STELLAR SPECTRA

ASTROPHYSICS

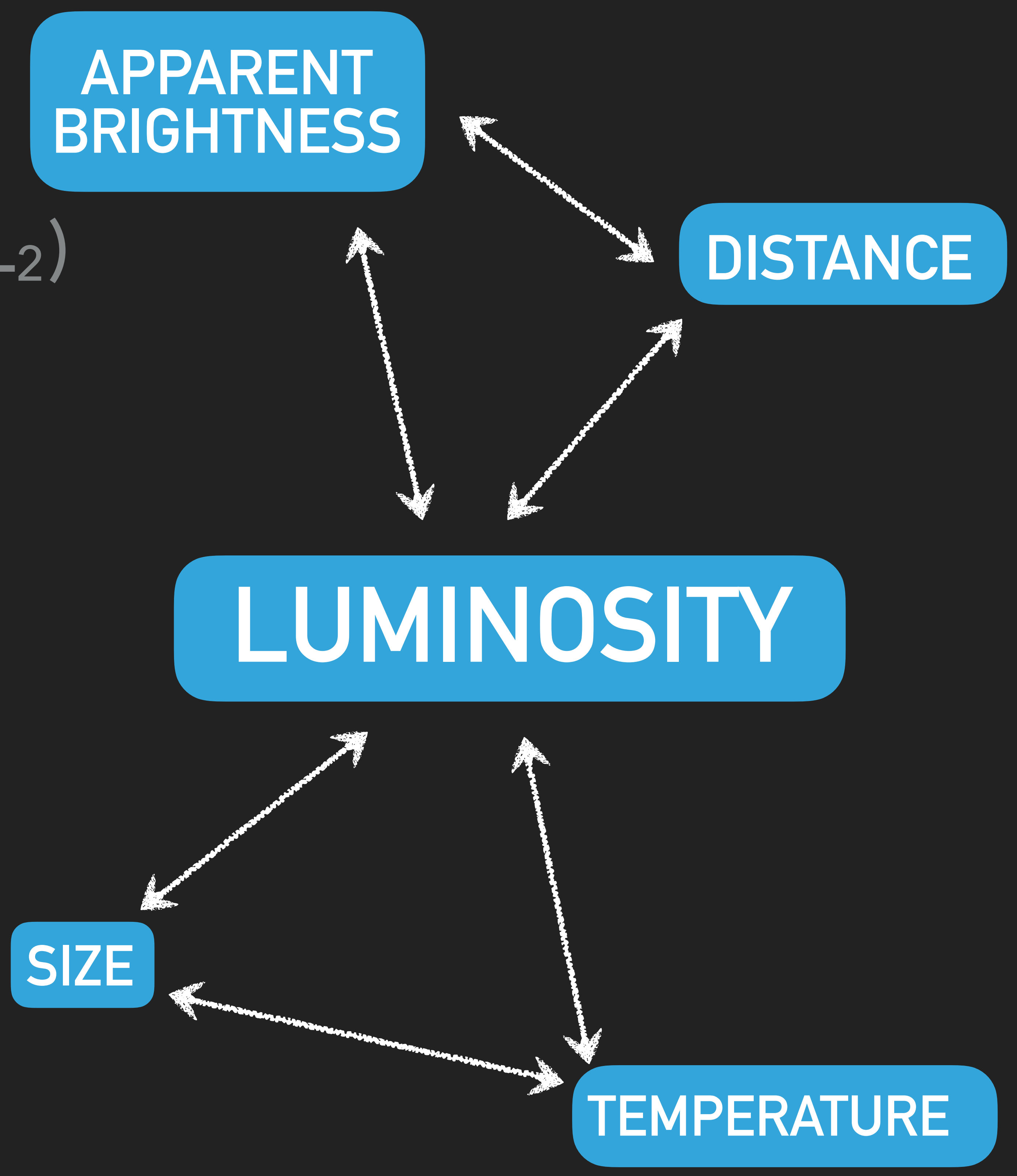
Dr H.T.Sener

VOCABULARY

Astronomy Term	Definition
Absolute Magnitude "M"	The apparent magnitude a star would have at 10 parsecs (32.6 light years)
Apparent Magnitude brightness "m"	Each division is 2.51 times brighter than the next magnitude, sun has m= -26
Apparent Magnitude scale	A modern version of Hipparchus scale
Intensity	Power per unit area at the observer: $I=P/4\pi r^2$
Luminosity	Total power radiated by a star (joules/sec=watts), depends on the temperature and distance between the star and the observer. $L= d^2T^4$
