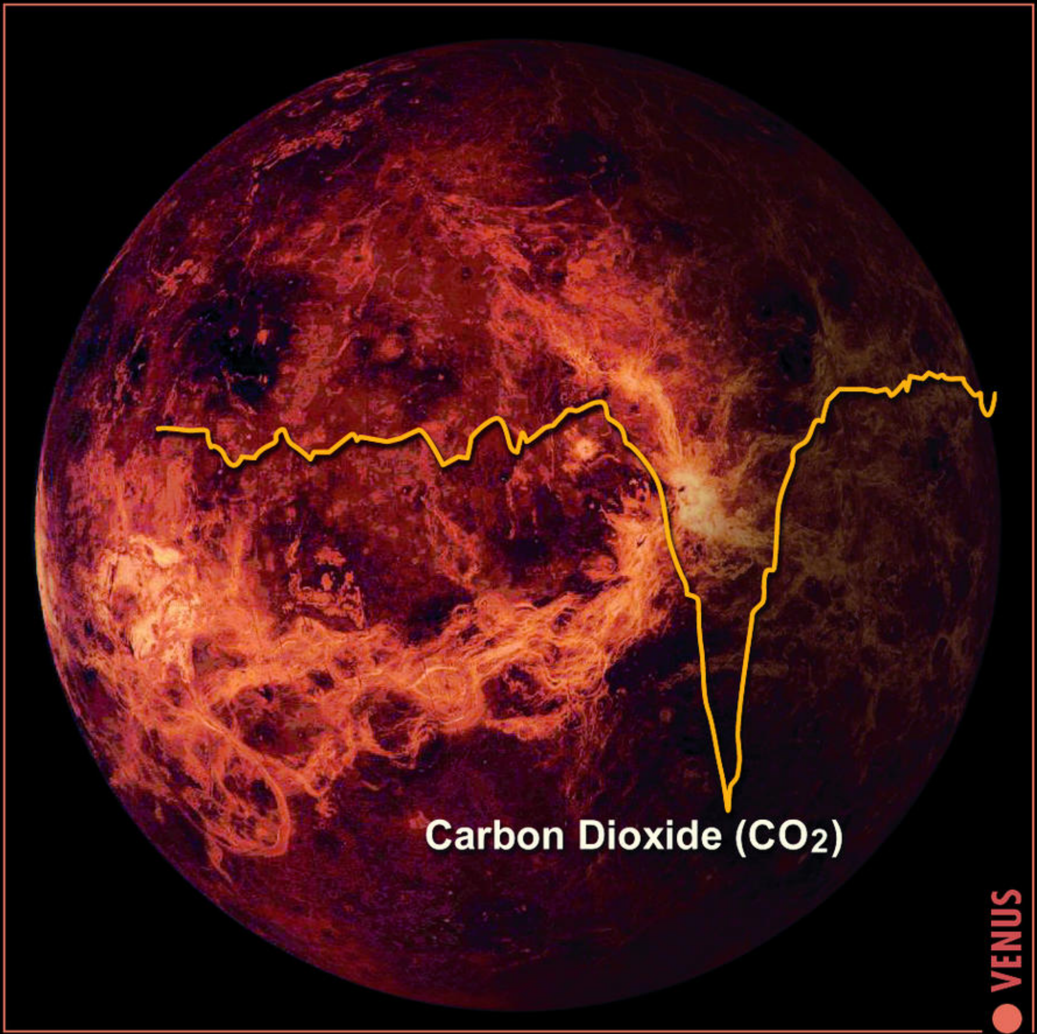
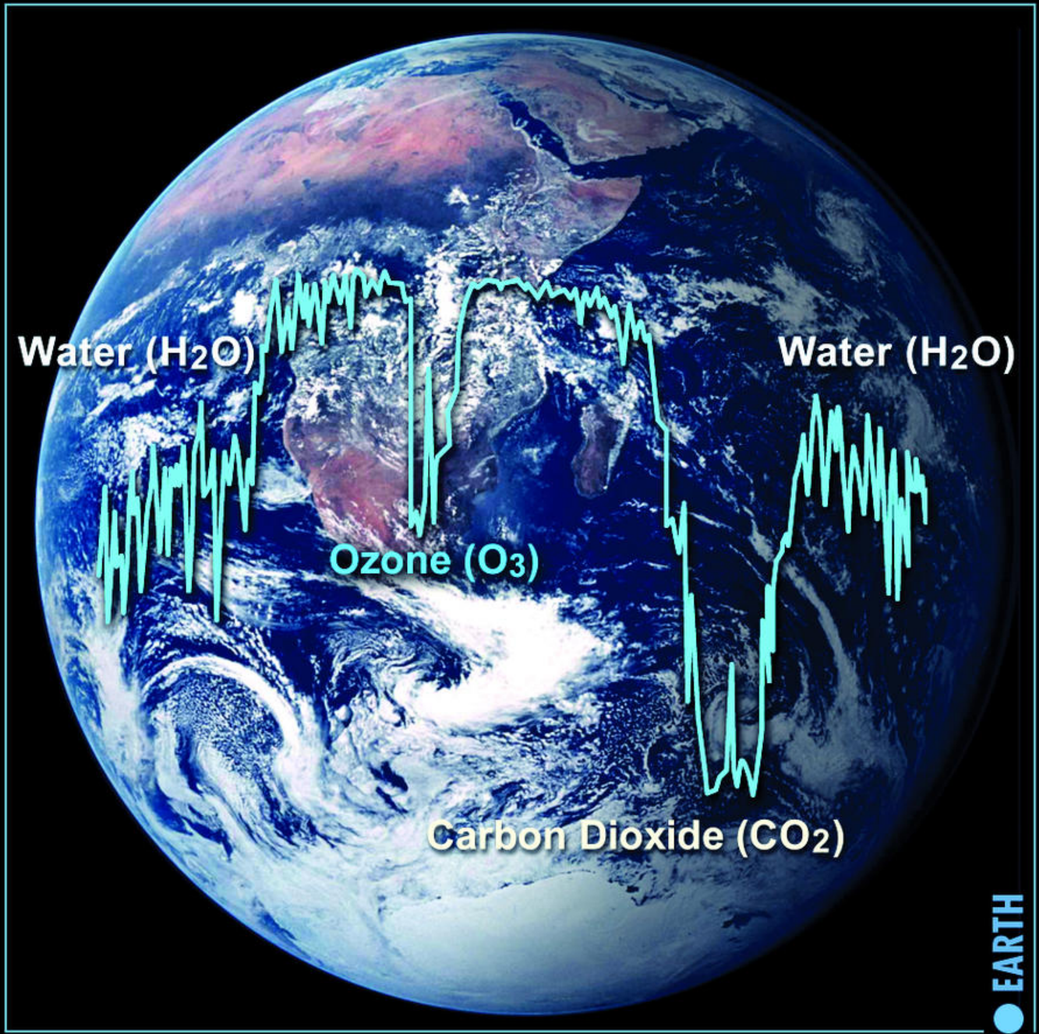
# Planetary Habitability

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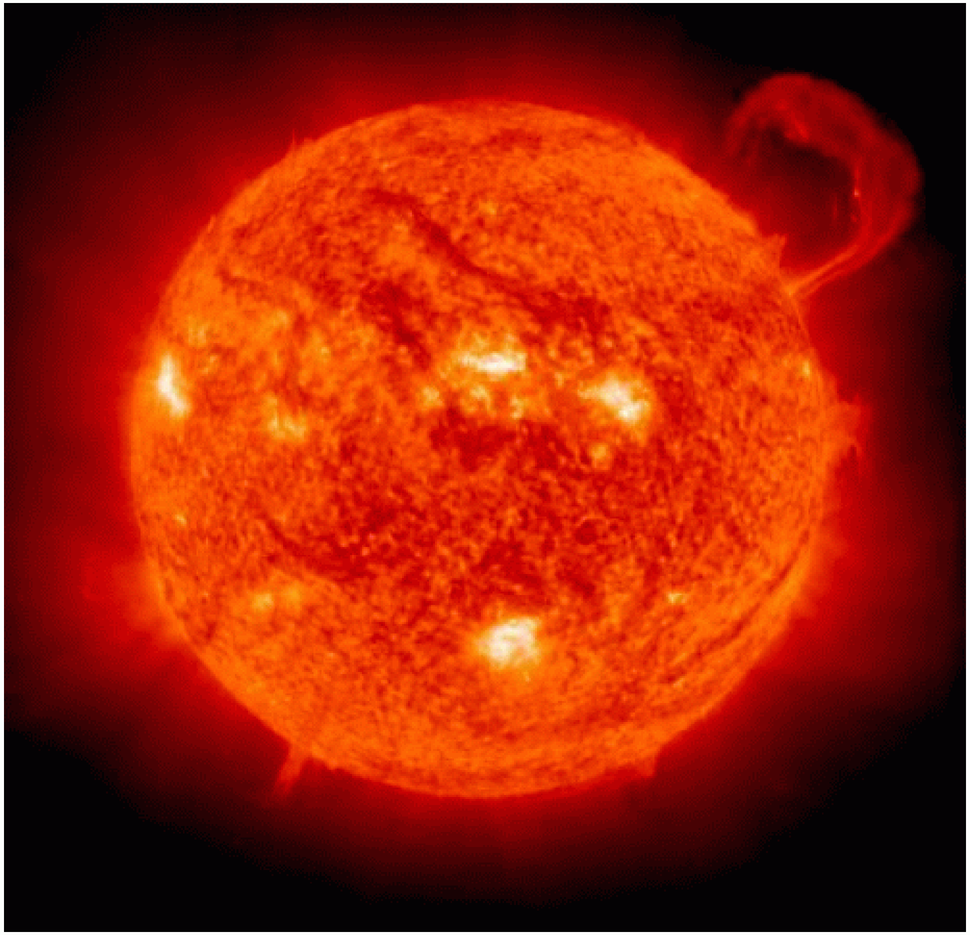
# Topics

- Lecture 1 – Introduction
- Lecture 2 – Habitability Factors
- Lecture 3 - Stars
- Lecture 4 – Planetary Atmospheres
- Lecture 5 – Planetary Interiors
- Lecture 6 – Planetary Energy Balance
- Lecture 7 – Habitable Zone I
- Lecture 8 – Habitable Zone II
- Lecture 9 – Earth as a Living Planet
- Lecture 10 – Mars
- Lecture 11 – Icy Moons
- Lecture 12 – Venus
- Lecture 13 – Mercury & the Moon
- Lecture 14 – The Role of Giant Planets
- Lecture 15 – Stellar Influences
- Lecture 16 – Magnetic Fields
- Lecture 17 – Milankovitch Cycles
- Lecture 18 – Geological Cycles
- Lecture 19 – The Next Steps
- Lecture 20 – Summary/Discussion

# Intrinsic Properties of Stars

- Mass
- Radius
- Effective Temperature
- Luminosity
- Composition (metallicity)
- Age

