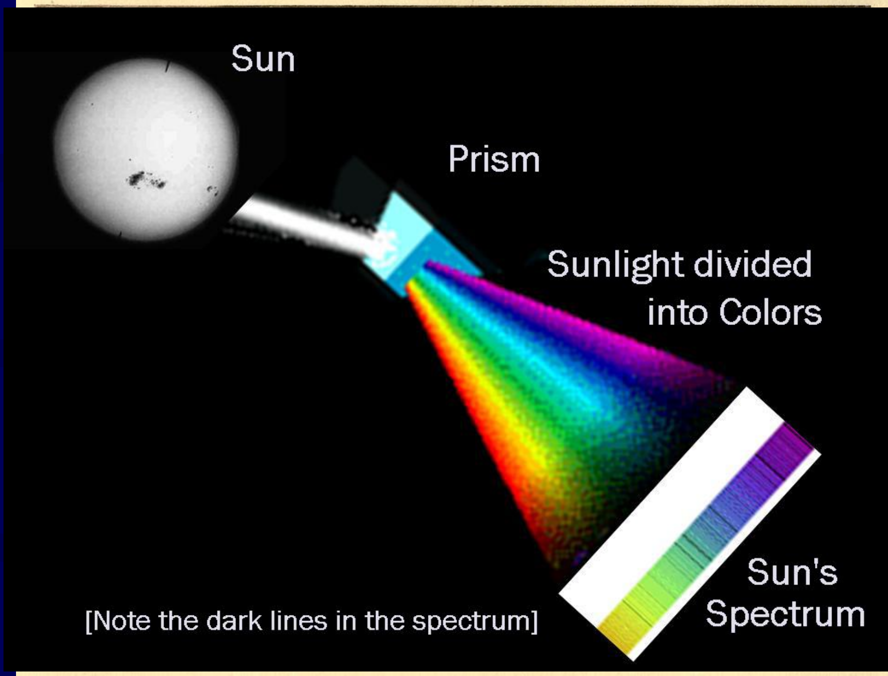
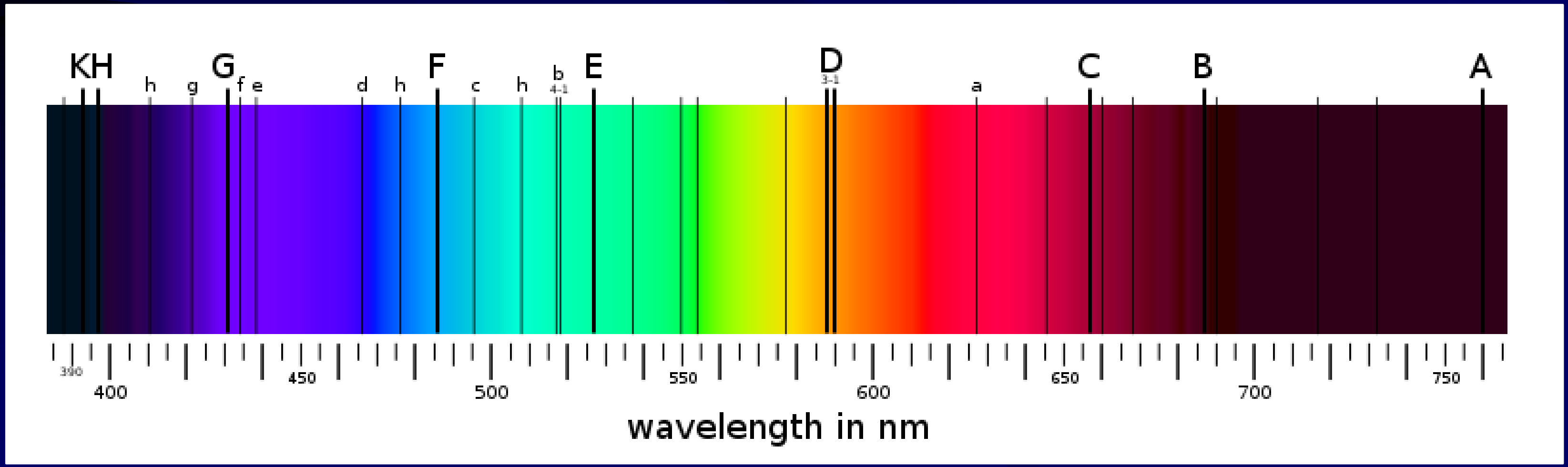
Spectra, Blackbody Radiation and Astrophyics

