Reading: OpenStax, Chapter 5, Section 5.2; Chapter, Section 17.2

Brief review of last time: **Universal Forces & Messengers from the Cosmos**

- Four fundamental forces: gravity, electromagnetism, strong and weak nuclear
- Light from electromagnetism
- Gravitational waves (very brief intro)

Today: **Thermal Radiation — the light from stars**

- Blackbody radiation
- Can learn a LOT about stars just from their light
- Very brief intro to spectroscopy

Light

- (almost) the only way to learn about stars and (almost) everything else in the Universe
- we MUST squeeze out all we can from the feeble light from the stars

What Light Can Tell Us:

- location in space
- energy output
- temperature
- composition
- motion through space
- etc . . .

Measuring Light

- **Luminosity**
  - total rate of energy emission
  - intrinsic to the star

$$L = \frac{\text{energy}}{\text{time}}$$ “ergs per second”

Think “lightbulb” — luminosity measured in Watts
(different units than ergs/sec)

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  - rate of energy passage through a fixed area:
  - depends on distance

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- **INVERSE SQUARE LAW OF LIGHT**

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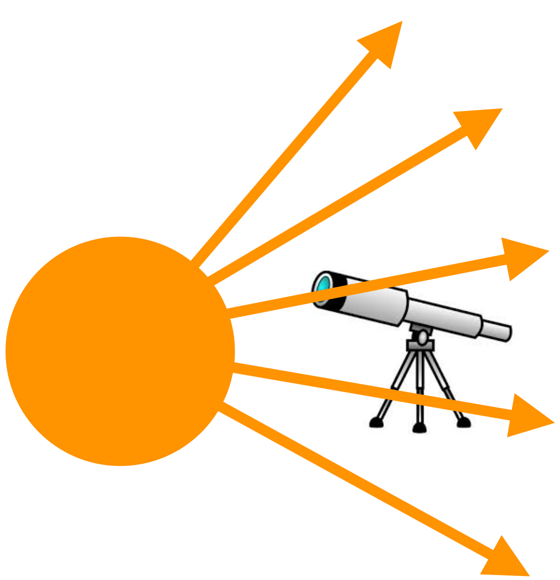

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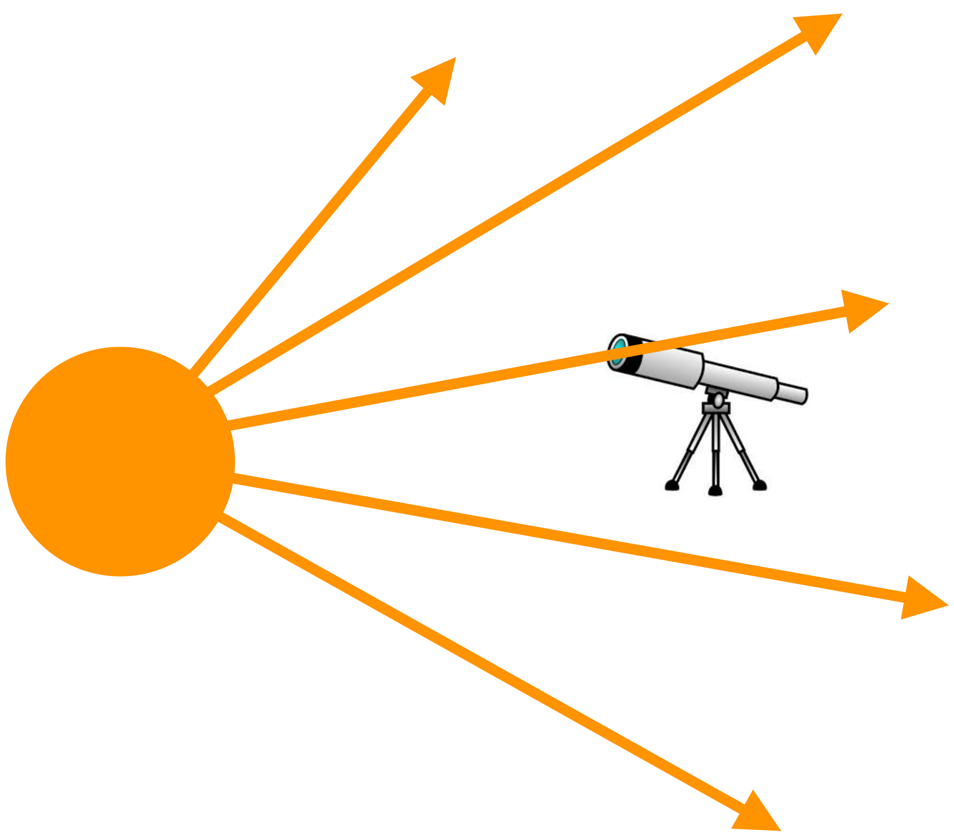