Parallax Angle	The shift, relative to the background, caused by a shift in the observer's position.
Parsec	The distance at which one AU subtends an angle of one arc second (1/3600th of a degree), 1 pc = 3.26 light years
Relative Brightness scale	A scale created by in 120 BC where 1 is the brightest star and 6 is the dimmest star

SUMMARY

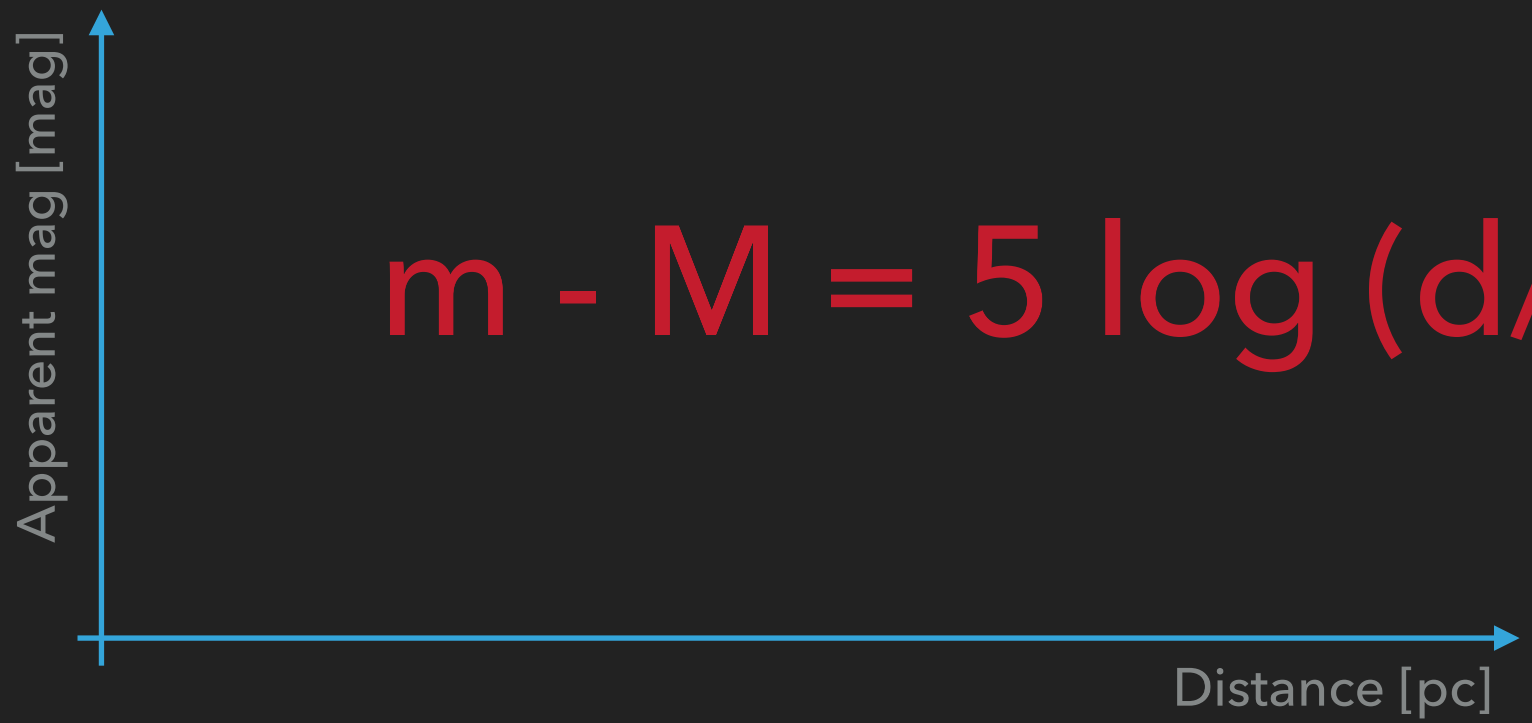
- Apparent brightness
  - $m_2 - m_1 = 2.5 \log (L_1/L_2)$
- Absolute magnitude
  - $m - M = 5 \log (d/10)$
- Luminosity
  - $L = \sigma T^4 \times 4 \pi r^2$
- Flux
  - $F = L / 4 \pi d^2$