Fraunhofer Lines in Sunlight discovered (1814)

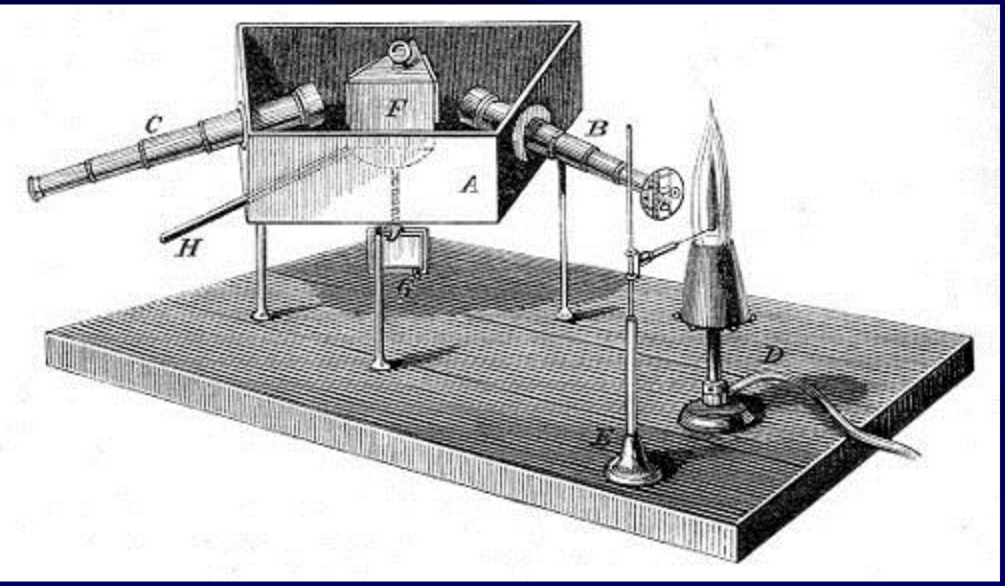


- Dark lines appear in sunlight falling through a prism, aka the spectrum of the sun



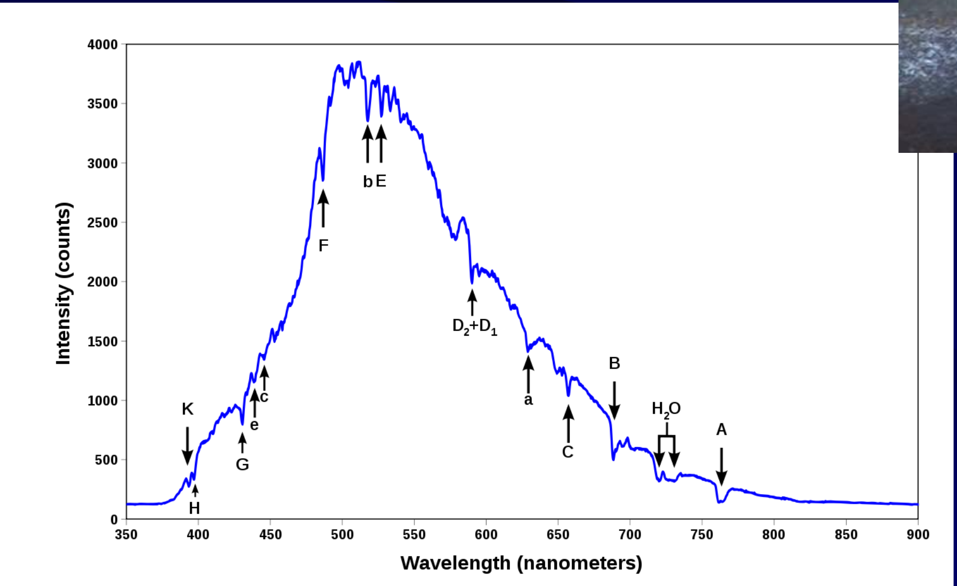
Bight lines appear in the flames of chemical elements

- Salt (sodium + chloride) flame produces a yellow double line at 589 nm.