# Numbers you should know: The Sun



source: SOHO/EIT

Mass $\approx 2 \times 10^{30}$ kg = 1 $M_\odot$

Radius $\approx 7 \times 10^{8}$ m = 1 $R_\odot$

Distance = $1.5 \times 10^{11}$ m = 1 AU

Luminosity = $4 \times 10^{26}$ W = 1 $L_\odot$

Surface temperature = 5800 K

age $\approx$ 4.5 Gyr

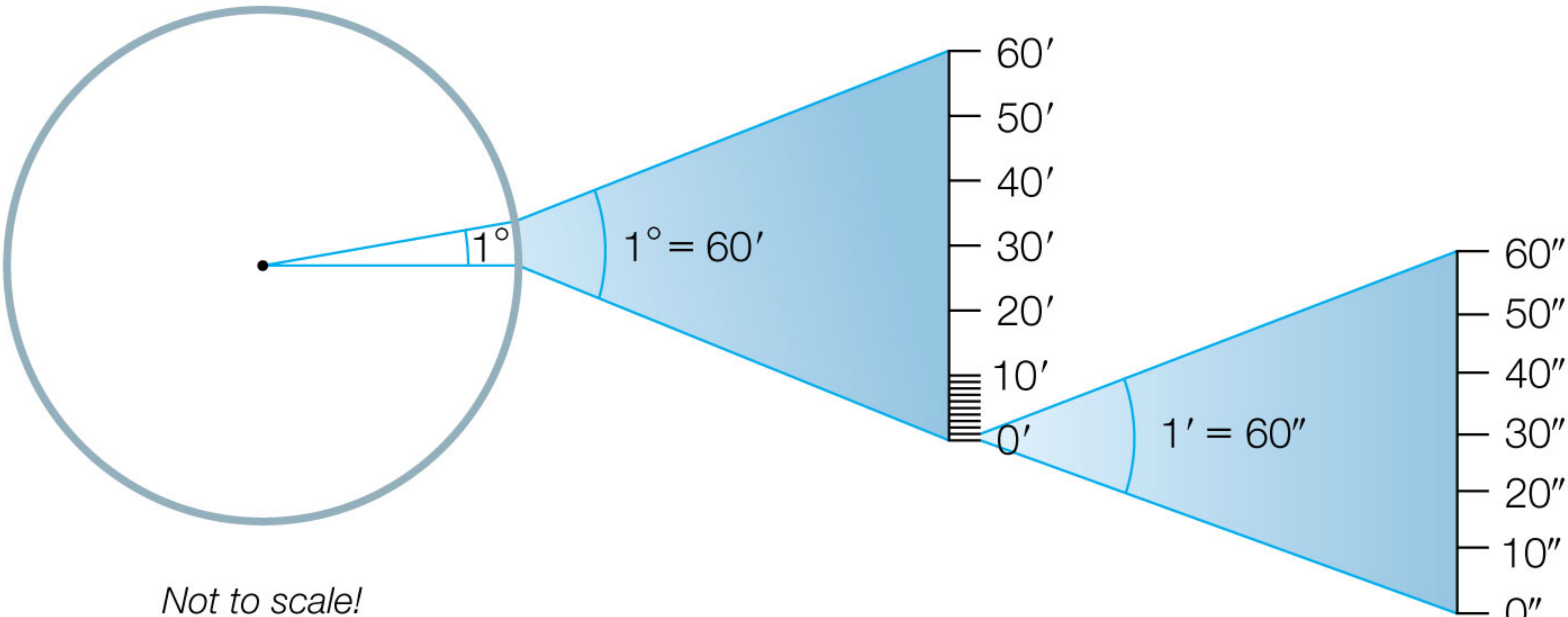
spectral type = G2 V

All other stars are scaled to these parameters for convenience.

# Stellar Parallax

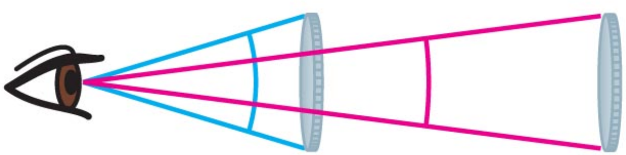
# Angular Measurements

- Full circle = 360º
- 1º = 60´ (arcminutes)
- 1´ = 60˝ (arcseconds)

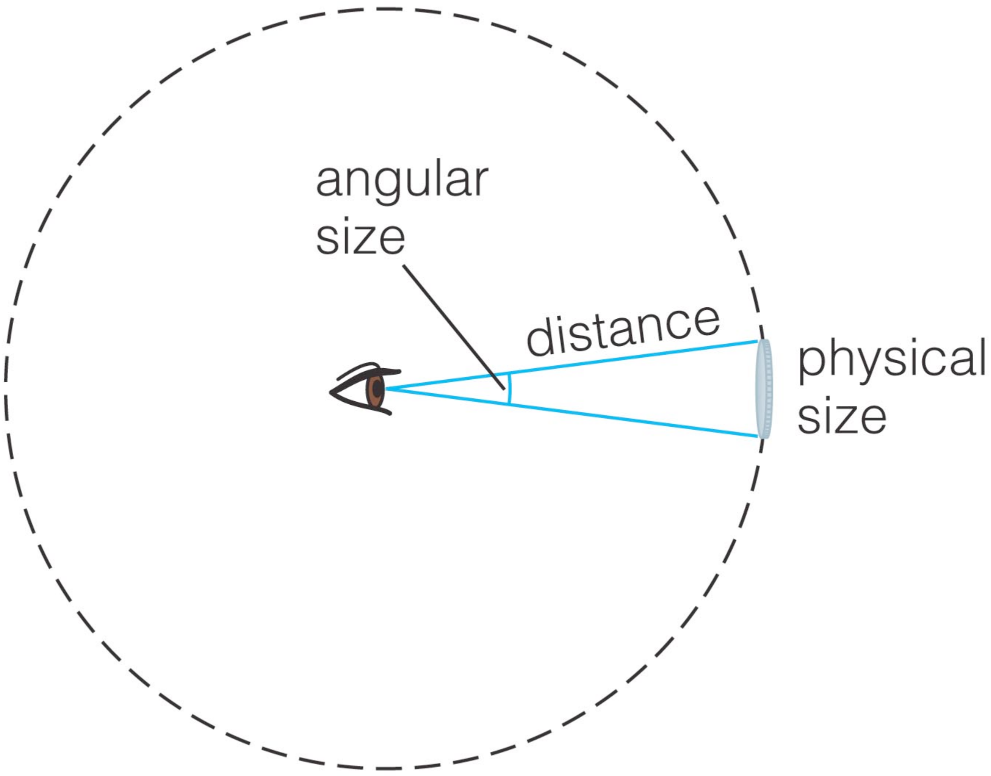


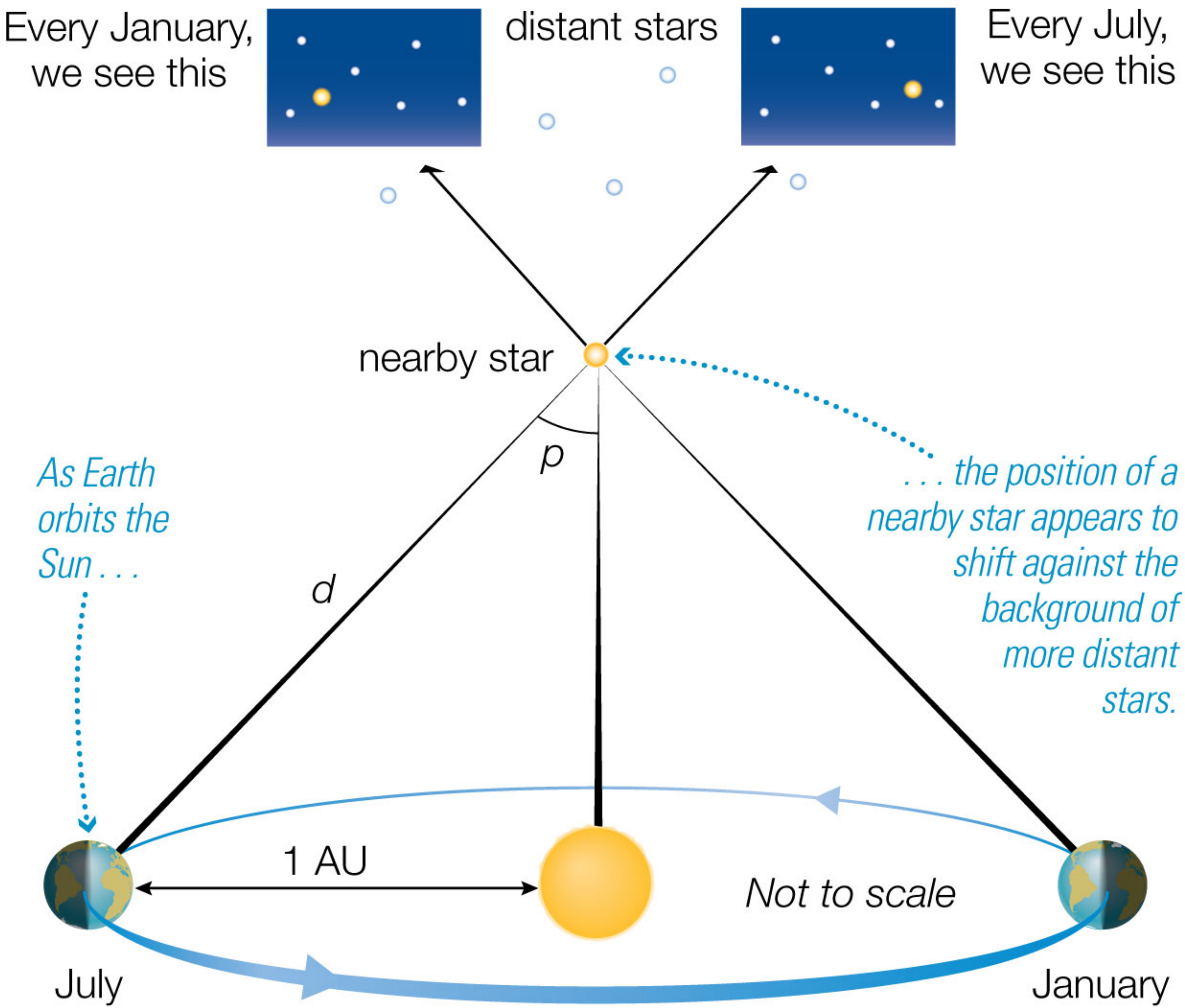
# Angular Size

$$\text{angular size} = \text{physical size} \cdot \frac{360 \text{ degrees}}{2\pi \cdot \text{distance}}$$



An object's angular size appears smaller if it is farther away.





Every January, we see this
distant stars
Every July, we see this
nearby star
p
d
As Earth orbits the Sun . . .
. . . the position of a nearby star appears to shift against the background of more distant stars.
1 AU
Not to scale
July
January

# Parallax and Distance

$$p = \text{parallax angle}$$

$$d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}}$$

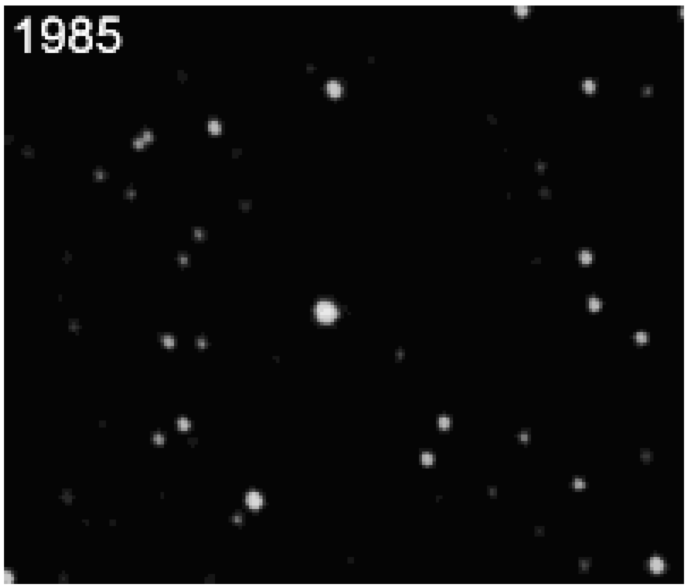
$$d \text{ (in light-years)} = 3.26 \cdot \frac{1}{p \text{ (in arcseconds)}}$$

One **parsec** is the distance at which the mean radius of the Earth's orbit subtends an angle of one second of arc.

