Particle nature of EM radiation

- **End of 1800's** - Black-body radiation could not be explained by EM theory framework.

An object can absorb/emit radiation: $\begin{cases} \text{Absorption } \uparrow T \\ \text{Emission } \downarrow T \end{cases}$

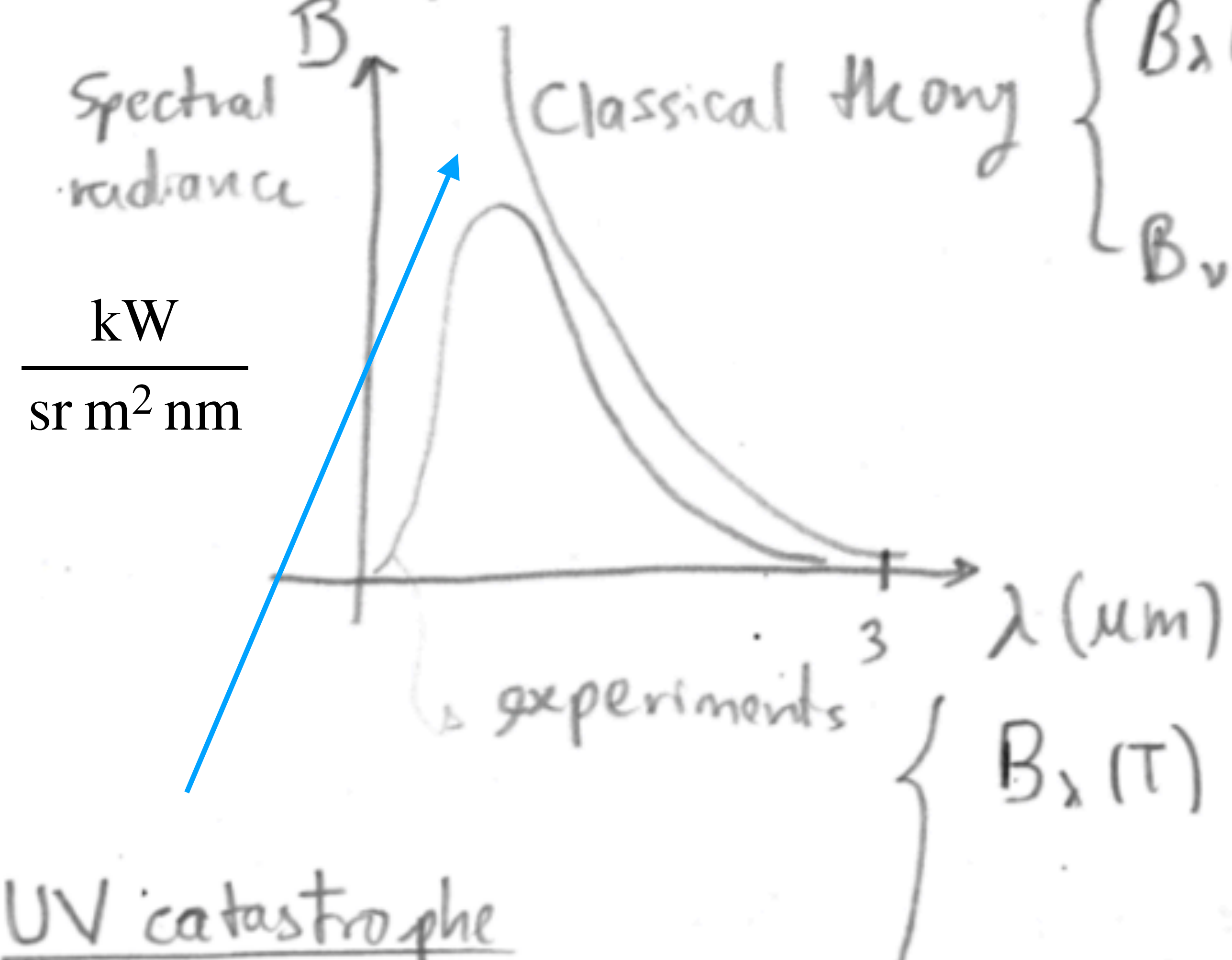
Kirchoff's law: Abs = Emission $\Rightarrow T = ct. \Leftrightarrow$ thermal eq.

Black body: Does not reflect radiation

Particle nature of EM radiation

- **End of 1800's** - Black-body radiation could not be explained by EM theory framework.