Hot solid objects give off light at all kinds of wavelengths

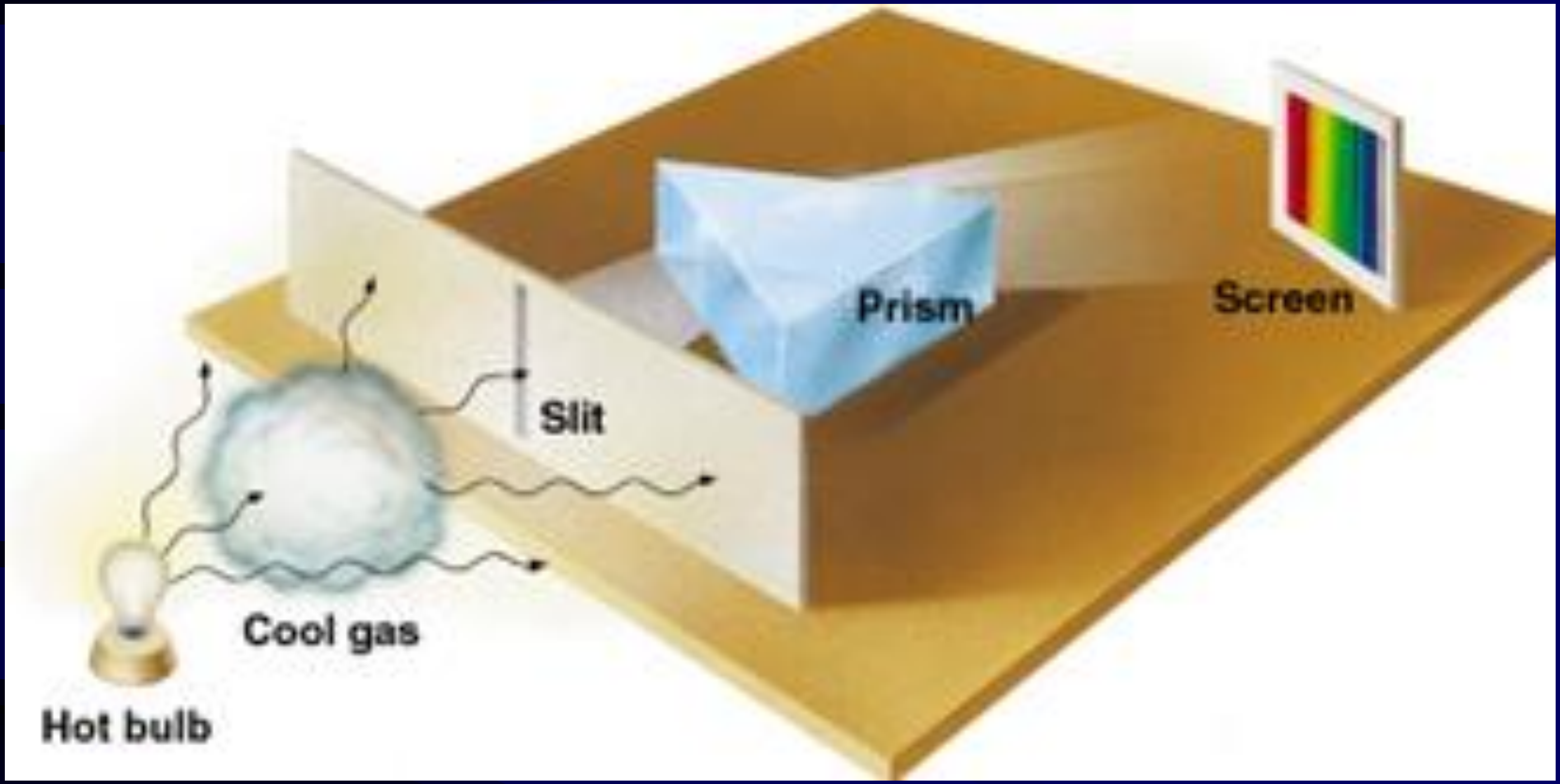
- Iron at a blacksmith
- Spectrum of the blue sky