HOMEWORK

- Given an absolute magnitude of 3.0, find the apparent magnitude at a distance of 5pc, 10pc, 15pc, 20pc, 50pc and 100pc.

- Plot these data on distance vs apparent magnitude.

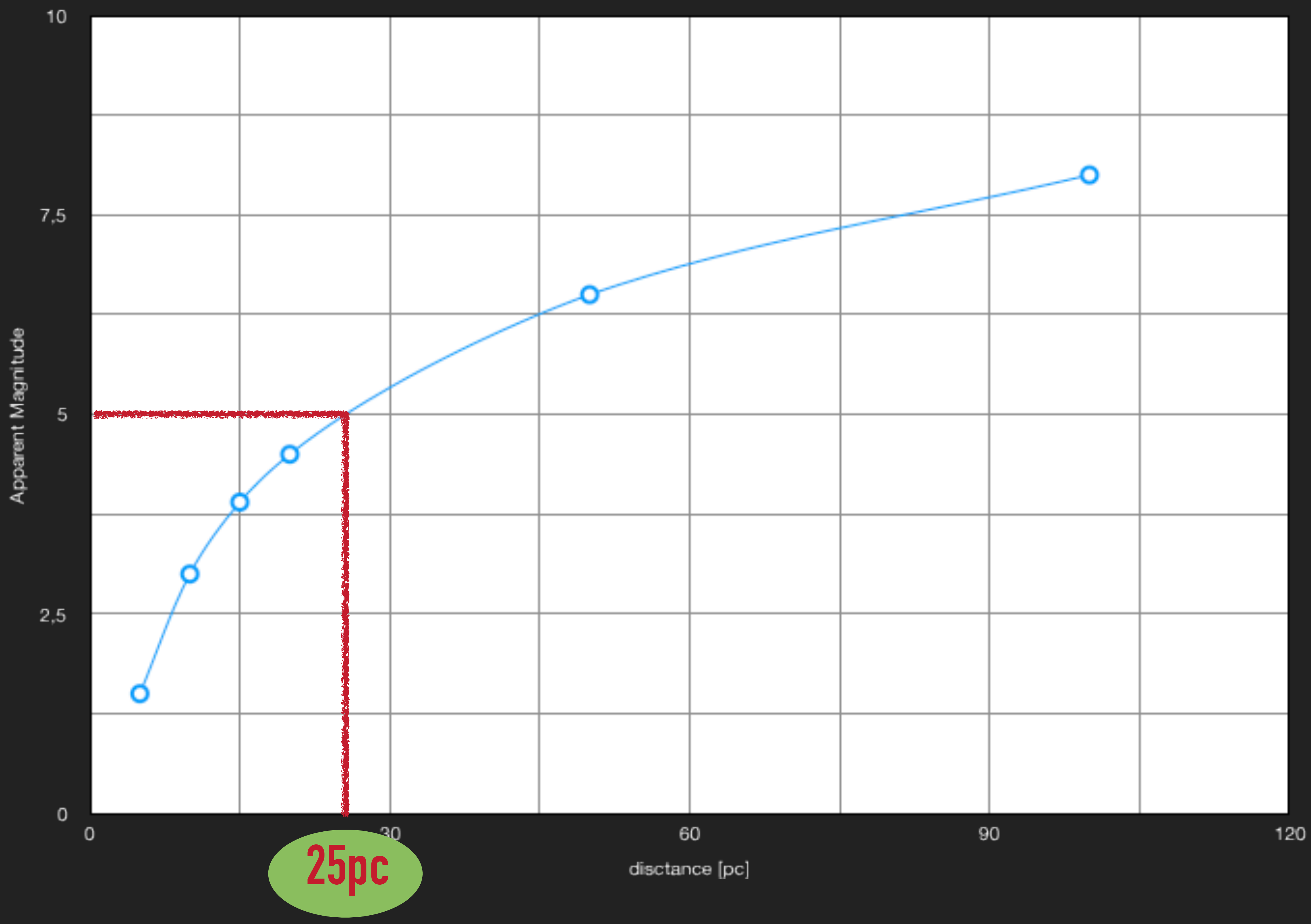


$$m - M = 5 \log (d/10)$$

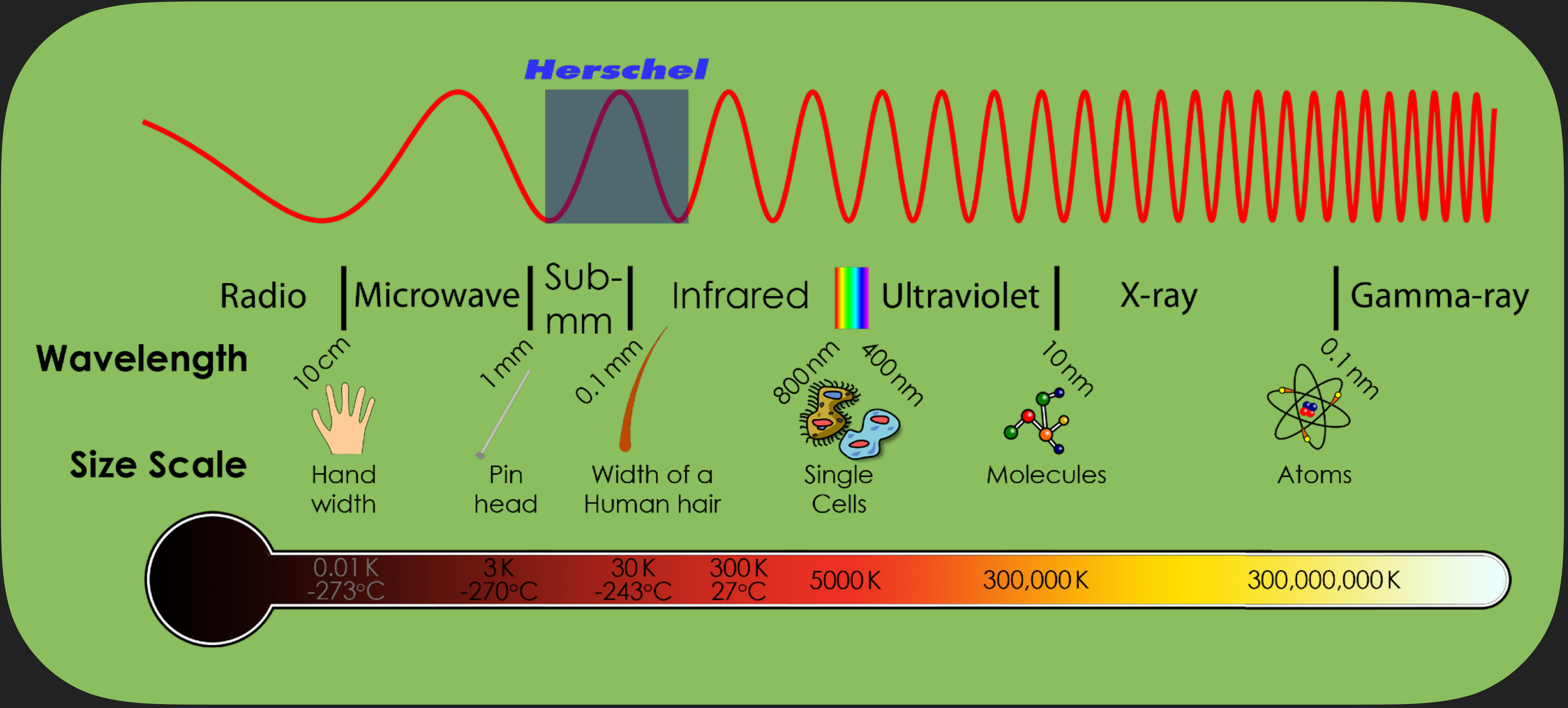
- How far away must the star be to have an apparent magnitude of 5.0?