Robert Innis – discovered Proxima in 1915

# Proxima Centauri

Nearest star to the Solar System and Sun



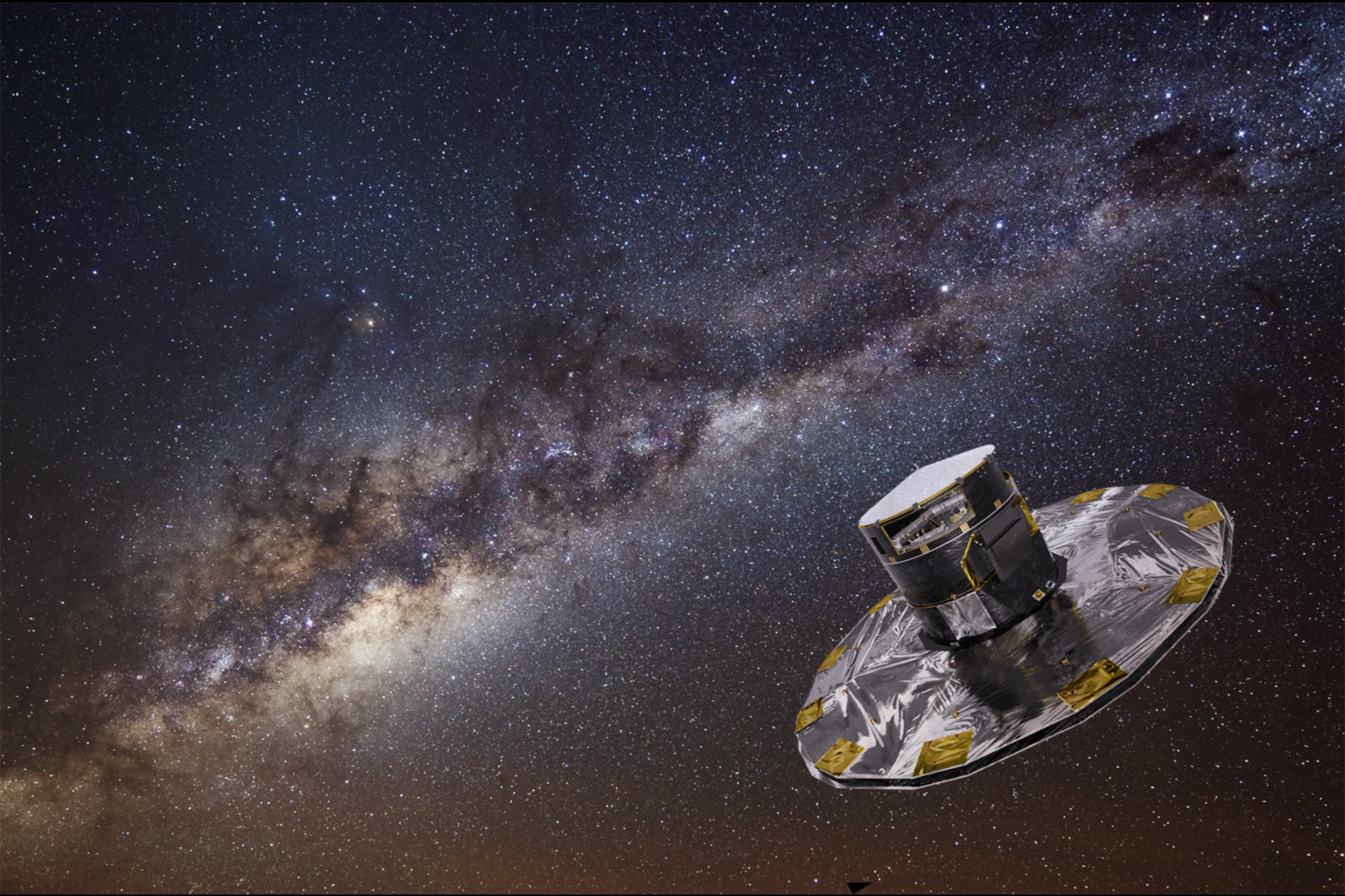

**Proper motion over 25 years**

Observed parallax shift on the sky over a six month time interval is

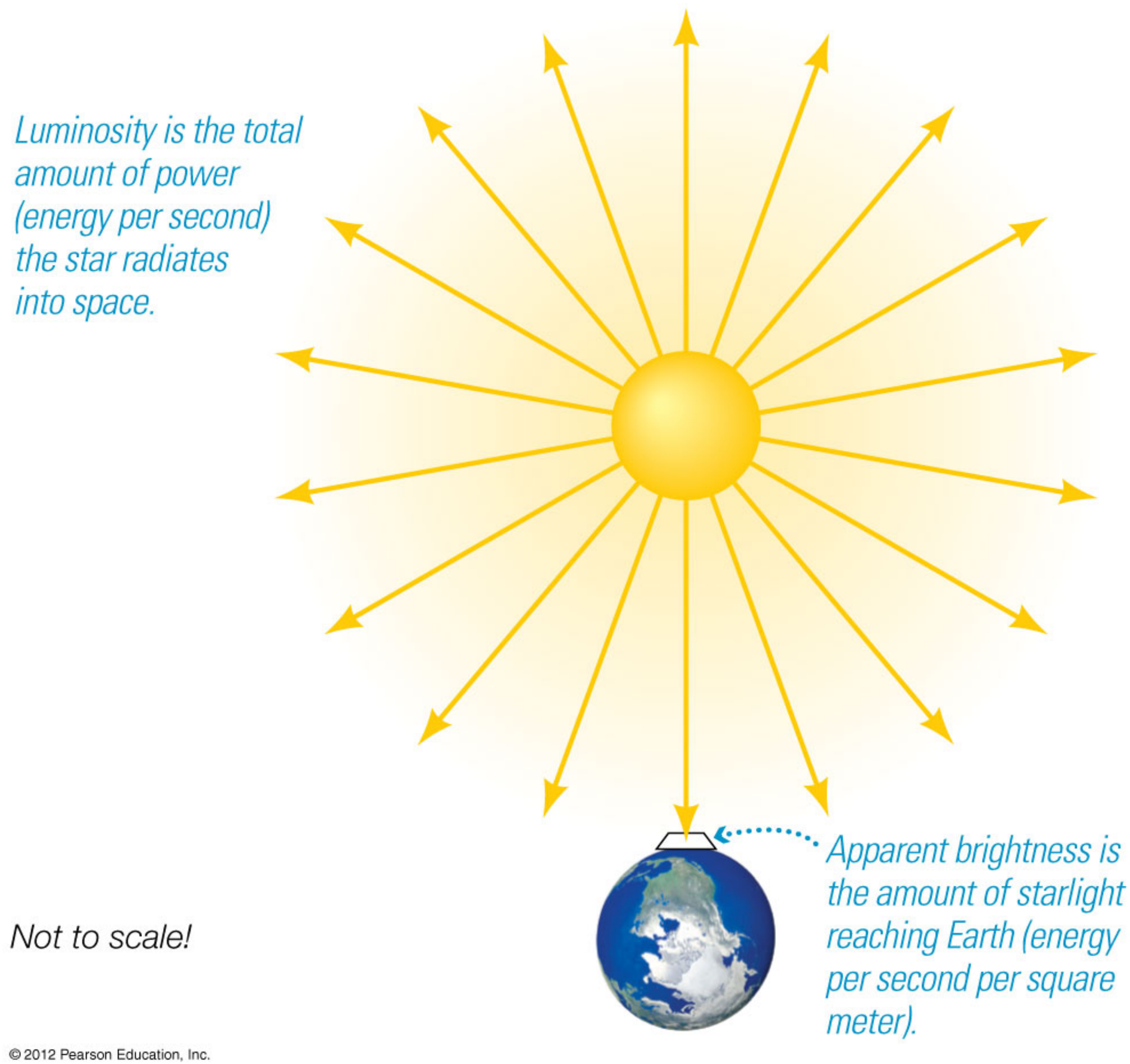
Angle = 1.5377 arc seconds
= 0.00042714 degrees
= 2 x P

Angle of parallax = P = 1.5377 / 2 = 0.76885 arc seconds

Distance to Proxima = 1 / P = 1/0.76885 = 1.301 parsecs



# The Magnitude Scale




***Luminosity:***

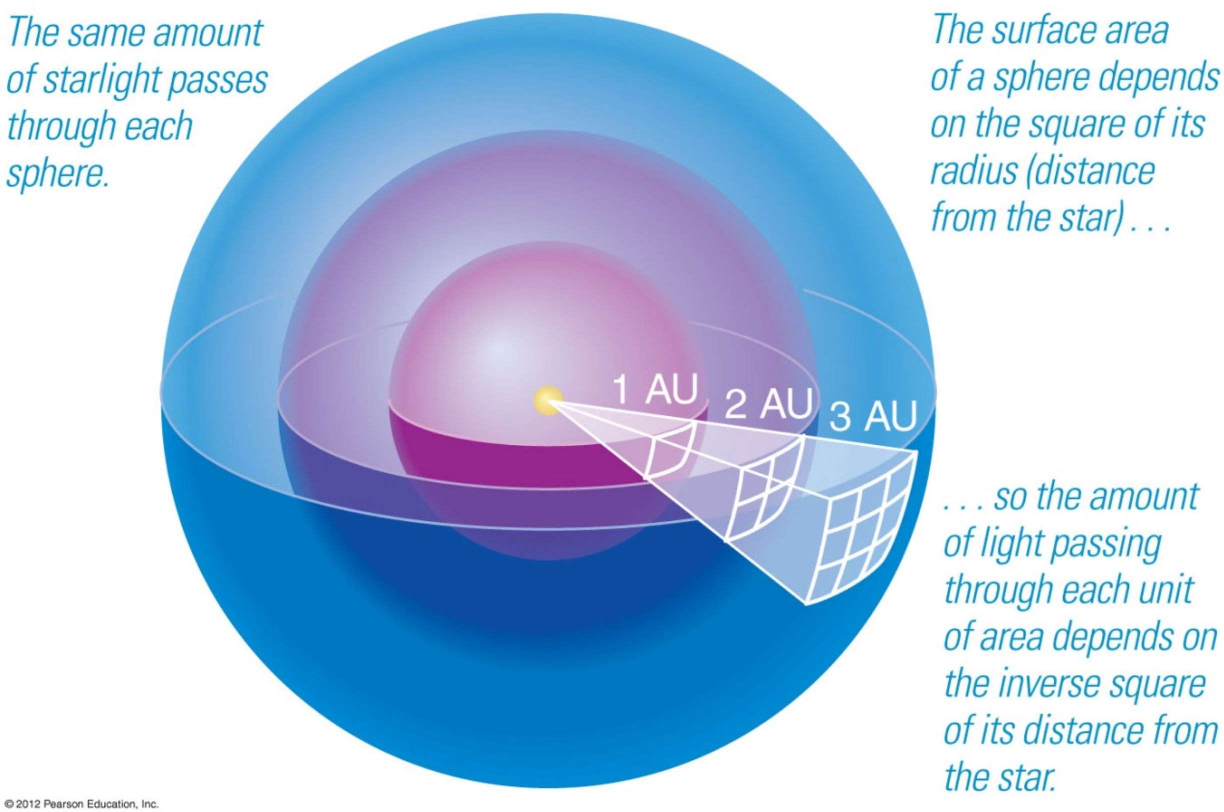
Amount of power a star radiates

(Joules per second = watts)

***Apparent brightness:***

Amount of starlight that reaches Earth

(energy per second per unit area)




Apparent brightness follows the **inverse square law**.

Luminosity passing through each sphere is the same.

Area of sphere:
$4\pi\ (\text{radius})^2$

Divide luminosity by area to get brightness.

The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2}$$

We can determine a star’s luminosity if we can measure its distance and apparent brightness:

$$\text{Luminosity} = 4\pi\,(\text{distance})^2 \times (\text{Brightness})$$

# Flux and luminosity

- Flux decreases as we get farther from the star – like 1/distance$^2$

$$F = \frac{L}{4\pi D^2}$$

# The Magnitude Scale

- **Apparent magnitude** is a description of how bright stars appear on the sky.
- A difference of 5 magnitudes represents a factor of 100 difference in brightness.
- **Absolute magnitude** is the apparent magnitude of a star at a distance of 10 parsecs.
- The absolute magnitude of the Sun is 4.8.

| Object | Apparent Magnitude |
|---|---|
| Sun | – 26.5 |
| Full moon | – 12.5 |
| Venus (at brightest) | – 4.4 |
| Mars (at brightest) | – 2.7 |
| Jupiter (at brightest) | – 2.6 |
| Sirius (brightest star) | – 1.4 |
| Canopus (second brightest star) | – 0.7 |
| Vega | 0.0 |
| Spica | 1.0 |
| Naked eye limit in urban areas | 3–4 |
| Uranus | 5.5 |
| Naked eye limit in rural areas | 6–6.5 |
| Bright asteroid | 6 |
| Neptune | 7.8 |
| Limit for typical binoculars | 9–10 |
| Limit for 15-cm (6-in.) telescope | 13 |
| Pluto | 15 |
| Limit for visual observation with largest telescopes | 19.5 |
| Limit for photographs with largest telescopes | 23.5 |
| Expected limit for Hubble Space Telescope | 28± |