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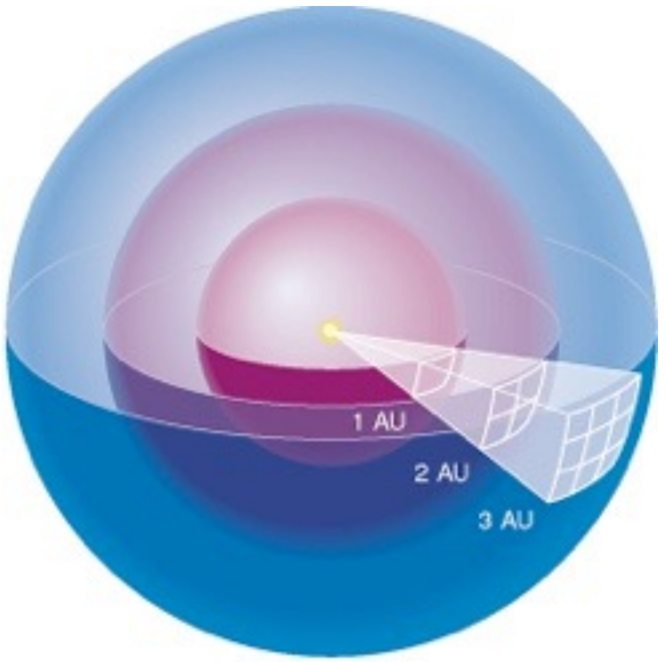
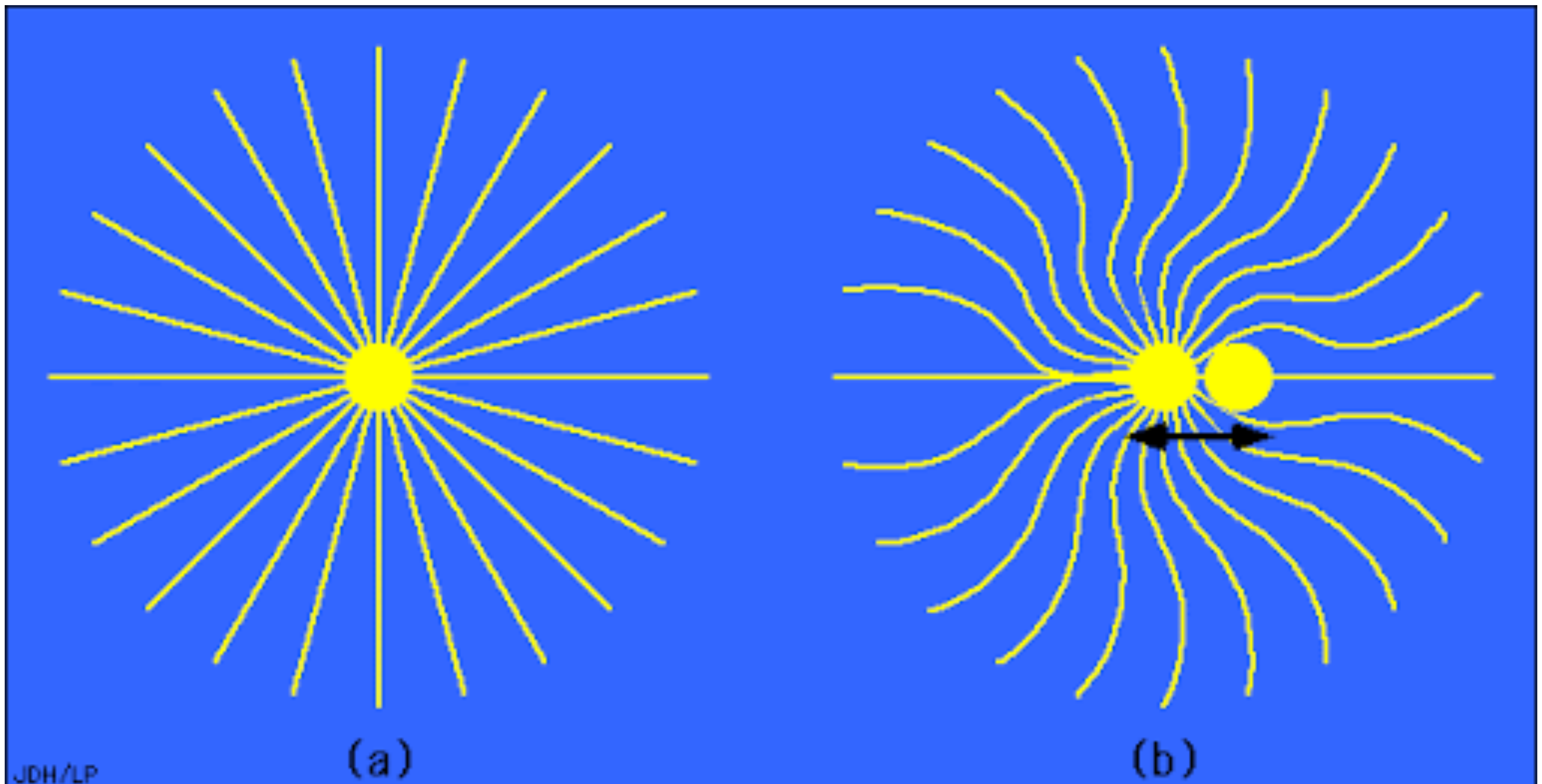
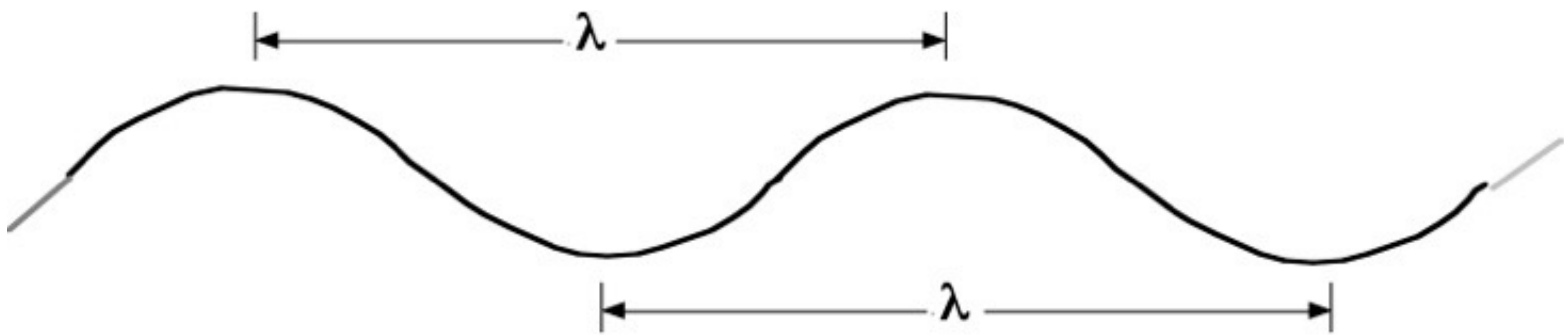


Electromagnetic waves are light



Electric field lines around an electron (a) become wavy as the electron vibrates back and forth (b). The moving electron also generates a magnetic field that forms waves that reinforce the electrical waves and vice versa.