Kirchhoff's Laws

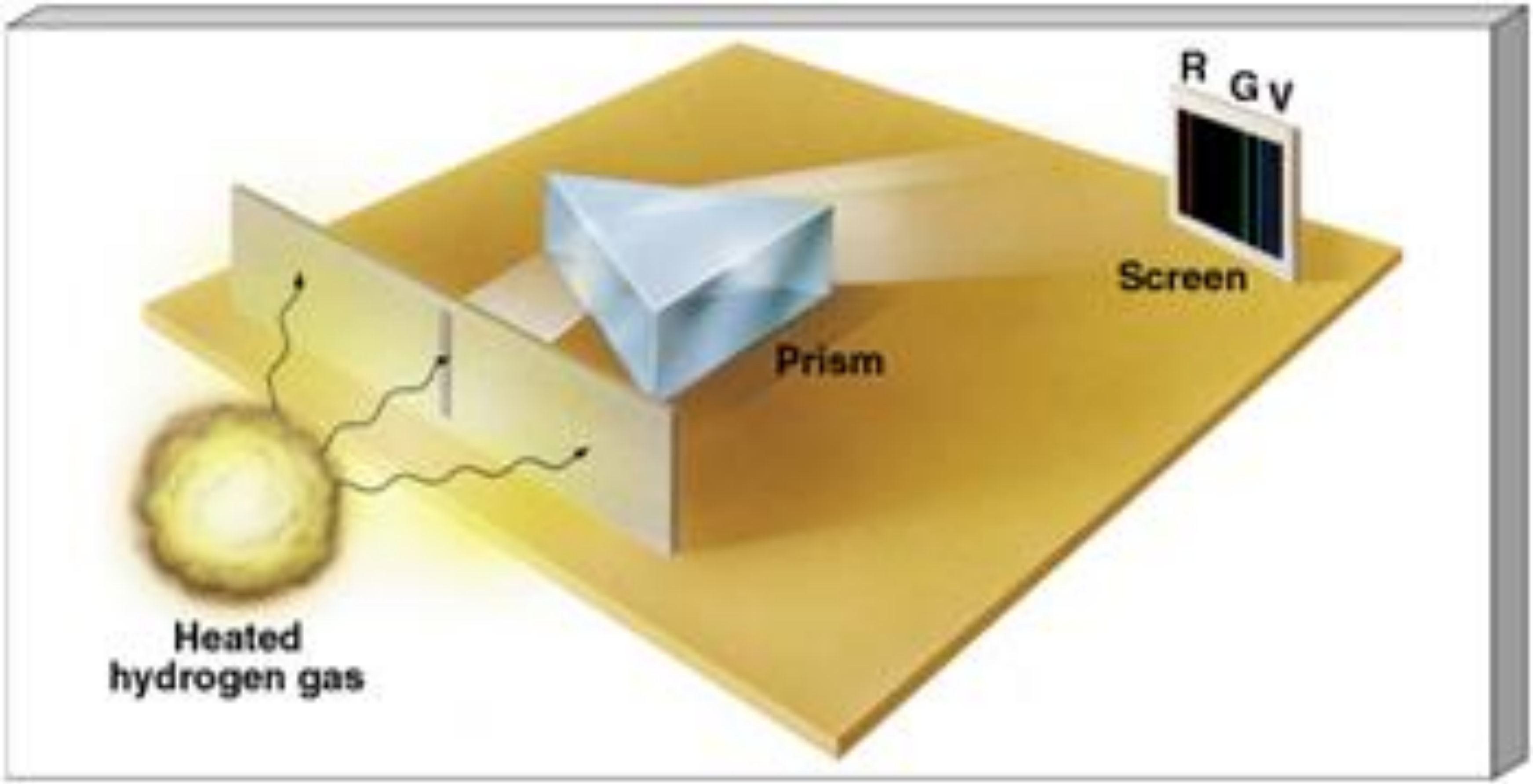
1. A luminous solid or liquid (or a sufficiently dense gas) emits light of all wavelengths: the black body spectrum
2. Light of a low density hot gas consists of a series of discrete bright emission lines: the positive "fingerprints" of its chemical elements!
3. A cool, thin gas absorbs certain wavelengths from a continuous spectrum
   ➔ dark absorption ("Fraunhofer") lines in continuous spectrum: negative "fingerprints" of its chemical elements, precisely at the same wavelengths as emission lines.