**Apparent magnitudes of selected objects**

Hartmann/The Cosmic Journey, 4th ed., Fig. 16-T1; The Cosmic Voyage, Fig. 16-T1

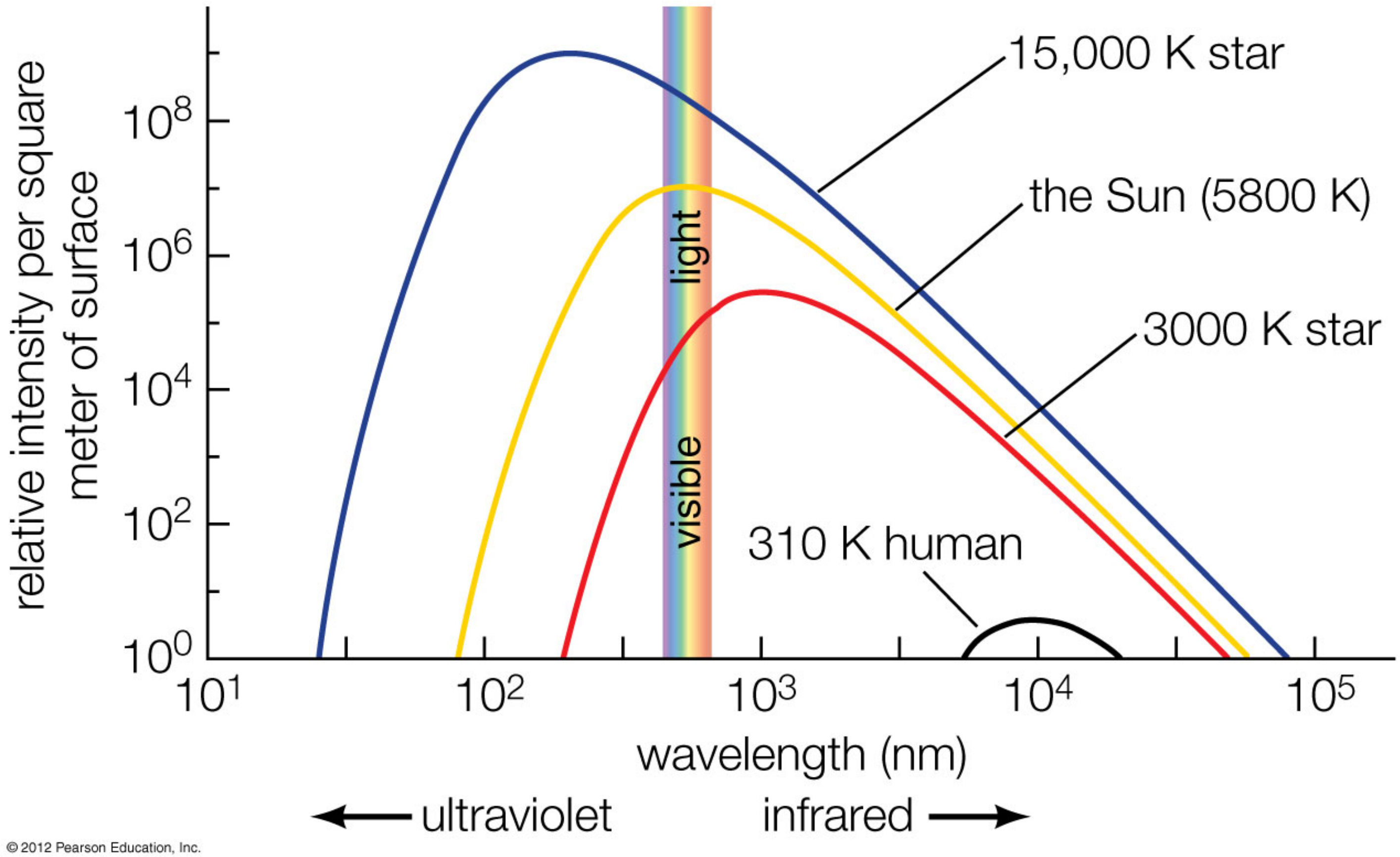
# Blackbody Radiation

# Thermal (Blackbody) Radiation

- Nearly all large or dense objects emit thermal radiation, including stars, planets, and you.
- An object's thermal radiation spectrum depends on only one property: its **temperature.**
- A **blackbody** is an ideal emitter that absorbs all incident energy and reradiates the energy.
- We can use this to determine the temperatures of stars and planets.

# Properties of Thermal Radiation

1. Hotter objects emit more light at all frequencies per unit area (Stefan-Boltzmann law).
2. Hotter objects emit photons with a higher average energy (Wien's law).



# Stefan-Boltzmann law

- Stefan-Bolzmann constant:

$$\sigma = 5.670400 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}.$$

- For a spherical star of radius R:

$$\boxed{L = 4\pi R^2 \sigma T_e^4.}$$

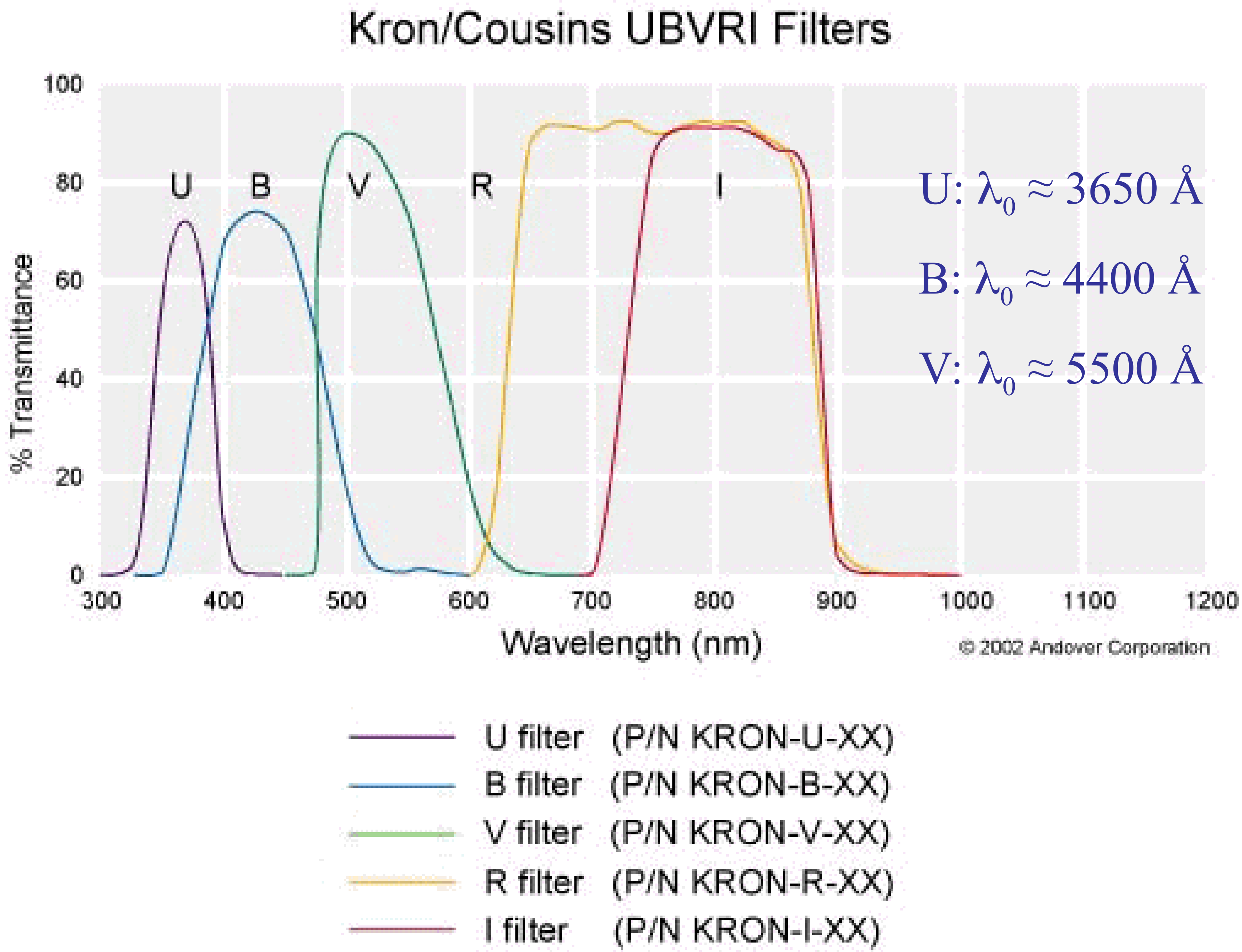
- The **Stefan-Boltzmann equation**.

# Wien's law

- Cooler objects produce radiation that peaks at lower energies = longer wavelengths = redder colors.
- Hotter objects produce radiation that peaks at higher energies = shorter wavelengths = bluer colors.
- Wavelength of peak radiation:
  Wien's Displacement Law