Wave Properties of Light



- "**Wavelength**" (λ)
  - distance between successive crests (or troughs)
- "**Frequency**" (***f***)
  - number of waves passing a point in 1 second
- "**speed of wave**" (***v*** or ***c***)
  - = wavelength x frequency

$$\boldsymbol{v} = \lambda \times f$$

$$V_{sound} = 340 \text{ meters / second}$$

$$\mathbf{V_{light} = c = 3 \times 10^{8} \text{ meters/ second}}$$

Newton (again! — yes, he was a genius)

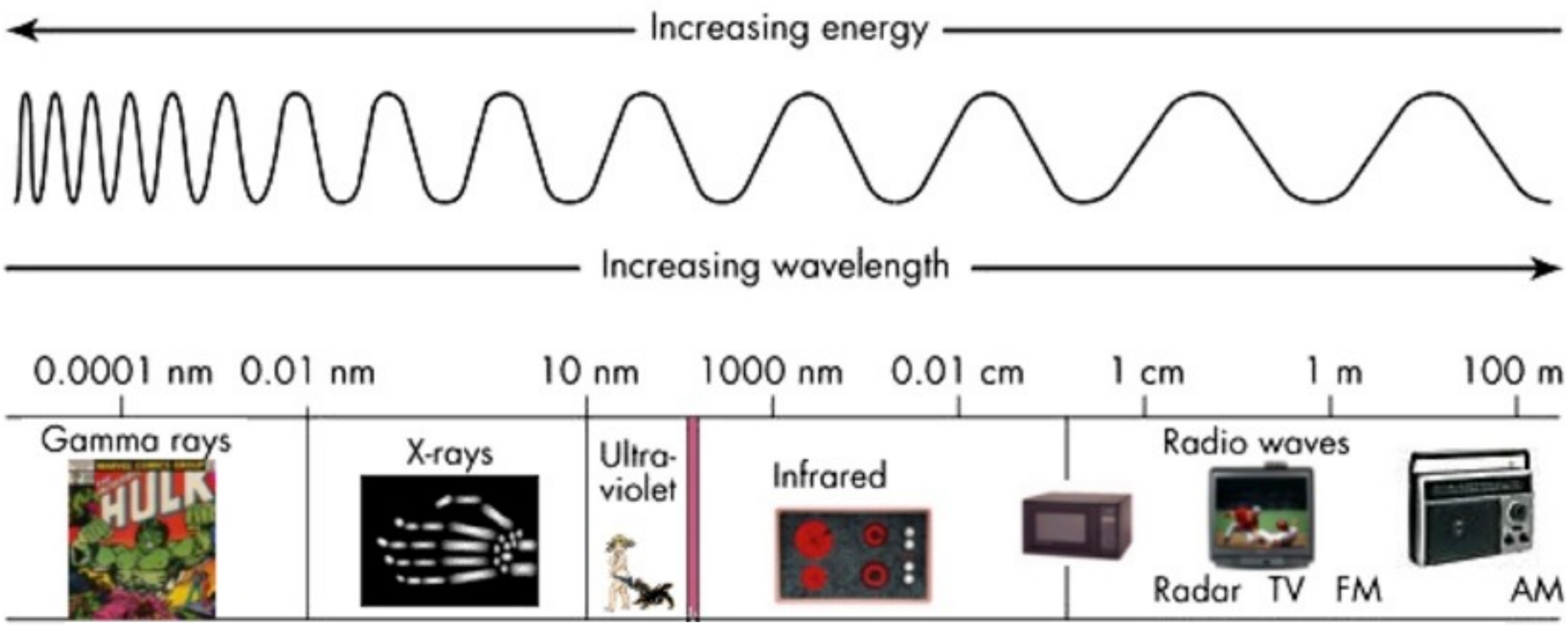
showed that white light is composed of many colors . . .
the **RAINBOW**

- Sound: different wavelength <–> different pitch
- Light: different wavelength <–> different color
- visible light has very short wavelength
  - blue: $\lambda = 4\text{x}10^{-7}$ meters
  - red: $\lambda = 7\text{x}10^{-7}$ meters
- new unit: the "nanometer" (nm) = 10^{-9} meter

visible light: λ = 400 to 700 nm

The Electromagnetic Spectrum

- visible light ranges from 400 nm to 700 nm
- Usable e-m radiation from 0.001nm to >10 km

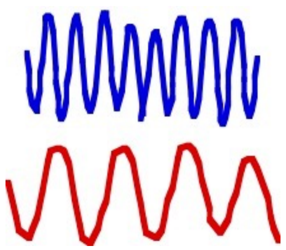


Fun fact: microwave radiation is very easily absorbed by water!