Kirchhoff's Laws: Dark Lines



Cool gas absorbs light at specific frequencies
➔ "the negative fingerprints of the elements"

Kirchhoff's Laws: Bright lines



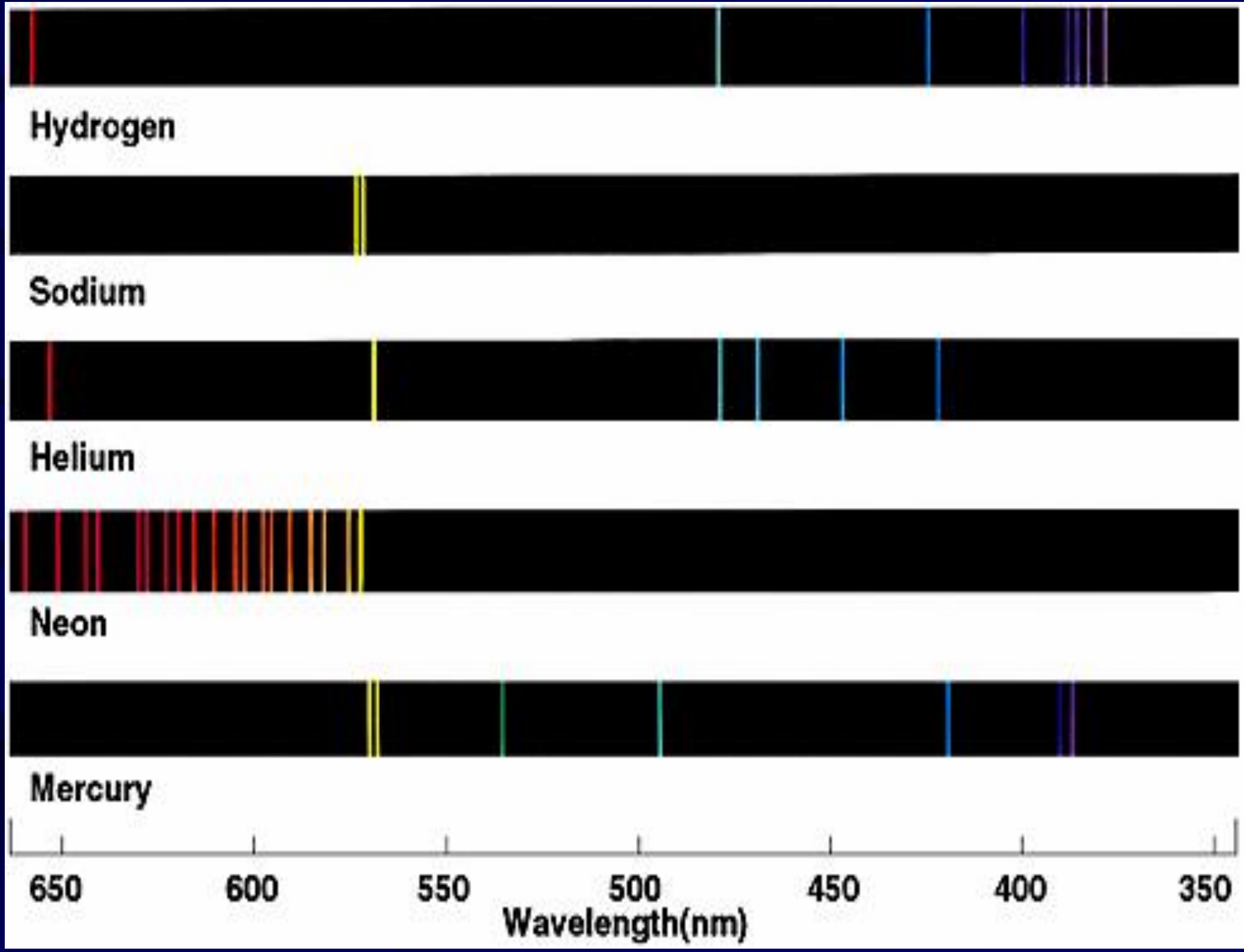
Heated Gas emits light at specific frequencies