HOMEWORK

$$5 - 3 = 5 \log (d/10)$$



ELECTROMAGNETIC SPECTRUM



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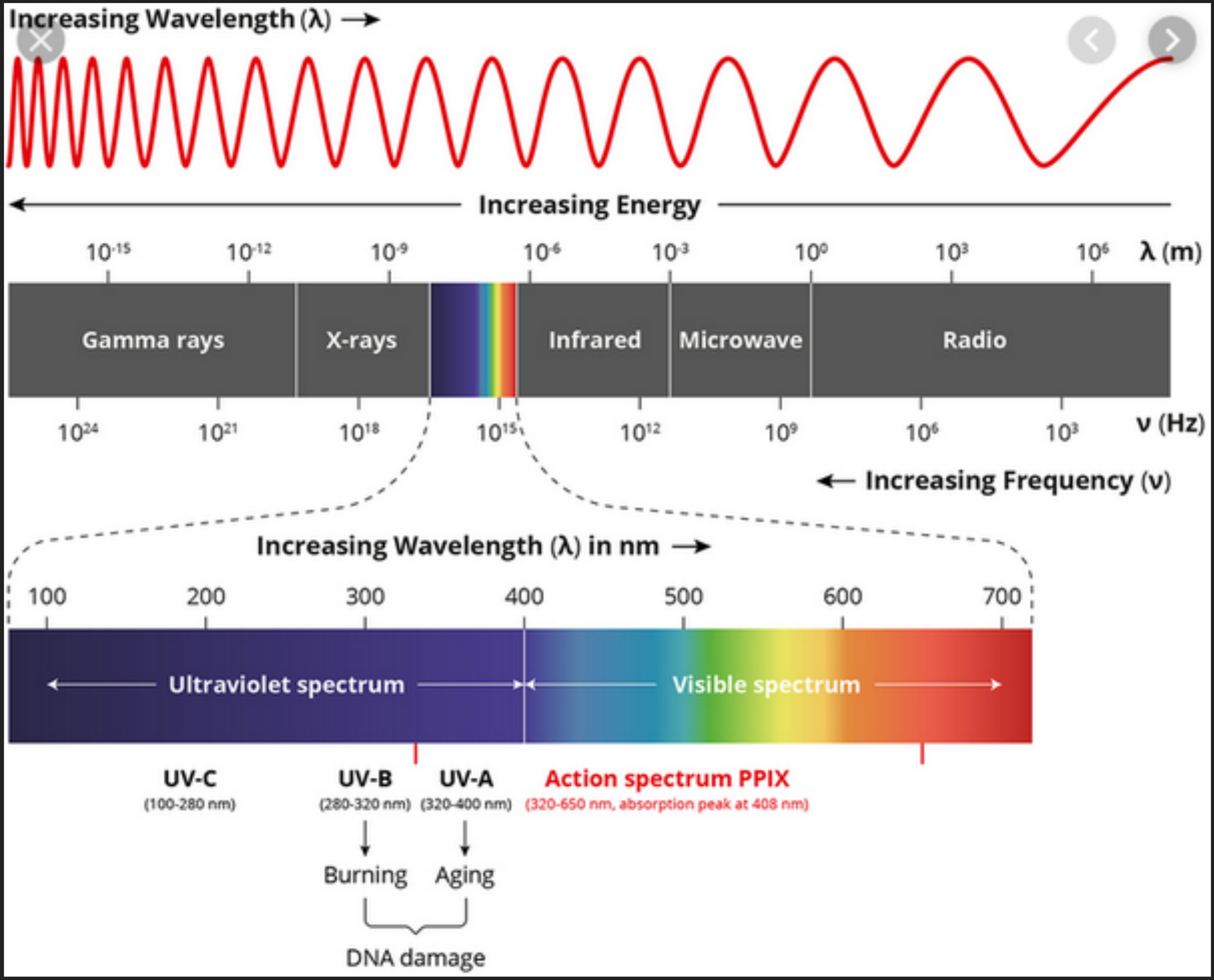