Particle-like Properties of Light

1890-1905 - early quantum mechanics

- light is made of particles called **photons**
- energy of photon is proportional to frequency:

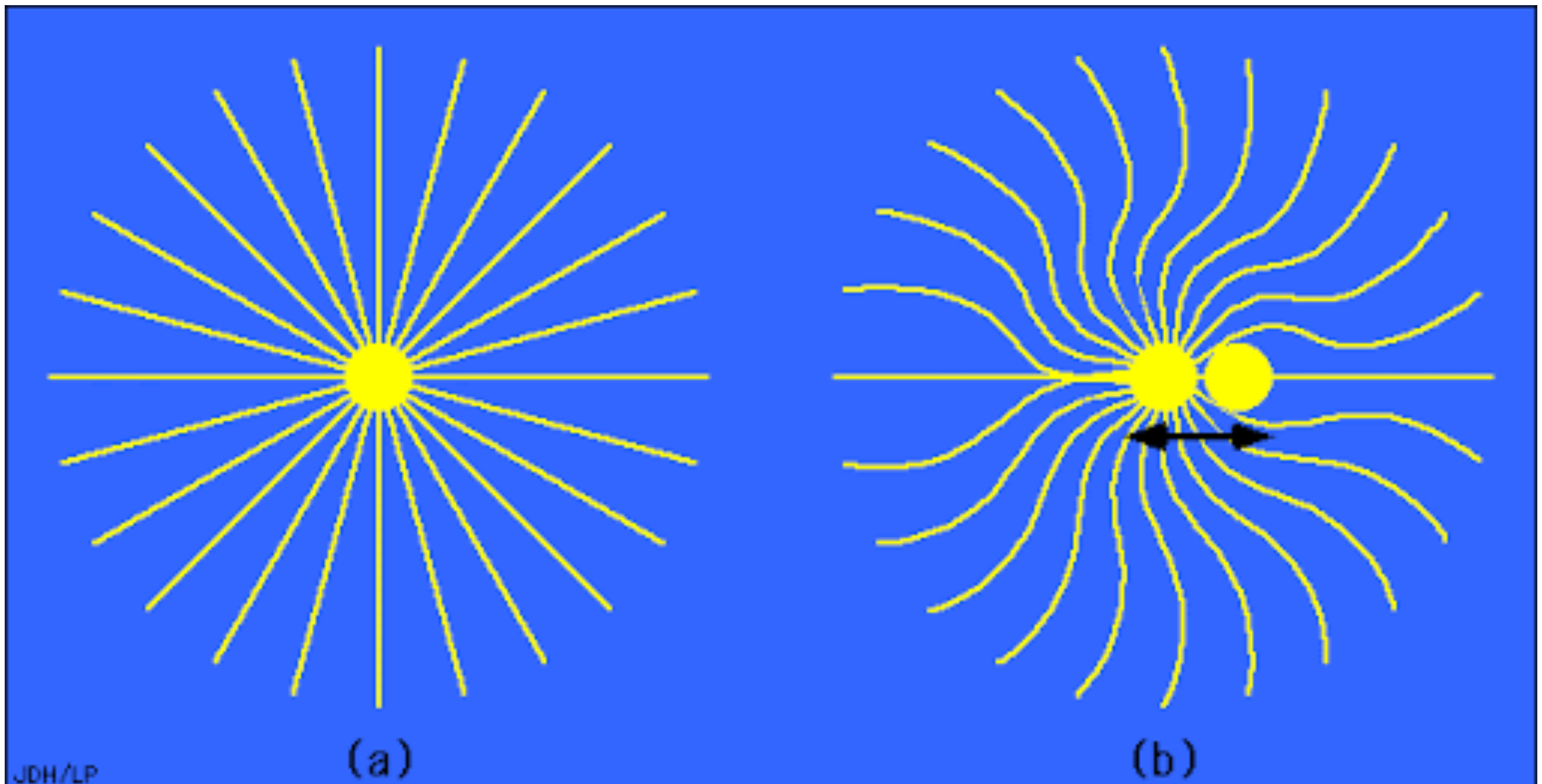


$$E_{photon} \propto f$$

- High Frequency (short wavelength) = high energy photon
- Low frequency (long wavelength) = low energy photon

- **“Blue” light = *higher energy* photons**
- **“Bright“ light = *lots* of photons**