$$\boxed{\lambda_{\text{max}} T = 0.002897755 \text{ m K.}}$$

# Optical Wavelength Bands

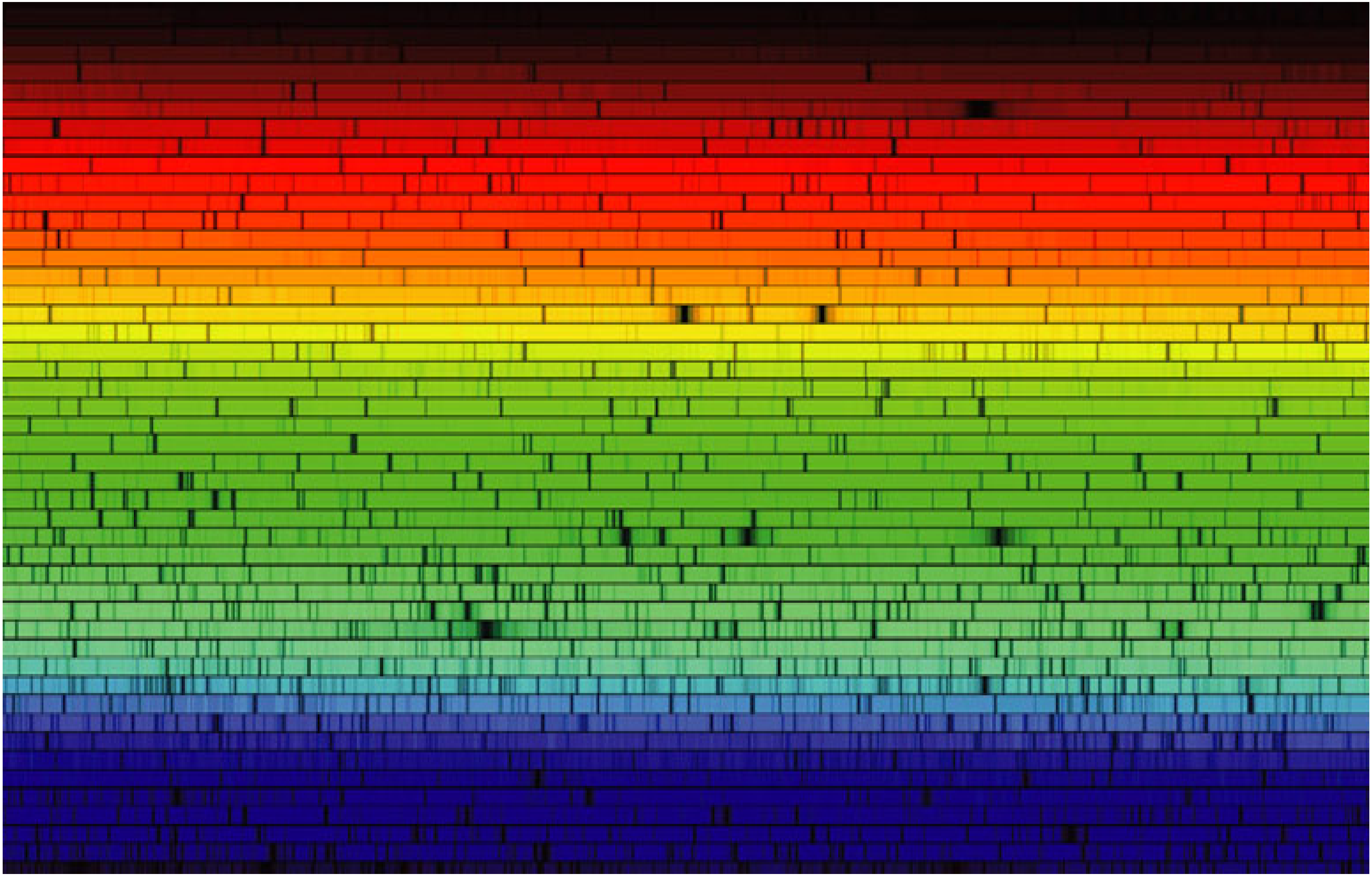



U: $\lambda_0 \approx 3650$ Å

B: $\lambda_0 \approx 4400$ Å

V: $\lambda_0 \approx 5500$ Å

# Stellar Spectra



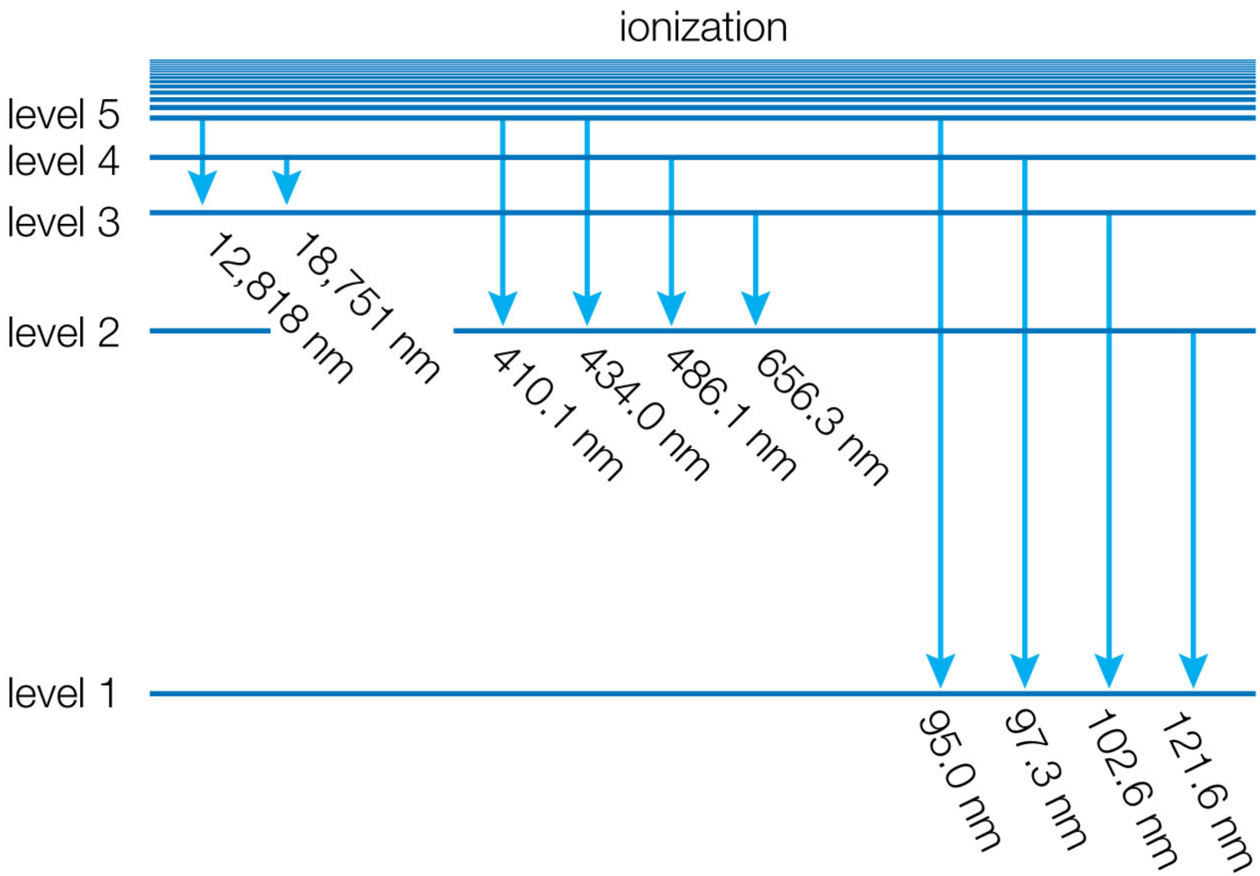
Absorption lines in the Sun’s spectrum
(Fraunhofer lines)

# Kirchoff’s laws

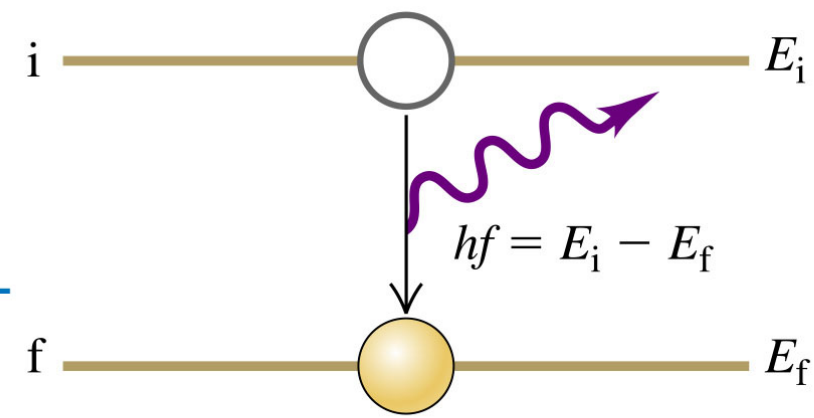
*Chemical Analysis by Spectral Observations* (Kirchoff & Bunsen)

- A hot solid, liquid, or dense gas produces a continuous spectrum.
- A thin gas in front of a cooler background produces an emission line spectrum.
- A thin gas in front of a hot source imprints absorption lines on the spectrum.  This is mainly what we see from stars.

# Chemical Fingerprints

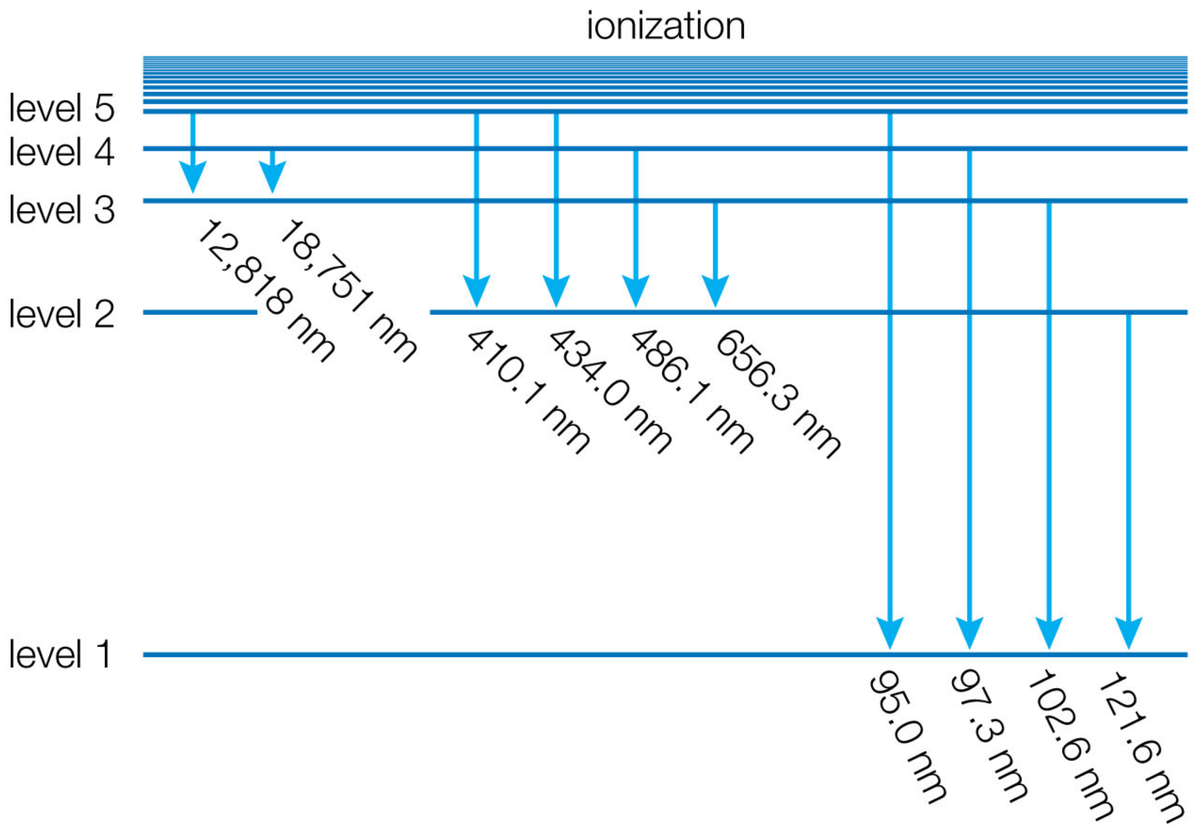



- Downward transitions produce a unique pattern of emission lines.

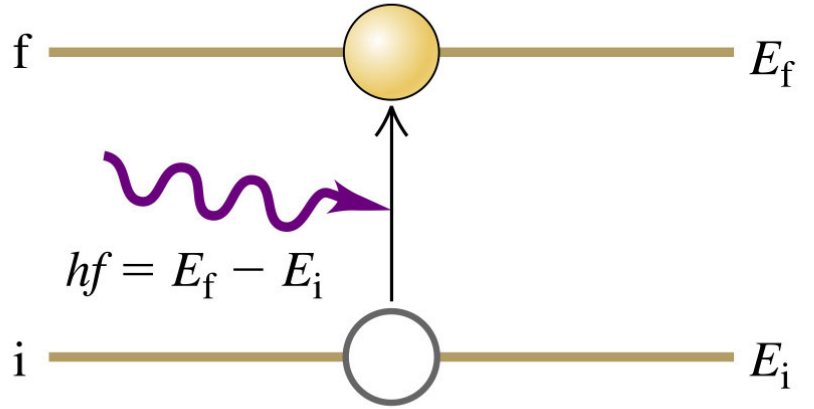




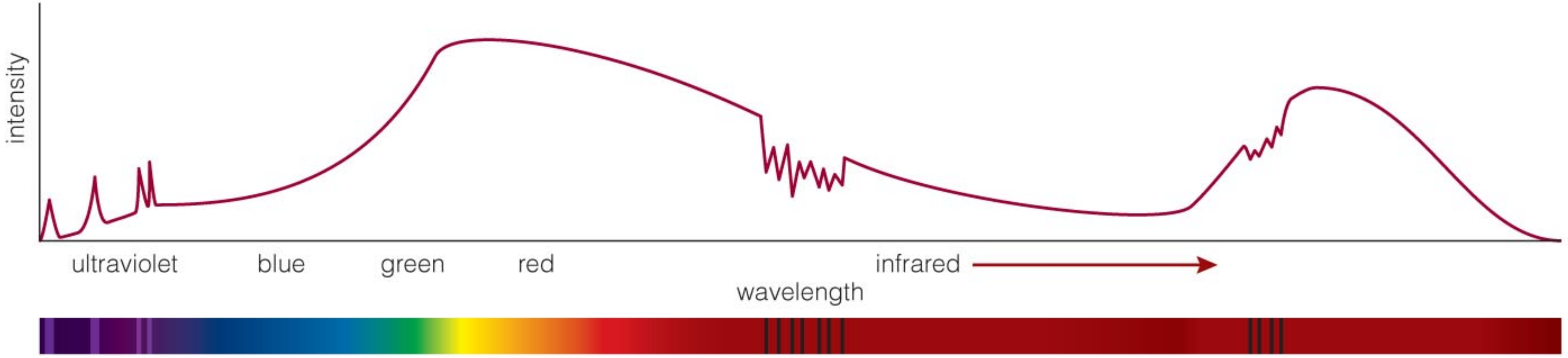

# Chemical Fingerprints




- Because those atoms can absorb photons with those same energies, upward transitions produce a pattern of absorption lines at the same wavelengths.