➔ "the positive fingerprints of the elements"

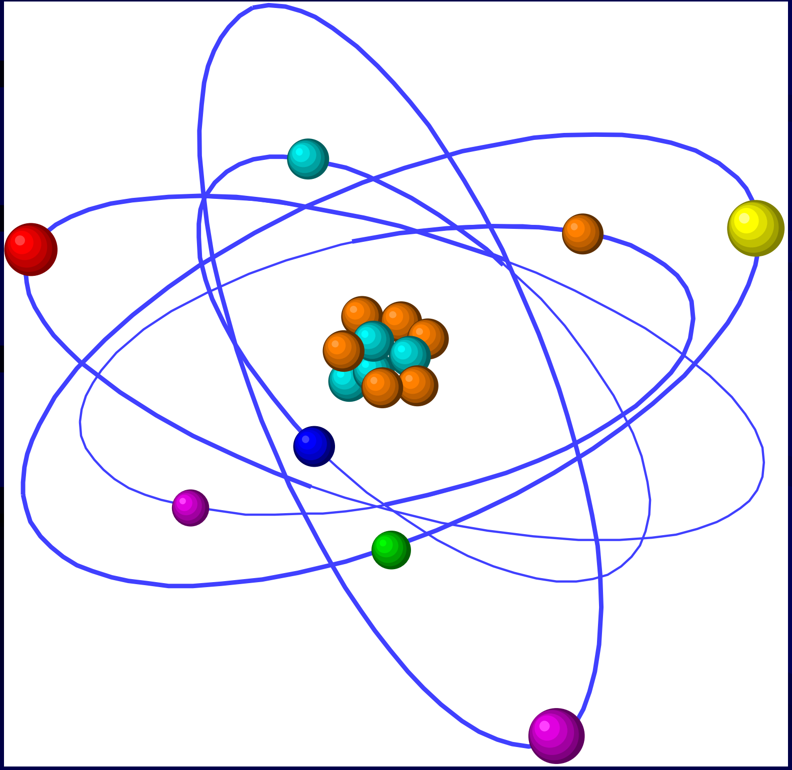
Spectral Lines – Fingerprints of the Elements

- Can use this to identify elements on distant objects!

- Different elements yield different emission spectra



Where do Spectral Lines come from?



- This was not known for another 100 years!
- The big obstacle was the discreteness of the lines: only some special selected colors or wavelengths appeared
- But nature is continuous?!
- Stay tuned!
-

Energy & Power Units

- Energy has units Joule (J)
- Rate of energy expended per unit time is called power, and has units Watt (W)
- Example: a 100 W = 100 J/s light bulb emits 100 J of energy every second
- Nutritional Value: energy your body gets out of food, measured in Calories = 1000 cal = 4200 J
- Luminosity is the same as power radiated