Reminder:
Moving charges create light



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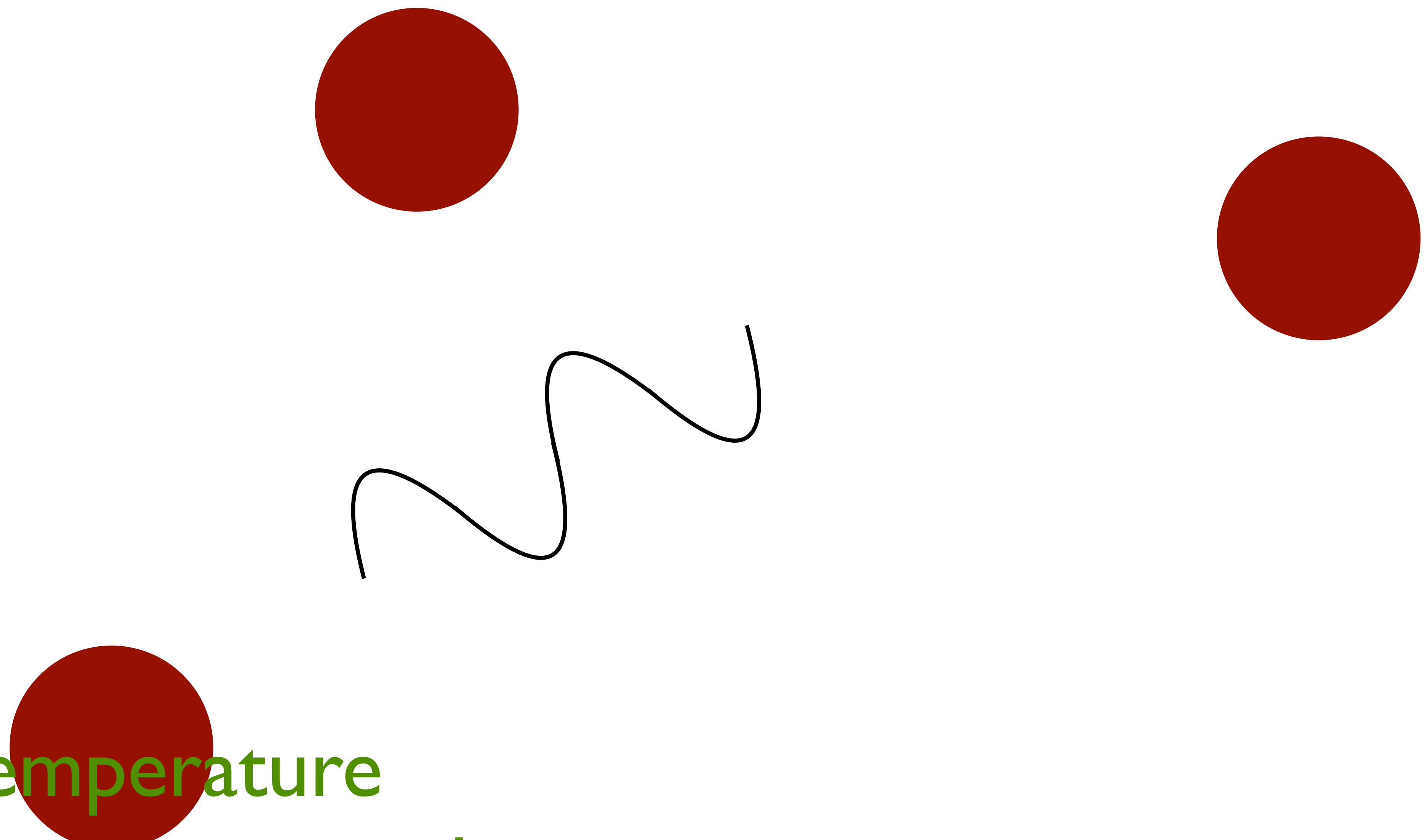
https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html

What happens when those particles emit light?



Lower temperature means lower energy, and lower frequency light

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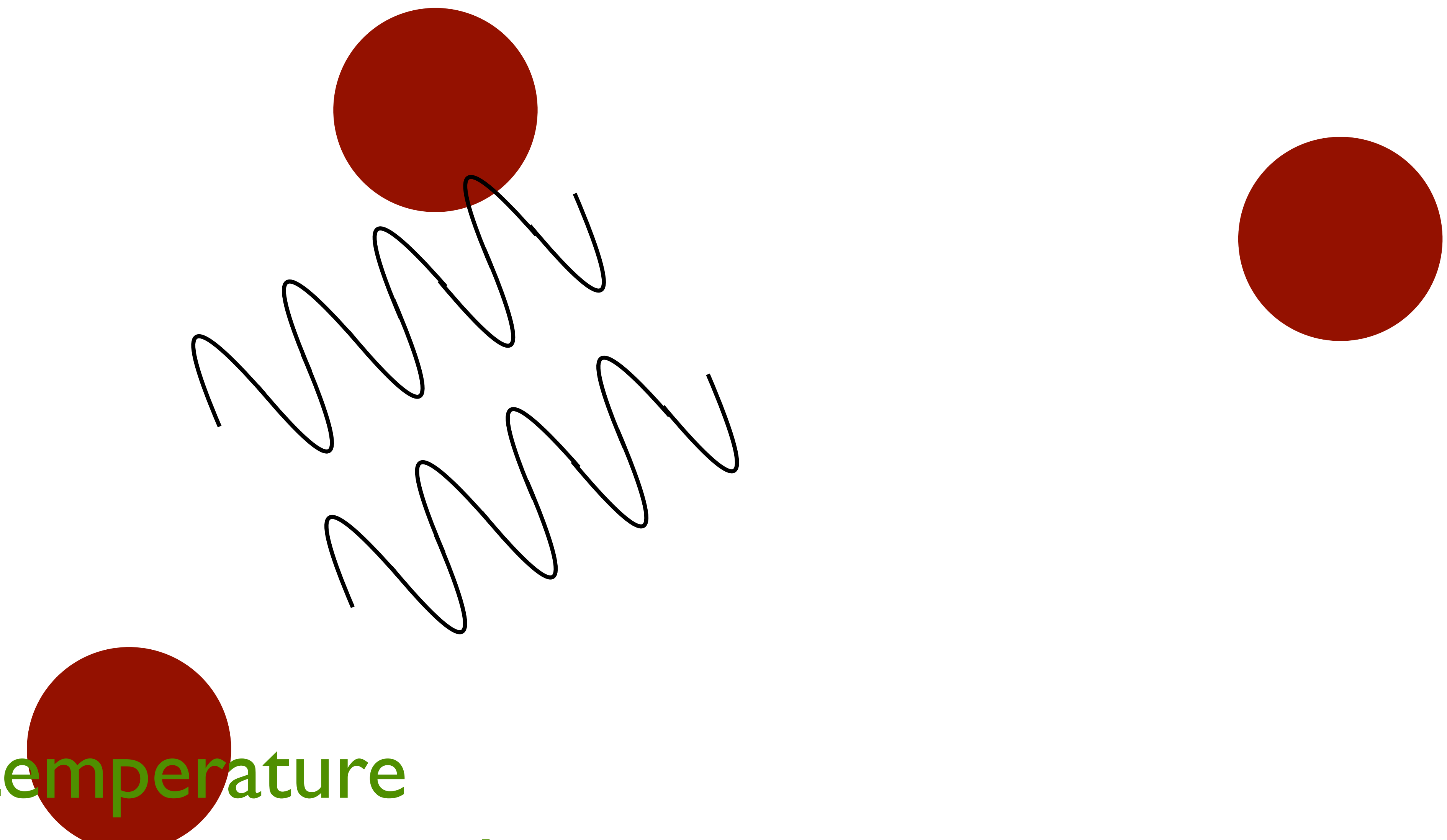