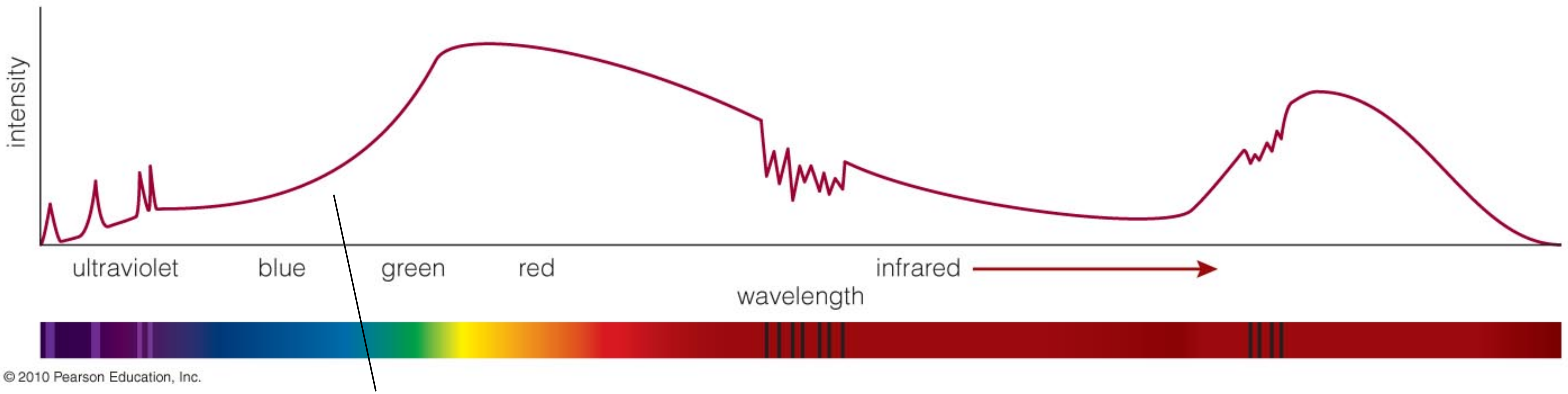

# Interpreting an Actual Spectrum





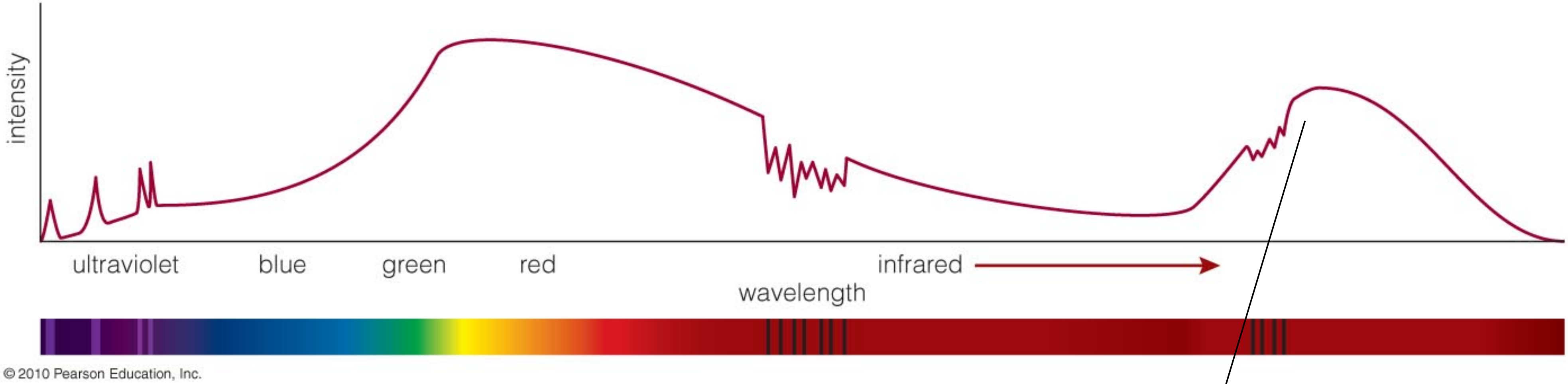

- By carefully studying the features in a spectrum, we can learn a great deal about the object that created it.

# Interpreting an Actual Spectrum



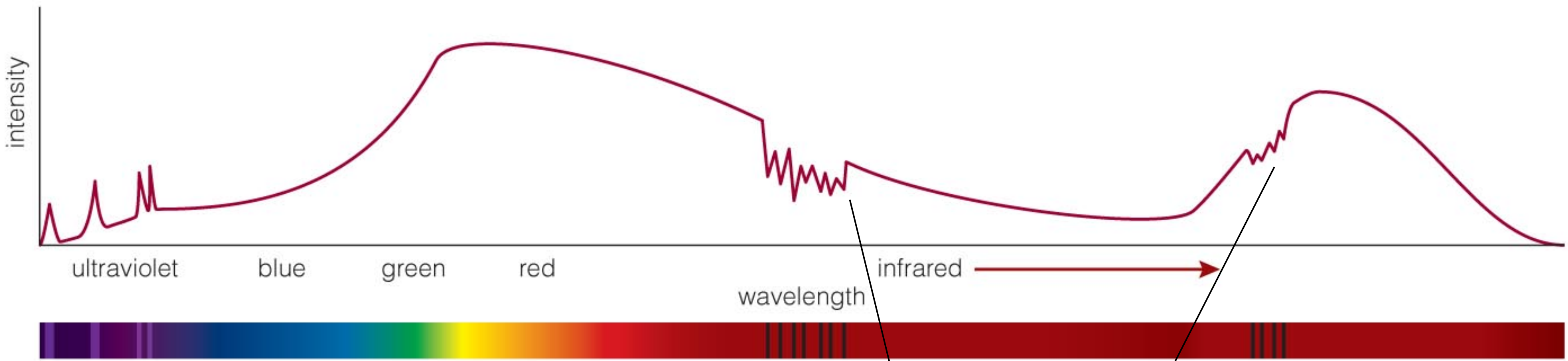

Reflected sunlight:
Continuous spectrum of
visible light is like the Sun's
except that some of the blue
light has been absorbed—
the object must look red.

# Interpreting an Actual Spectrum




Thermal radiation: Infrared spectrum peaks at a wavelength corresponding to a temperature of 225 K.

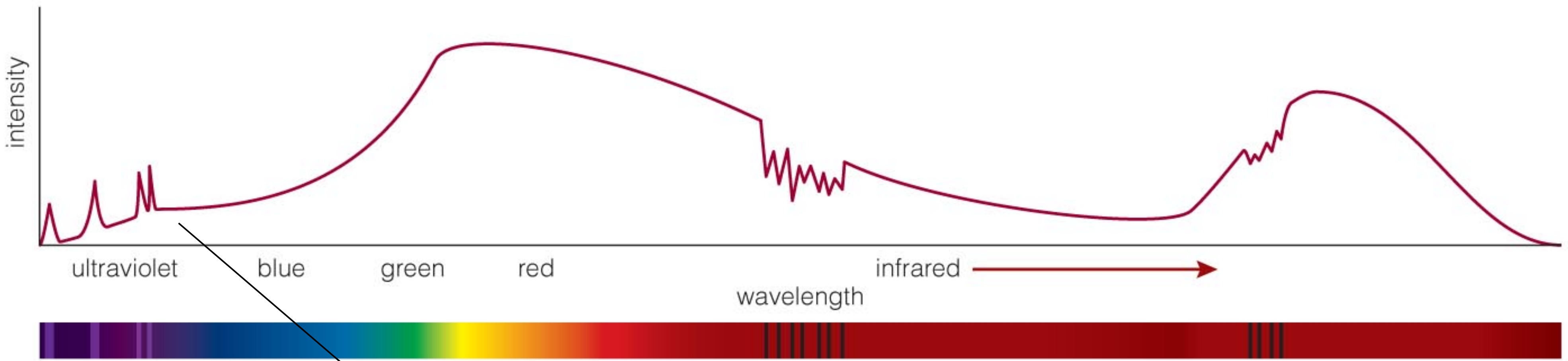
# Interpreting an Actual Spectrum






Carbon dioxide: Absorption lines are the fingerprint of $CO_2$ in the atmosphere.

# Interpreting an Actual Spectrum



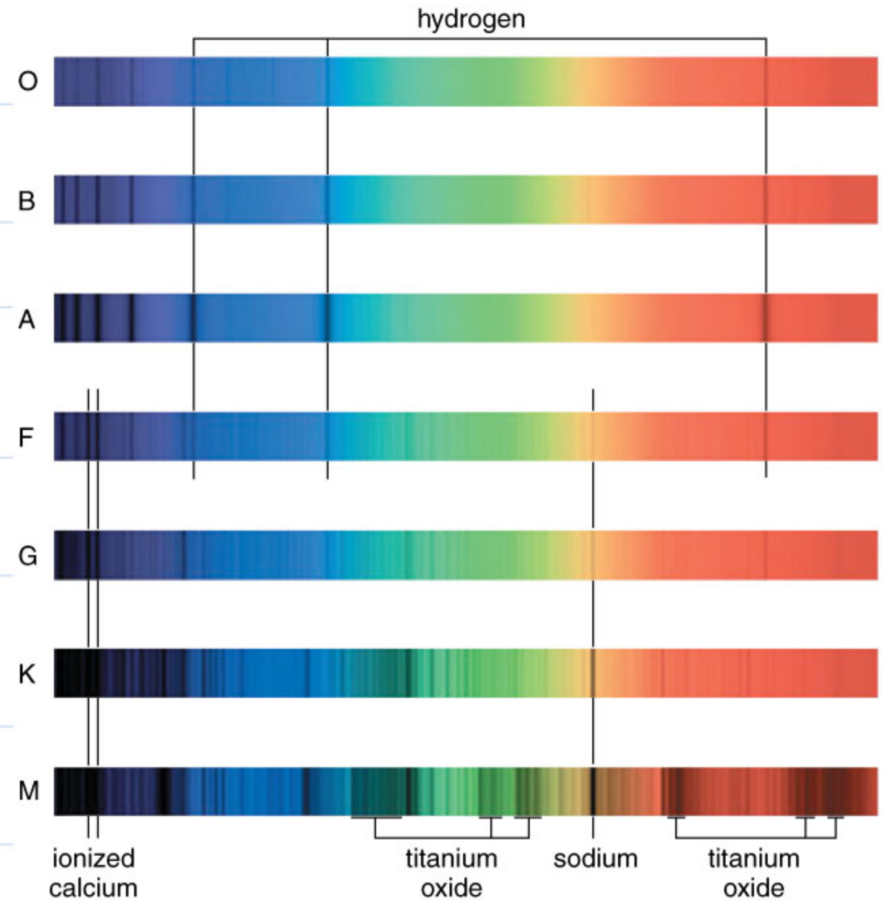


Ultraviolet emission lines:
Indicate a hot upper
atmosphere

**Table 11.1** *The Spectral Sequence*

| Spectral Type | Example(s) | Temperature Range | Key Absorption Line Features | Brightest Wavelength (color) |
|---|---|---|---|---|
| O | Stars of Orion's Belt | >30,000 K | Lines of ionized helium, weak hydrogen lines | >97 nm (ultraviolet)* |
| B | Rigel | 30,000 K–10,000 K | Lines of neutral helium, moderate hydrogen lines | 97–290 nm (ultraviolet)* |
| A | Sirius | 10,000 K–7500 K | Very strong hydrogen lines | 290–390 nm (violet)* |
| F | Polaris | 7500 K–6000 K | Moderate hydrogen lines, moderate lines of ionized calcium | 390–480 nm (blue)* |
| G | Sun, Alpha Centauri A | 6000 K–5000 K | Weak hydrogen lines, strong lines of ionized calcium | 480–580 nm (yellow) |
| K | Arcturus | 5000 K–3500 K | Lines of neutral and singly ionized metals, some molecules | 580–830 nm (red) |
| M | Betelgeuse, Proxima Centauri | <3500 K | Strong molecular lines | > 830 nm (infrared) |