Stefan's Law

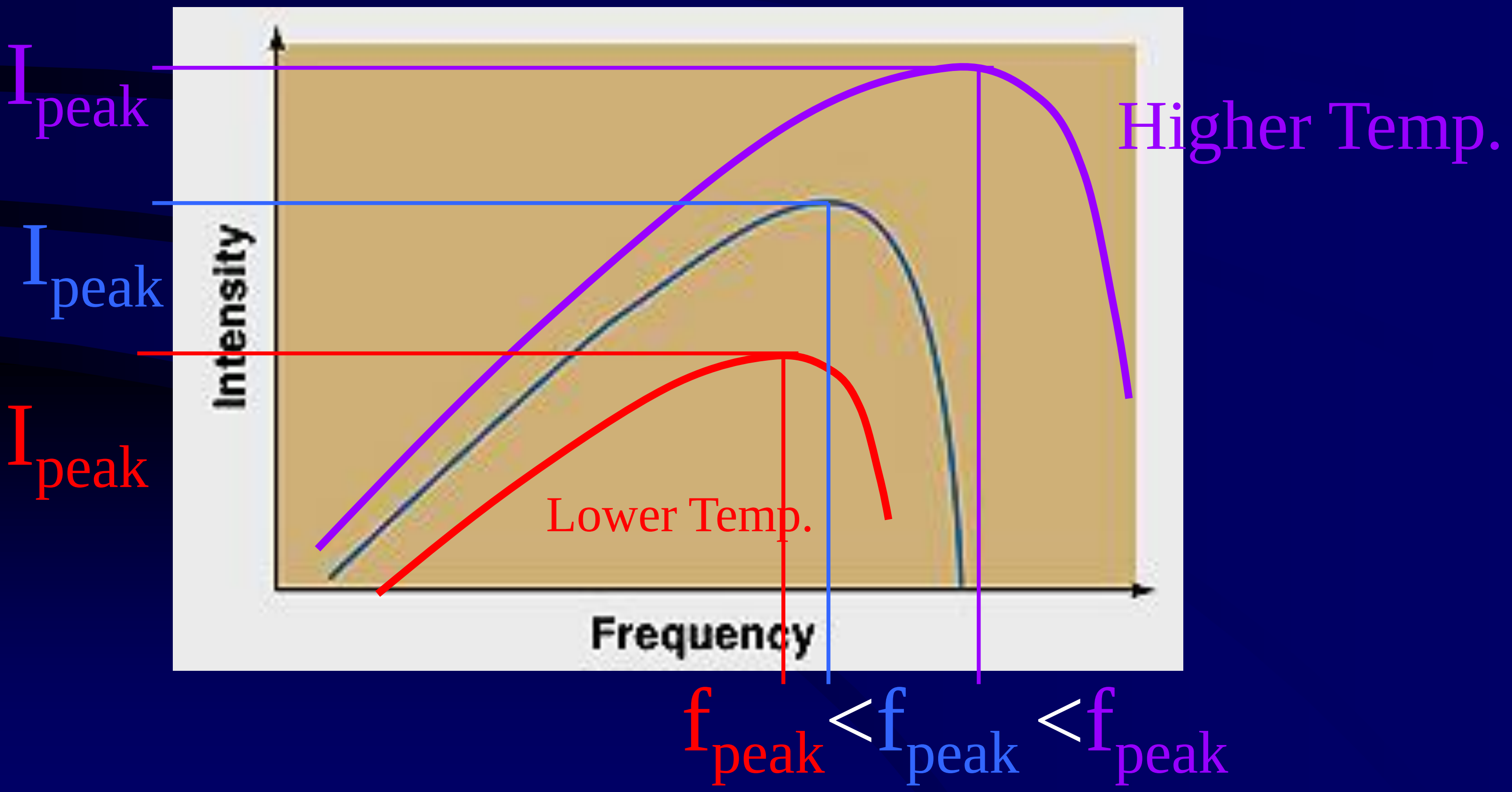
- A point on the Blackbody curve tells us how much energy is radiated per frequency interval
- Question: How much energy is radiated in total, i.e. how much energy does the body lose per unit time interval?
- Stefan(-Boltzmann)'s law: total energy radiated by a body at temperature T per second: $P = A \sigma T^4$
- $\sigma = 5.67 \times 10^{-8} W/(m^2 K^4)$

Example: Stefan-Boltzmann Law

- Sun T=6000K, Earth t=300K (or you!)
- How much more energy does the Sun radiate per time per unit area?
- Stefan: Power radiated is proportional to the temperature (in Kelvin!) to the fourth power
- Scales like the fourth power!
- Factor $f=T/t=20$, so $f^4 = 20^4 = 2^4 x 10^4 = 16 x 10^4$
- ➔160,000 x