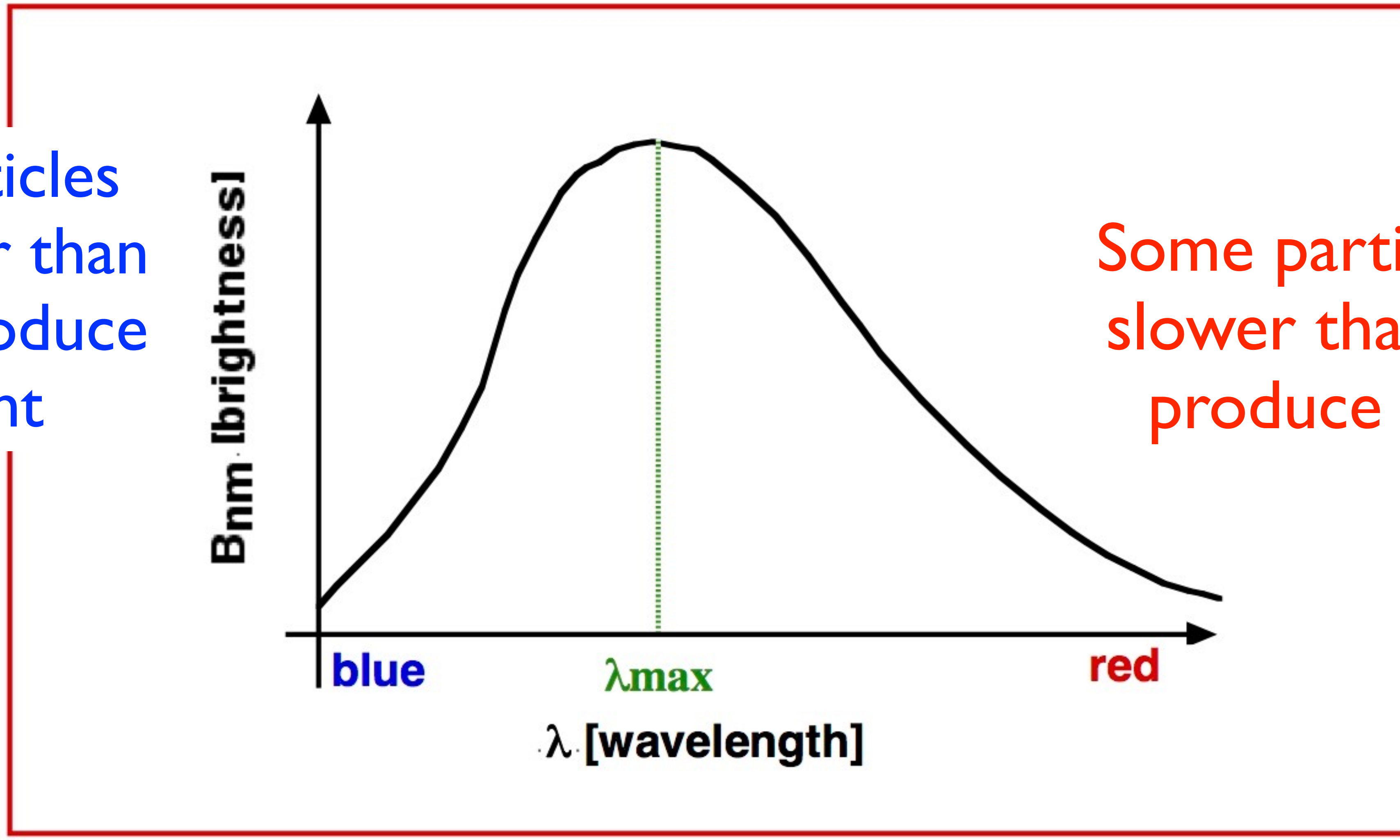
Higher temperature means higher energy, and higher frequency light https://phet.colorado.edu/sims/html/blackbody-spectrum/latest/blackbody-spectrum_en.html

“Continuous” Spectrum

is emitted by hot objects

- a.k.a. “thermal radiation” or “blackbody radiation”