Black body radiation:



$$\begin{cases} B_\lambda(T) = \dfrac{2ck_BT}{\lambda^4} \\ B_\nu(T) = \dfrac{2\nu^2 k_BT}{c^2} \end{cases}$$

Rayleigh-Jeans law

$$k_B = 1{,}38\times10^{-23}\ m^2\,kg\,s^{-2}\,K^{-1}$$

$$\begin{cases} B_\lambda(T) = \dfrac{2hc^2}{\lambda^5}\dfrac{1}{e^{\frac{hc}{\lambda k_BT}}-1} \\ B_\nu(T) = \dfrac{2h\nu^3}{c^2}\dfrac{1}{e^{\frac{h\nu}{k_BT}}-1} \end{cases}$$

Particle nature of EM radiation

- **1900 -** M. Planck proposes quantisation of EM radiation

Planck: EM can only be em./abs in discrete packets:

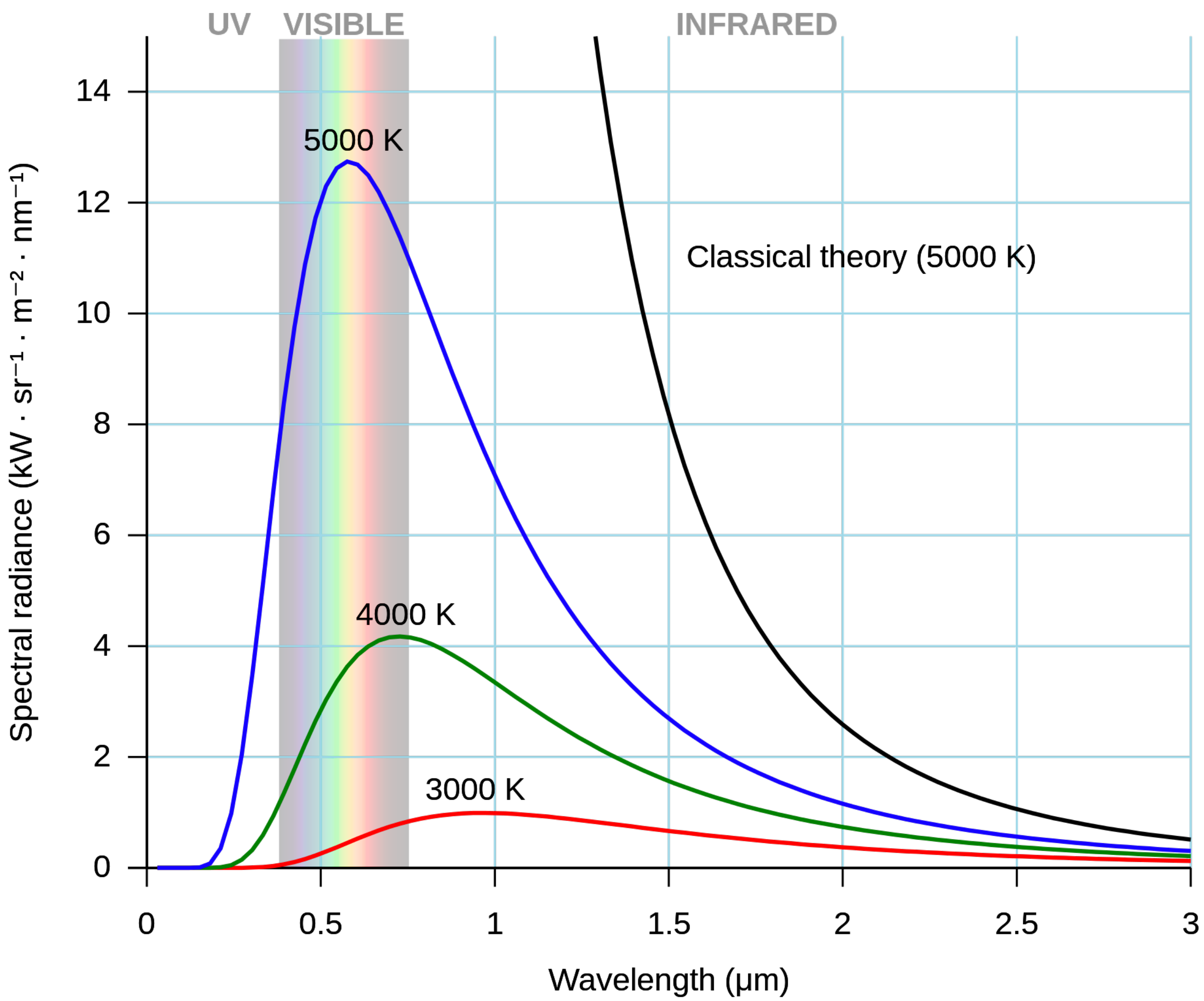
$$\boxed{E_{quanta} = h\nu = h\frac{c}{\lambda}}$$