Typical Spectrum

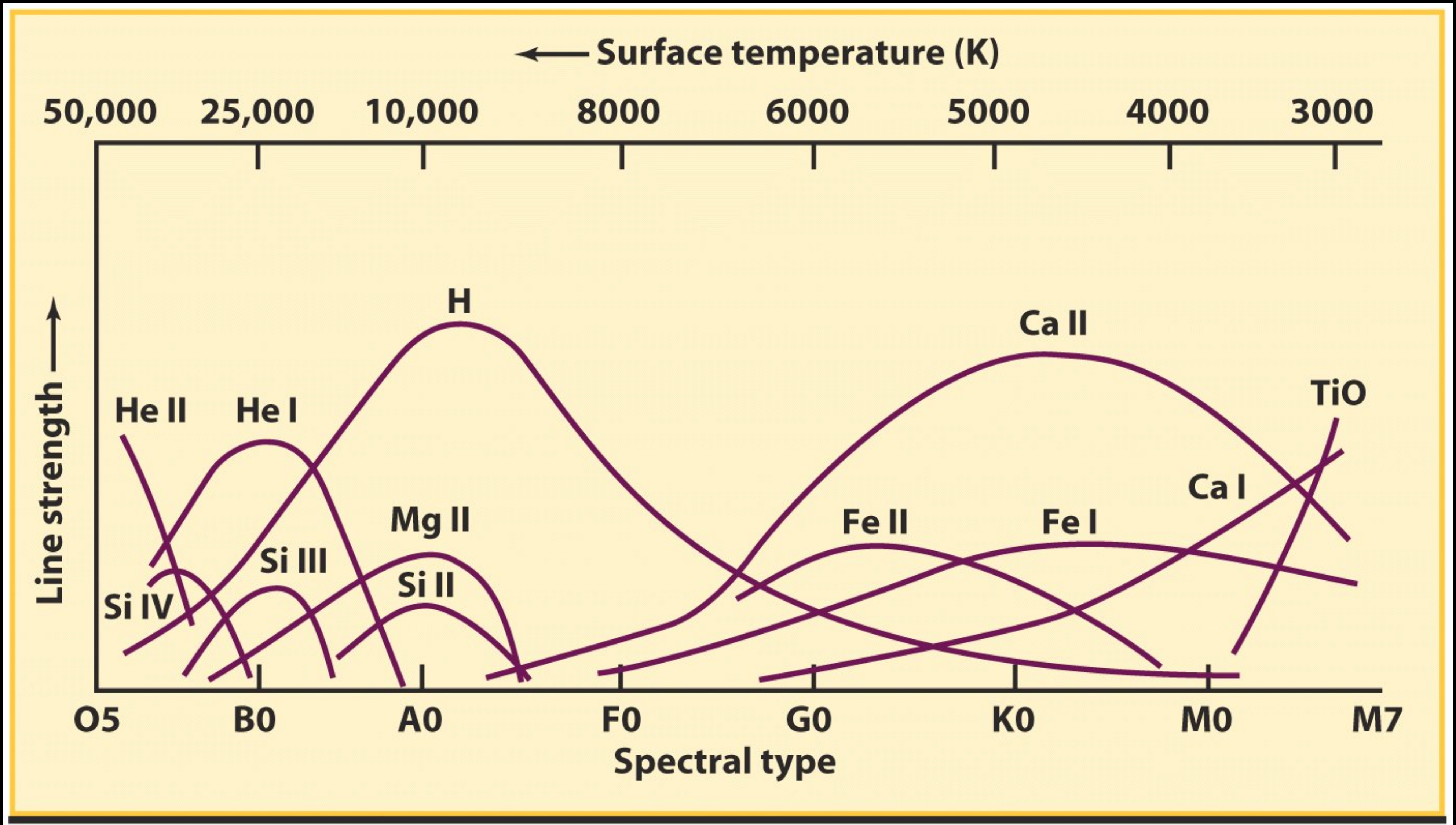



*All stars above 6000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.



Lines in a star's spectrum correspond to a ***spectral type*** that reveals its temperature:

(Hottest) O B A F G K M (Coolest)




- The spectral class of a star is directly related to its surface temperature
  - O stars are the hottest
  - M stars are the coolest

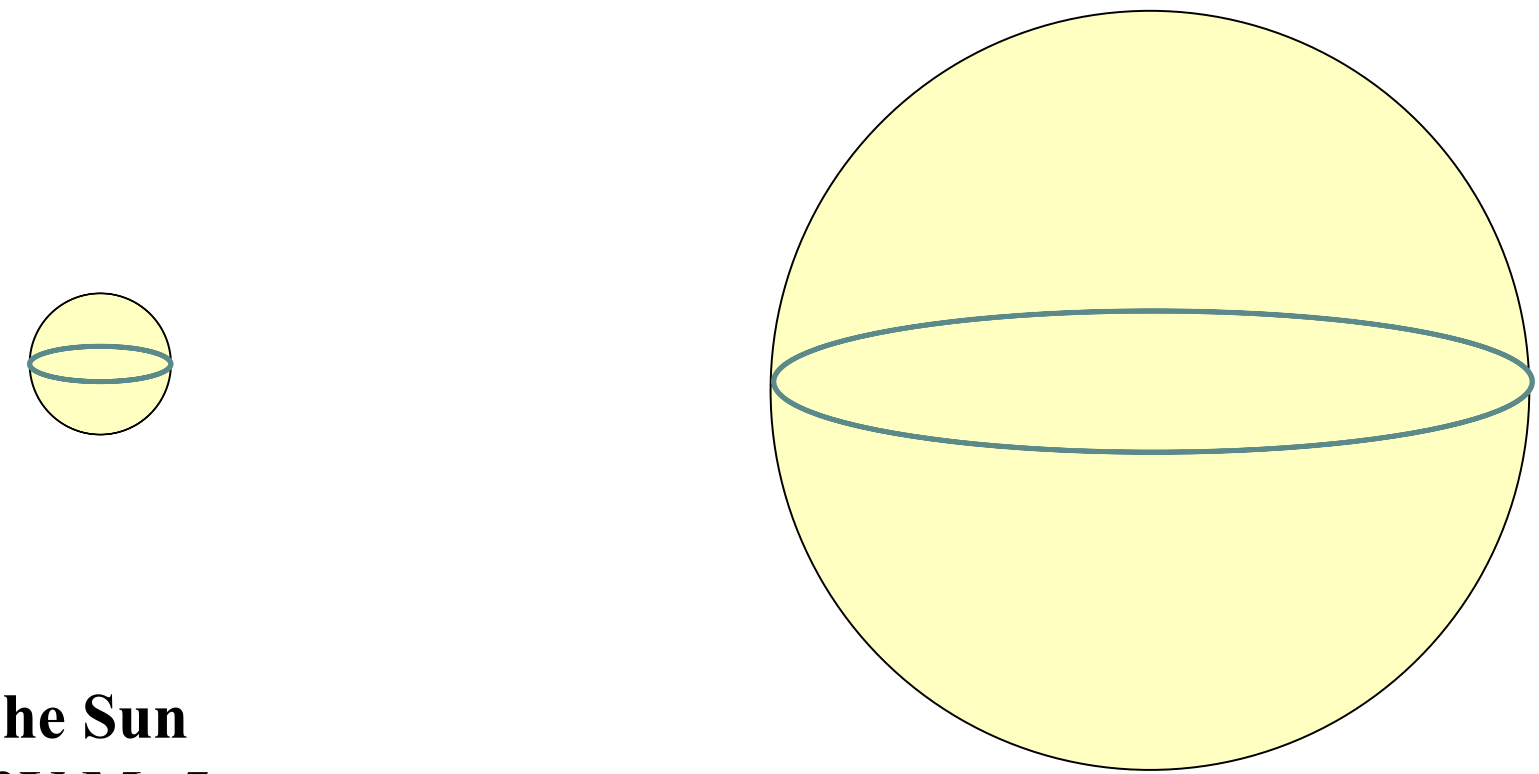
A star’s full classification includes spectral type (line identities) and luminosity class (line shapes, related to the size of the star):

| | |
|---|---|
| I | — supergiant |
| II | — bright giant |
| III | — giant |
| IV | — subgiant |
| V | — main sequence |

Examples: Sun — G2 V
Sirius — A1 V
Proxima Centauri — M5.5 V
Betelgeuse — M2 I

# Luminosity Class Implies Size

- Consider the Sun and Capella



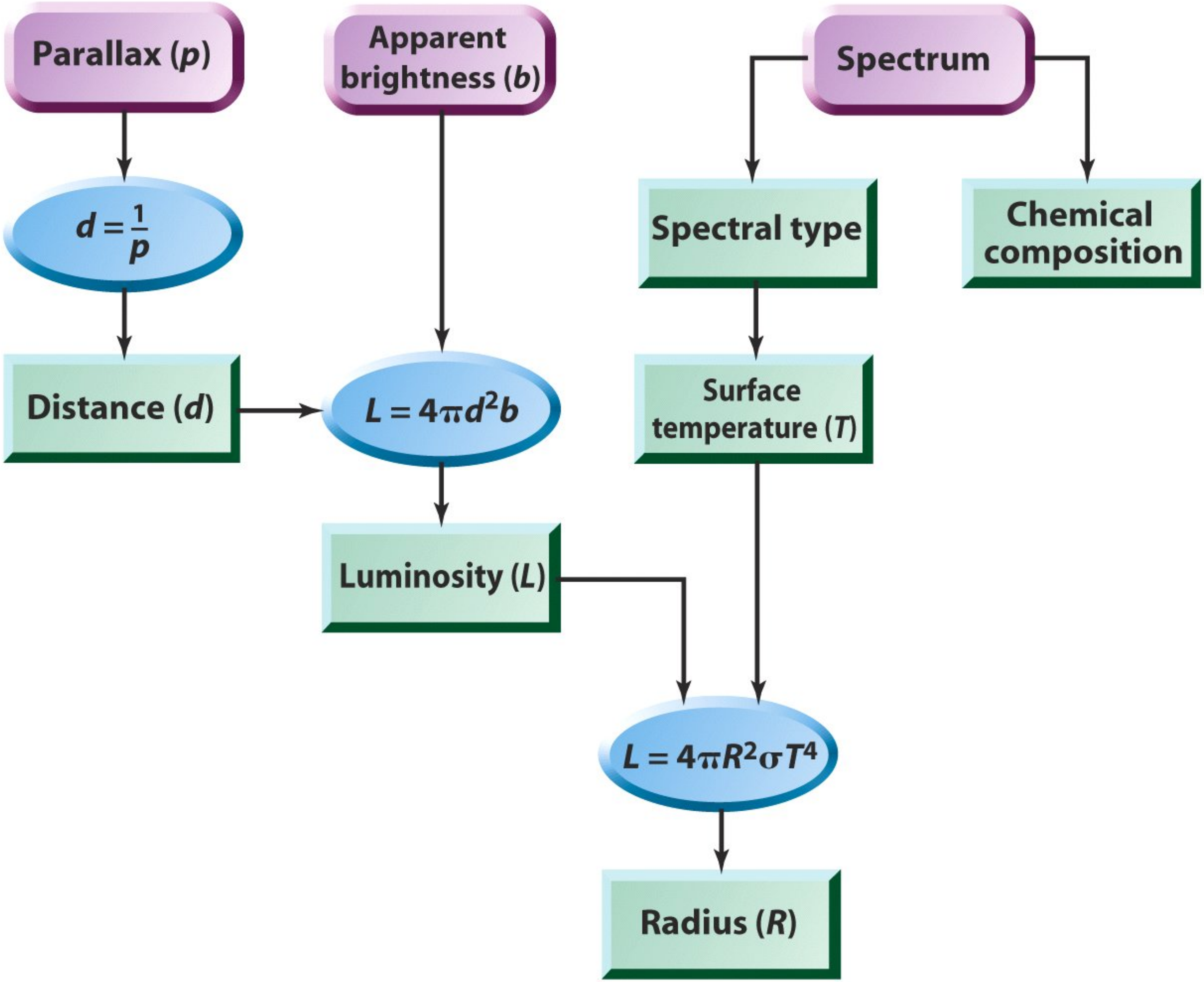
**The Sun**
**G2V M=5**

**Capella**
**G2III M=0**

# Luminosity Class Implies Size

- Equal sized pieces of each star are equally bright
- Capella is 100X brighter (5 magnitudes)
- Capella must have 100X as much area
- Surface area $\propto$ radius$^2$
- Capella must be 10X larger than Sun.