Black Body Spectrum

- Objects emit radiation of all frequencies, but with different intensities

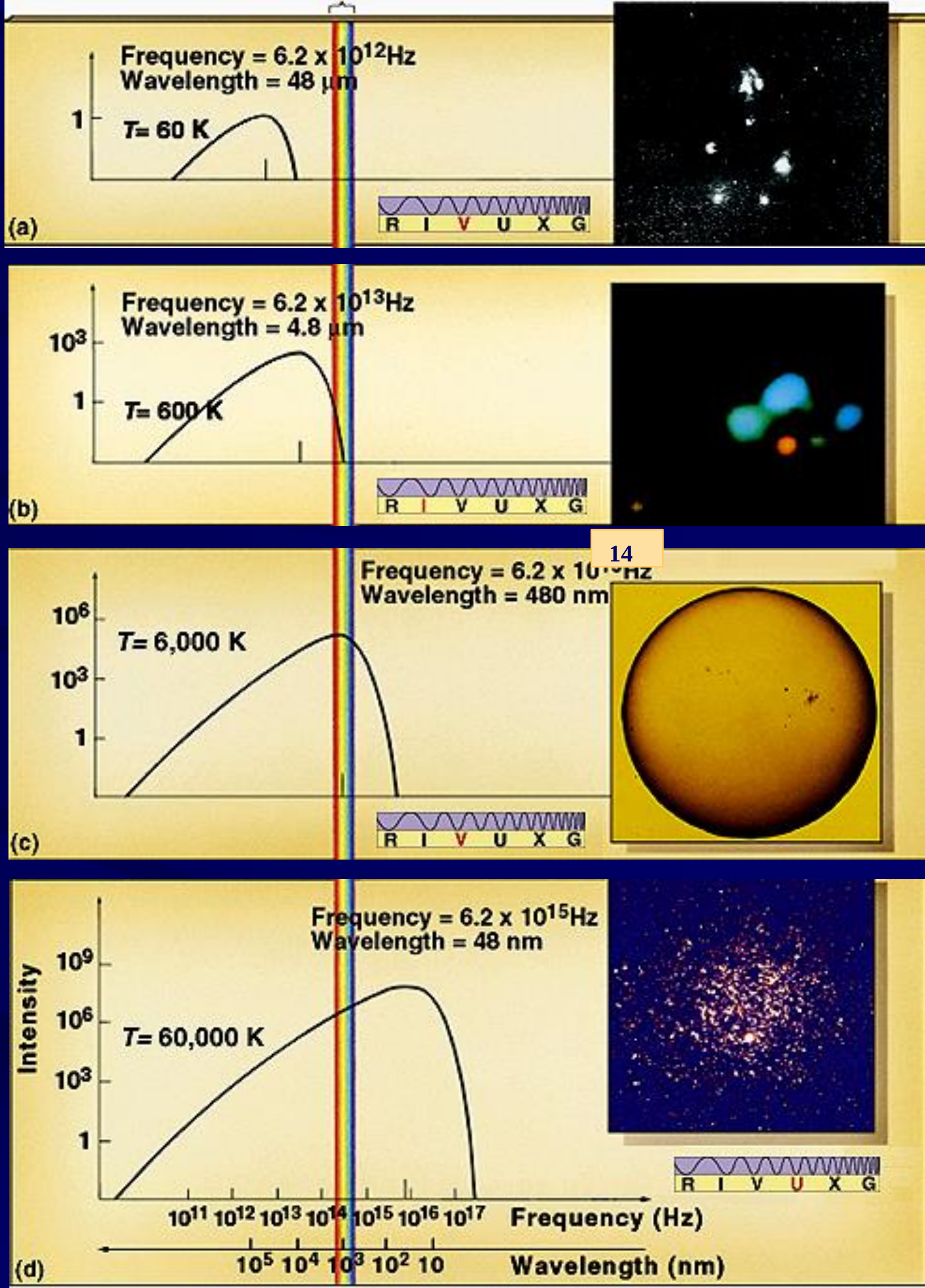


Cool, invisible galactic gas (60 K, f_{peak} in low radio frequencies)

Dim, young star (600K, f_{peak} in infrared)

The Sun's surface (6000K, f_{peak} in visible)

Hot stars in Omega Centauri (60,000K, f_{peak} in ultraviolet)



The higher the temperature of an object, the higher its I_{peak} and f_{peak}

Wien's Law

- The peak of the intensity curve will move with temperature, this is Wien's law:

Temperature * wavelength = constant

= 0.0029 K*m

So: the higher the temperature T, the smaller the wavelength, i.e. the higher the energy of the electromagnetic wave

Example

- Peak wavelength of the Sun is 500nm, so

  $T = (0.0029\ K*m)/(5 \times 10^{-7}\ m) = 5800\ K$

- Instructor temperature: roughly 100 °F = 37°C = 310 K, so

  wavelength = (0.0029K*m)/310 K

  $= 9.35 * 10^{-6}$ m

  = 9350 nm → infrared radiation

  ≈ 10 μm = 0.01 mm