- $E = h\nu = \hbar\omega$
- $\vec{p} = \hbar\vec{k}$

$$\hbar = \frac{h}{2\pi}$$

De Broglie relation:

$$\boxed{\lambda = \frac{2\pi}{k} = \frac{h}{p}} \Rightarrow E = pc$$



UV catastrophe

Reference: https://en.wikipedia.org/wiki/Ultraviolet_catastrophe

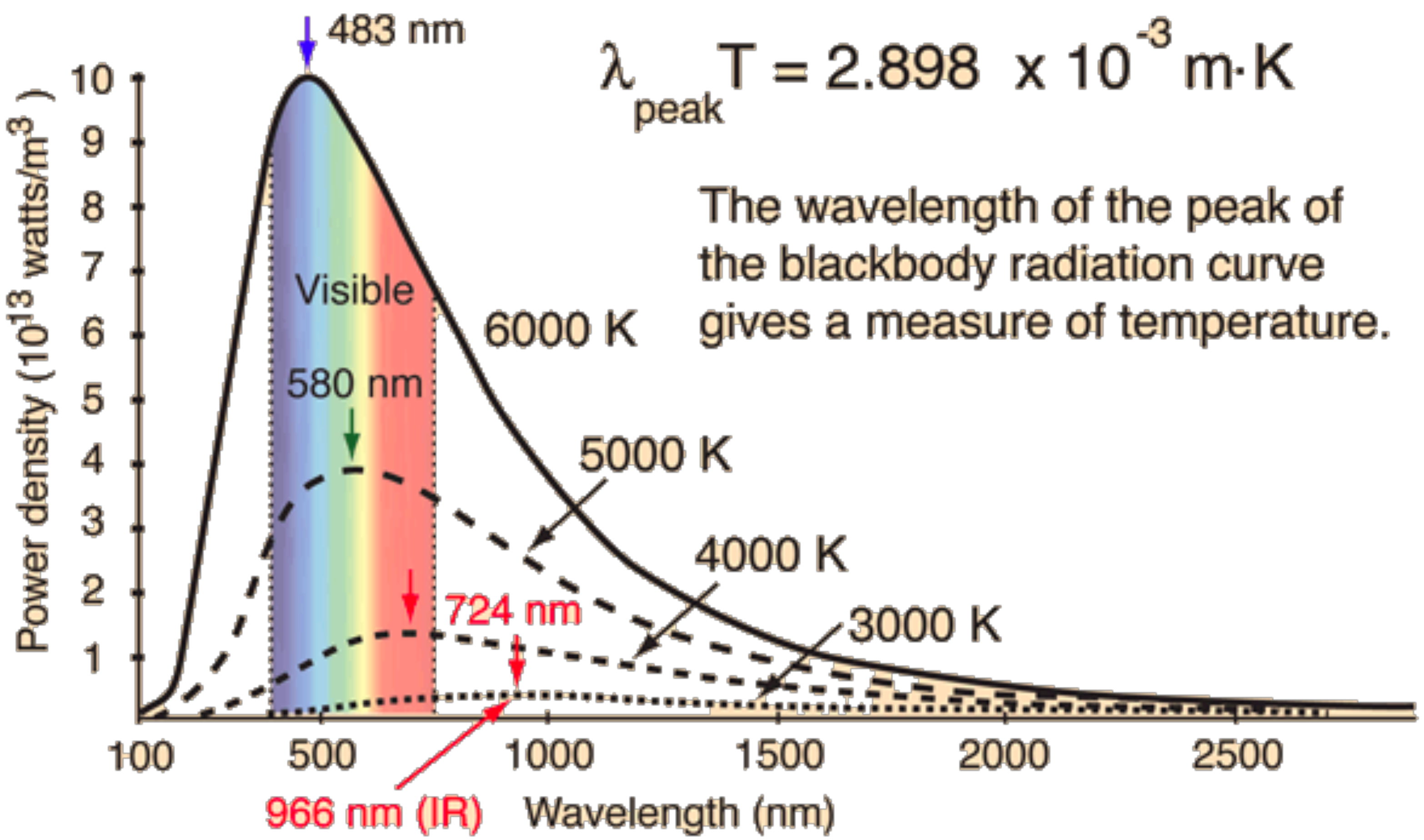
Particle nature of EM radiation

- **Wien's displacement law:**

λ at which an object emits more radiation.

$$\lambda_{max} = \frac{b}{T} \quad ; \quad b = 2.898 \times 10^{-3}\, mK$$
peak

$$\nu_{peak} = \frac{\alpha}{h} kT \approx 5.879 \times 10^{10} \frac{Hz}{K} \cdot T$$