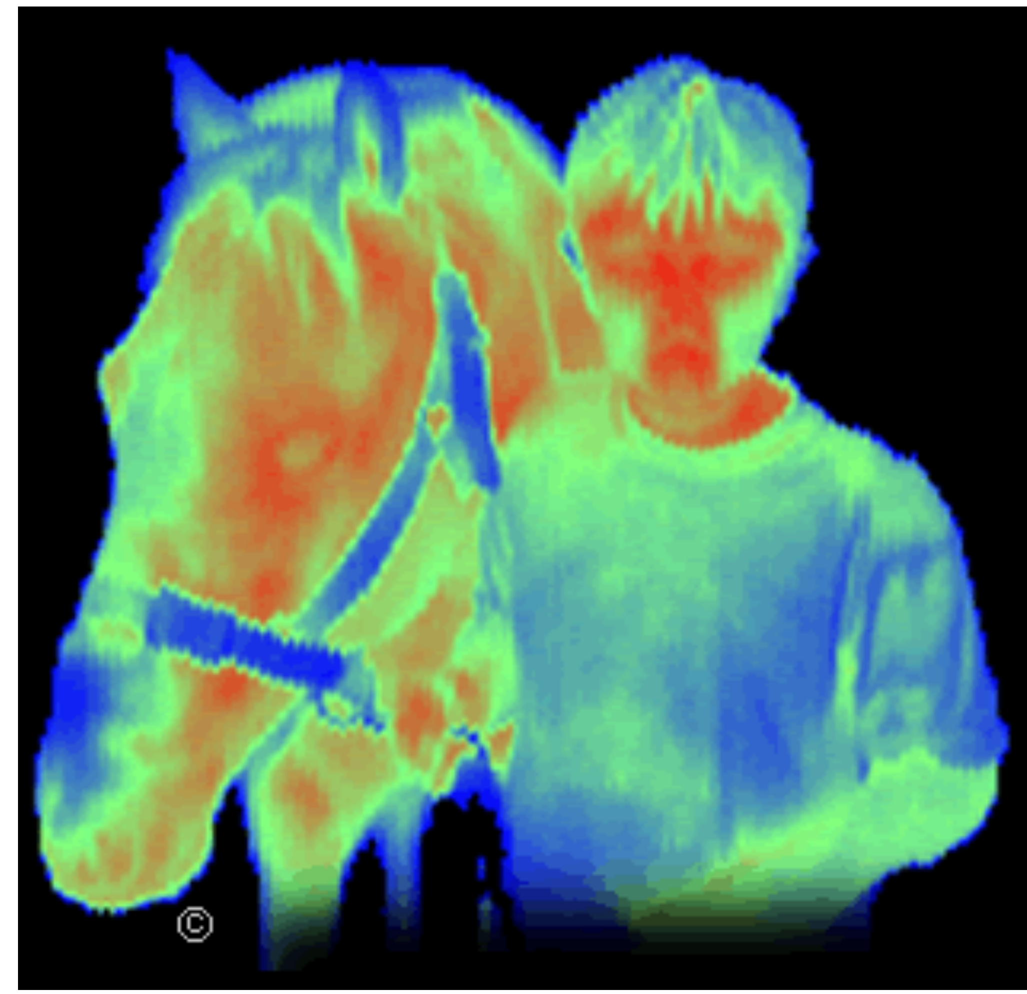
Some particles move faster than average: produce blue light



Some particles move slower than average: produce red light

- a black body is a “perfect radiator” ...
  - emits a continuous spectrum
  - spectrum shape determined by temperature only

Blackbody radiation



Fun fact: everyone emits blackbody radiation. We just can't see this radiation with our eyes because it's in the infrared

Properties of Thermal Radiation:

Wien's Law

- **increase Temperature**, and get shorter peak wavelength. Can write this down:

$$\lambda_{\rm max} = \frac{2.9 \times 10^6}{T[K]} \ \ {\rm nm}$$

Object	*Temperature*	*wavelength of max*	*Band*
Sun	5780 K	500 nm	visible
you	310 K	9,400 nm	infrared
neutron star	10,000,000 K	0.3 nm	X-ray

Properties of Thermal Radiation:

Stefan-Boltzmann Law

- **Hotter** objects
  - emit **more photons**
  - therefore **hotter** objects are **brighter**

Energy emitted per unit area $\propto T^4$

- Double an object's temperature and it emits 16 ($= 2^4$) times as much energy per unit area

- **Luminosity** of an object depends on
  - **temperature**
  - and **surface area**

luminosity $\propto R^2 T^4$

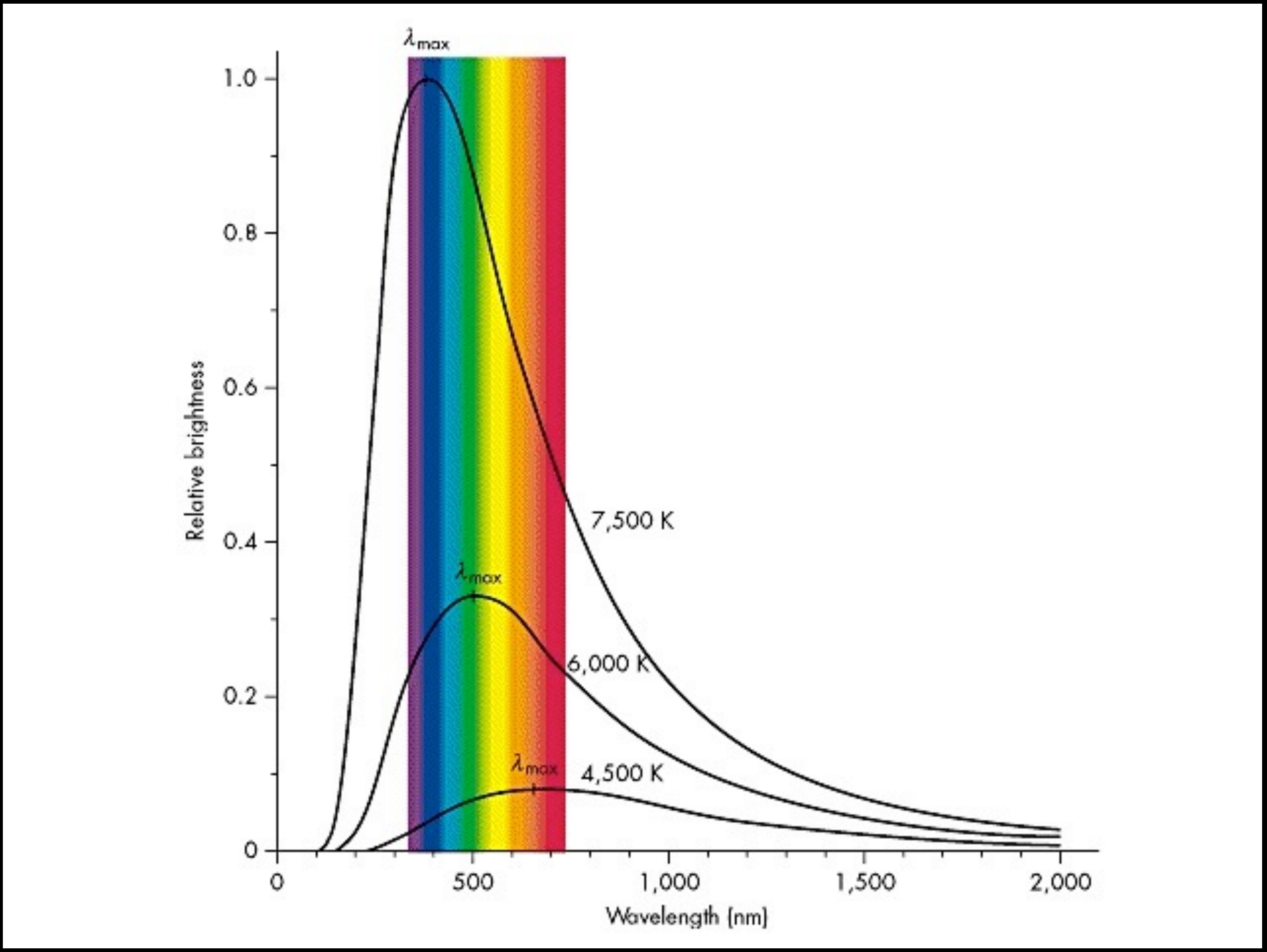
Stars are close approximations to black bodies