# Flowchart of Key Stellar Parameters



# Stellar Mass

- Fuel burning rate
- Lifetime $10^{10}\,\mathrm{yr}\,(M/M_{\mathrm{Sun}})^{-2.8}$
- Luminosity $L \propto M^{3.8}$
- Impossible to measure for isolated stars

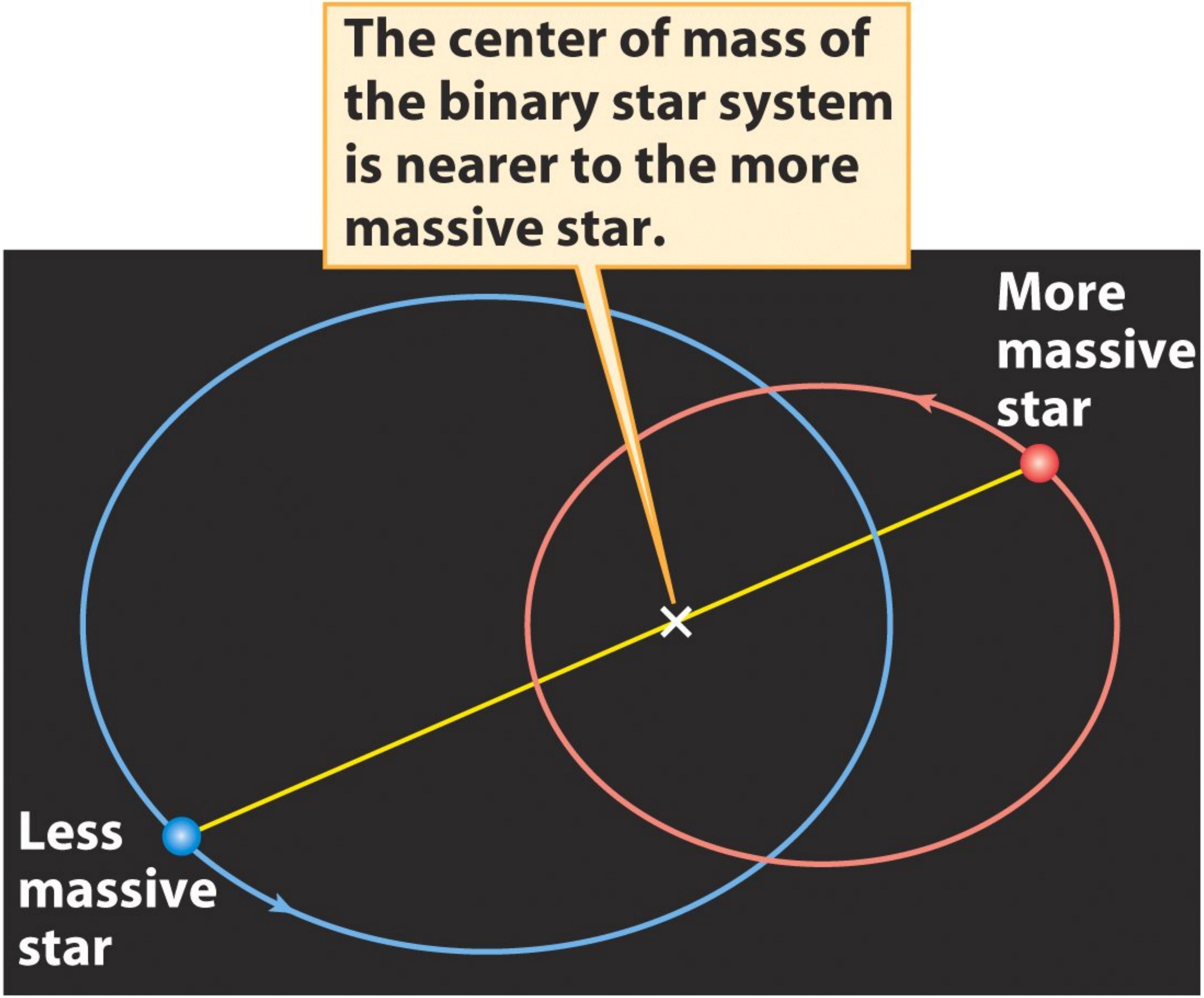
# How do we measure stellar masses?

## Binary Star Orbits

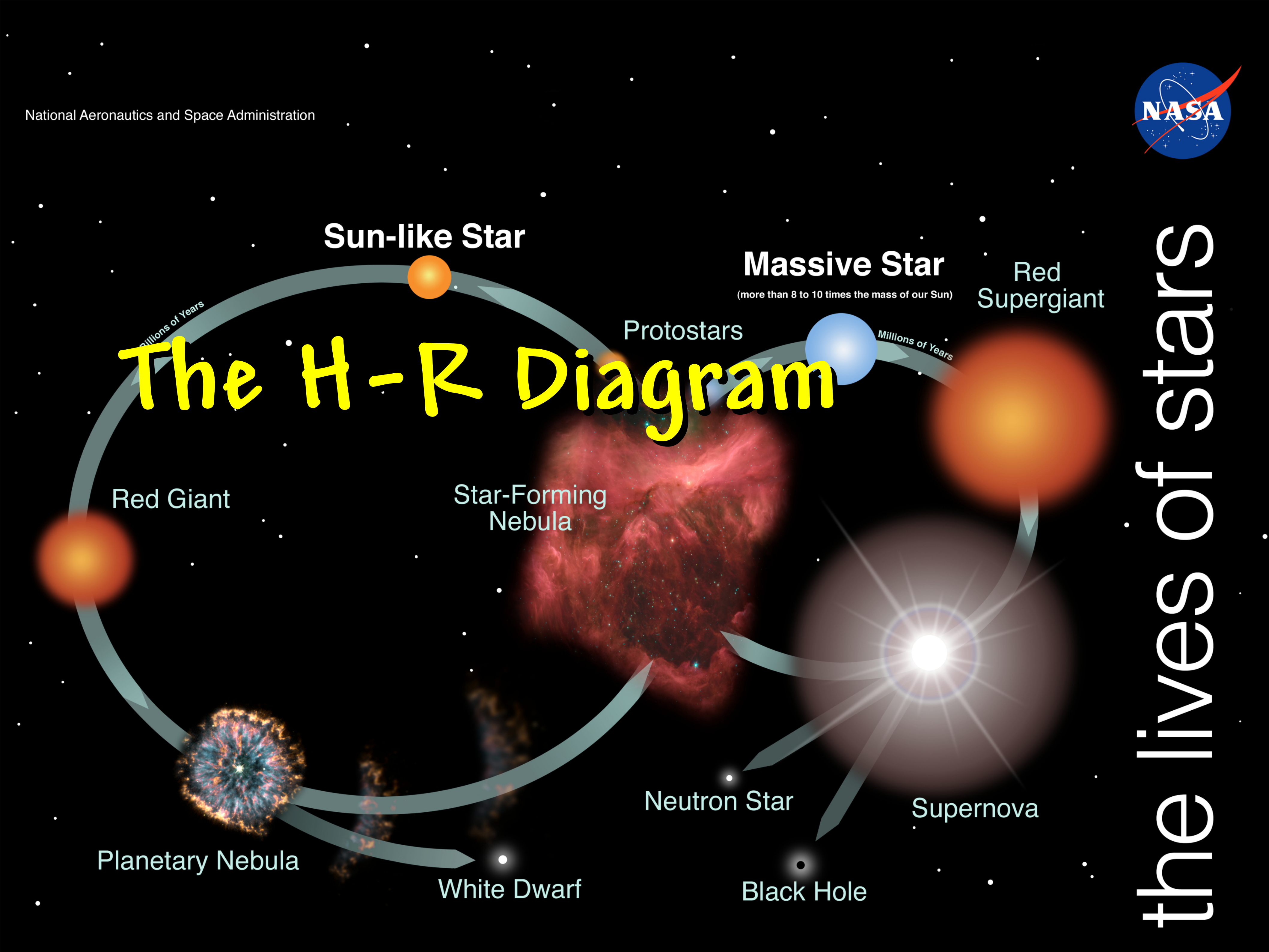
Two stars held in orbit around each other by their mutual gravitational attraction.

Each of the two stars in a binary system moves in an elliptical orbit about the center of mass of the system.

Orbit of a binary star system depends on the component masses.



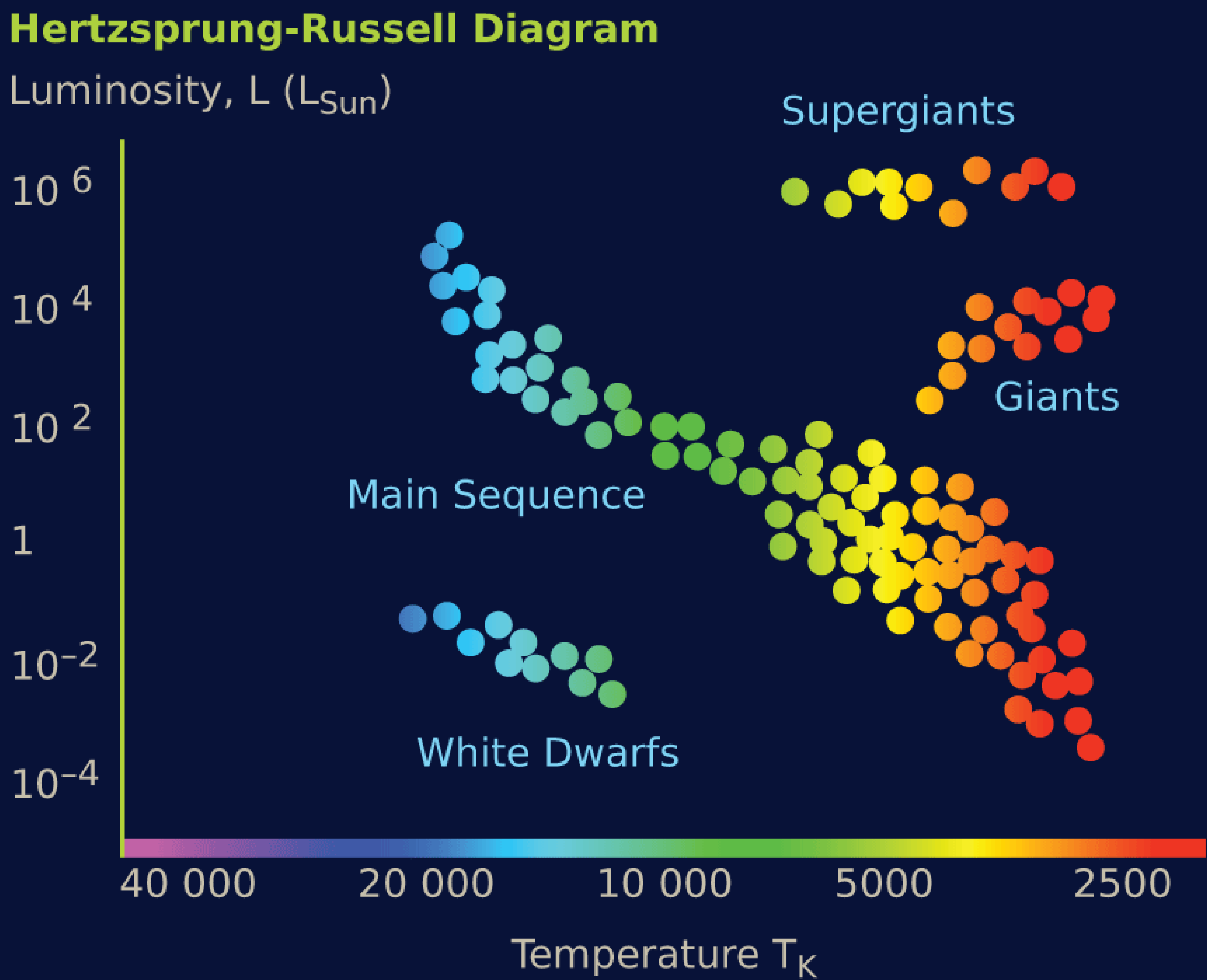
A binary star system


The H-R Diagram
National Aeronautics and Space Administration
NASA
the lives of stars
Sun-like Star
Massive Star
(more than 8 to 10 times the mass of our Sun)
Millions of Years
Millions of Years
Red Supergiant
Protostars
Red Giant
Star-Forming Nebula
Planetary Nebula
White Dwarf
Neutron Star
Black Hole
Supernova

# The Hertzsprung-Russell Diagram

- Distances
- Radial velocity
- Proper motion & tangential velocity
- Flux – distance – luminosity
- Apparent magnitudes
- Absolute magnitudes
- Spectral types
- Ionization vs temperature
- Diameters of stars
- Masses of stars
- Spectroscopic binaries
- Mass-luminosity relationship

**The Hertzsprung-Russell diagram can visualize all of these things**


Hertzsprung-Russell Diagram
Luminosity, L (L Sun)
Supergiants
Giants
Main Sequence
White Dwarfs
10 6
10 4
10 2
1
10−2
10−4
40 000
20 000
10 000
5000
2500
Temperature T K