Reference: http://hyperphysics.phy-astr.gsu.edu/hbase/wien.html

Particle nature of EM radiation

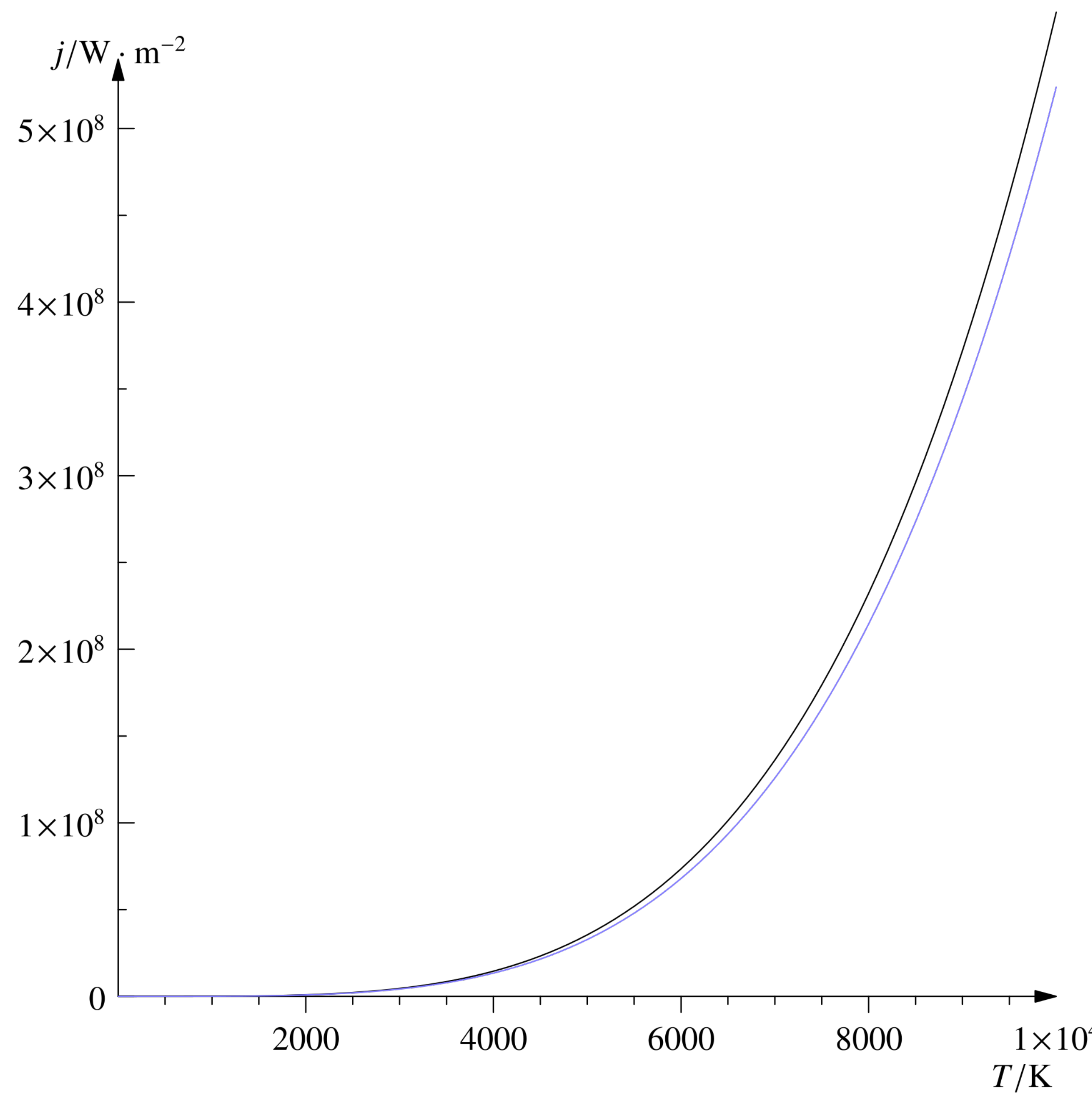
- **Stefan-Boltzmann law:**

Total radiation emitted at all λ:

$$j = \sigma T^4 \quad \left[\frac{W}{m^2}\right]$$

$$\sigma = \frac{2\pi^5 k^4}{15c^2h^3} = 5.67\times10^{-8}\,\frac{W}{m^2K^4}$$

↳ SB constant



Reference: https://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law

Particle nature of EM radiation

- **Planck's constant:** h

The units of h are units of angular momentum.

$$E_\gamma = h\nu$$

Units of h: $[h] = \frac{[E]}{[\nu]} = \frac{[ML^2T^{-2}]}{[T^{-1}]} = [ML^2T^{-1}]$

$$[h] = \underset{\uparrow}{L} \cdot \underset{\uparrow}{[MLT^{-1}]} = [r]\cdot[p] = \underset{\uparrow}{[\ell]}$$

Length Momentum Angular momentum

Example:

Spin 1/2 particle

$$|\vec{s}| = \frac{1}{2}\hbar$$