- **Wien's law ($\lambda_{max} \propto 1/T$)** says
  - **a star's color tells you its temperature**
  - red stars are cool (T < 5,000K)
  - blue stars are hot (T > 10,000K)

- **Stefan-Boltzman Law ($L \propto R^2 T^4$) says**
  - two stars with same radius:
    blue star more luminous than red star

. . .

These two stars are at
~ the same distance from us



How can they be the same brightness ? ? ?

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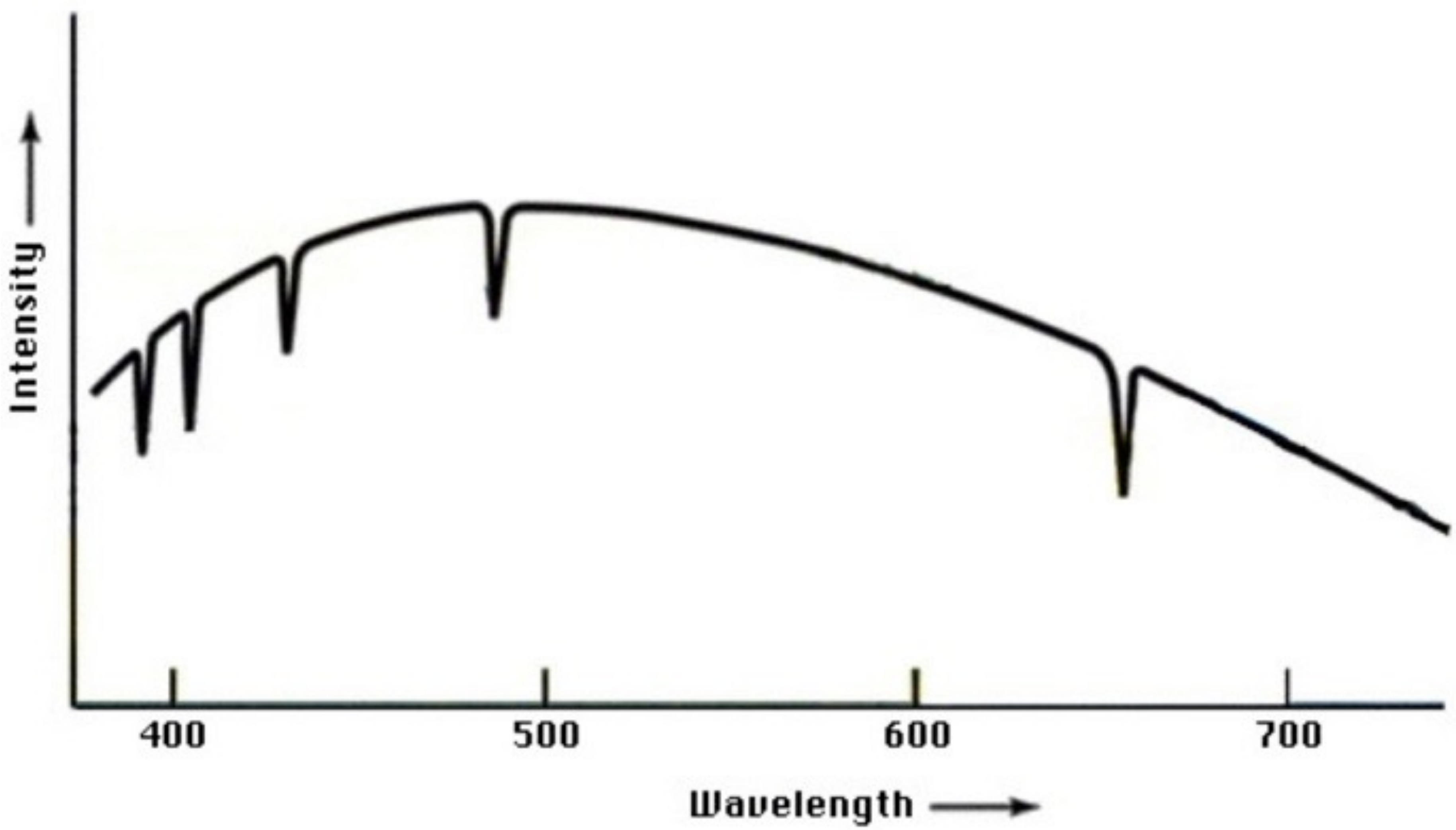
A more realistic stellar spectrum



Stellar Spectra show Continuum + DARK LINES !?