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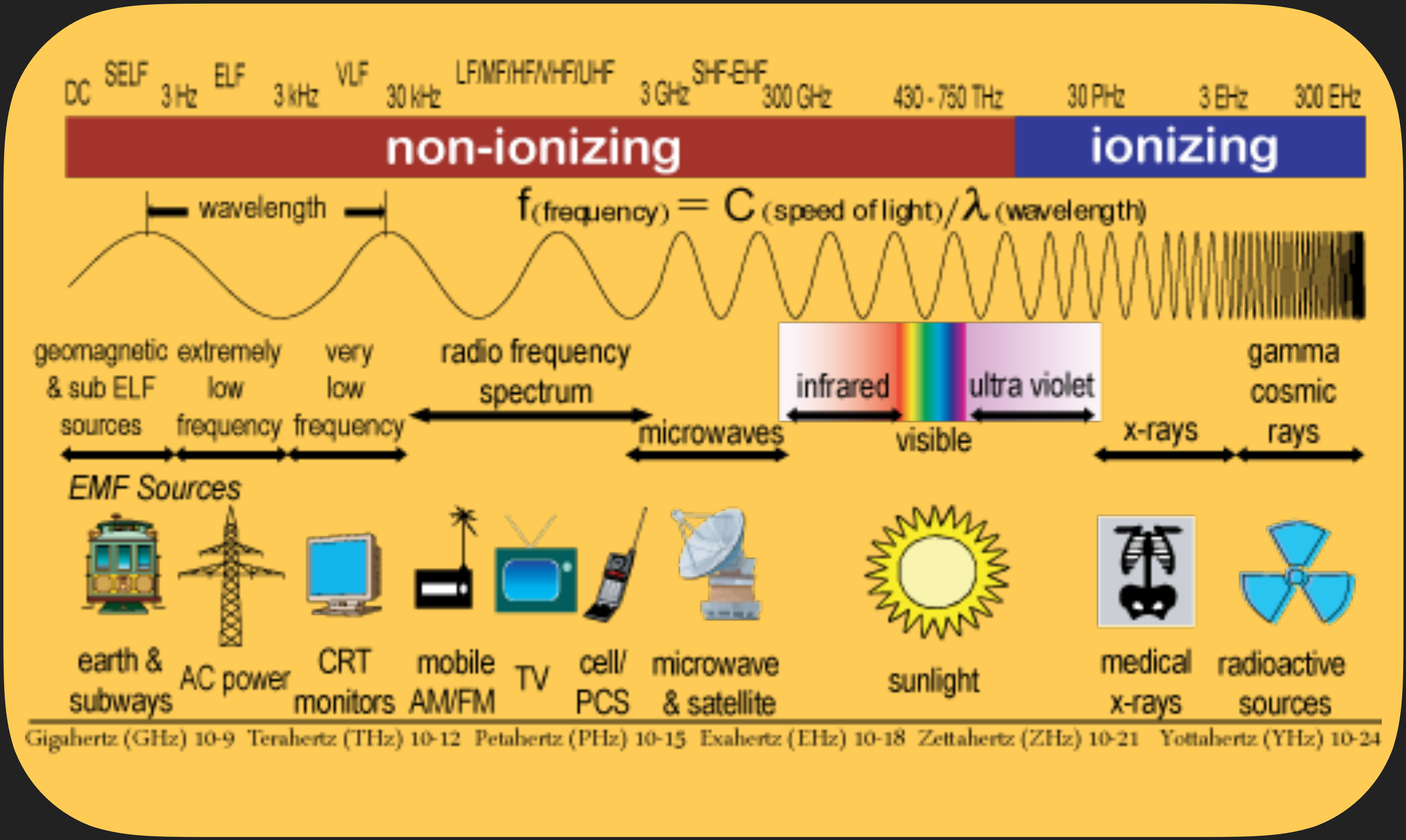
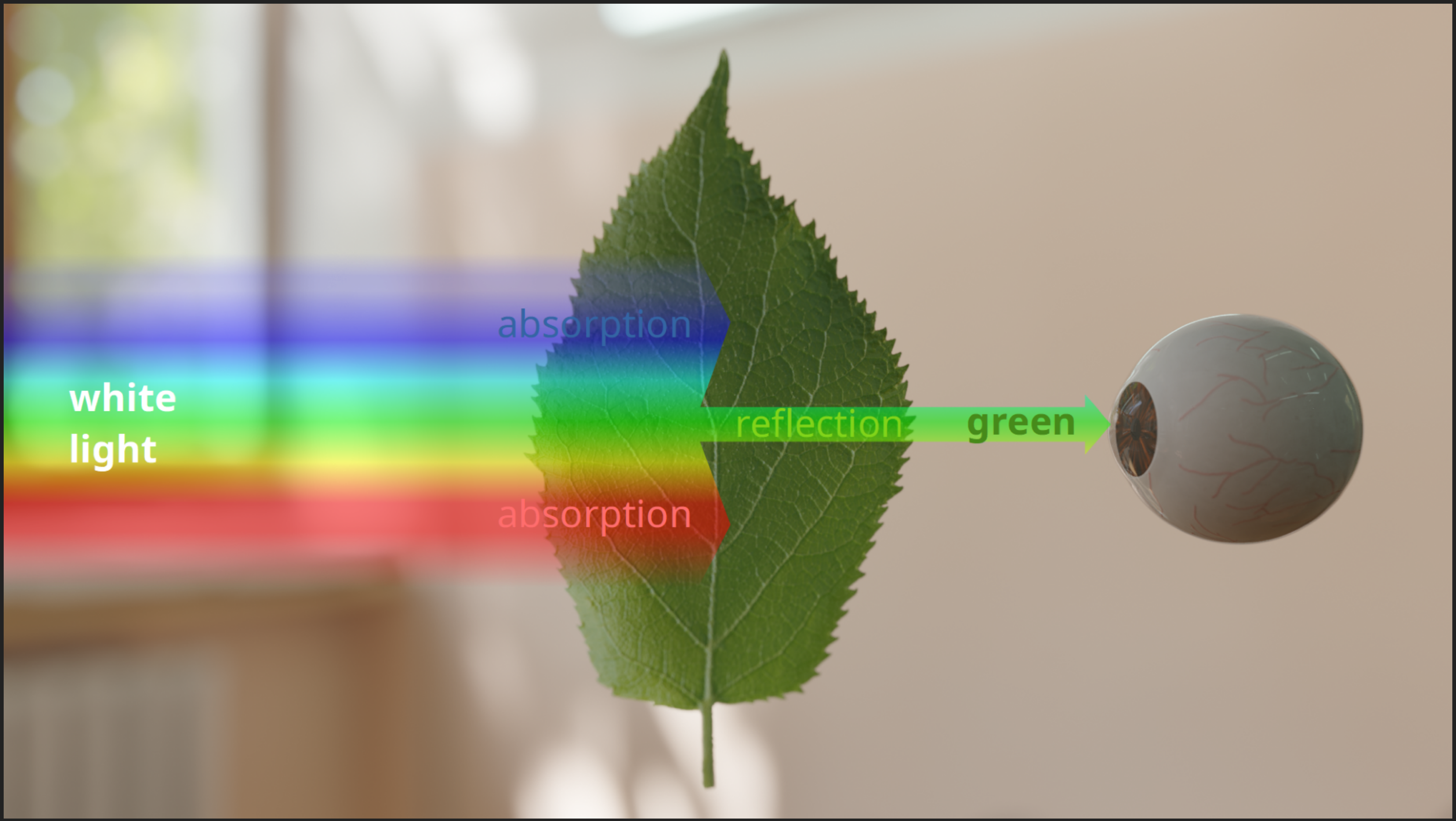


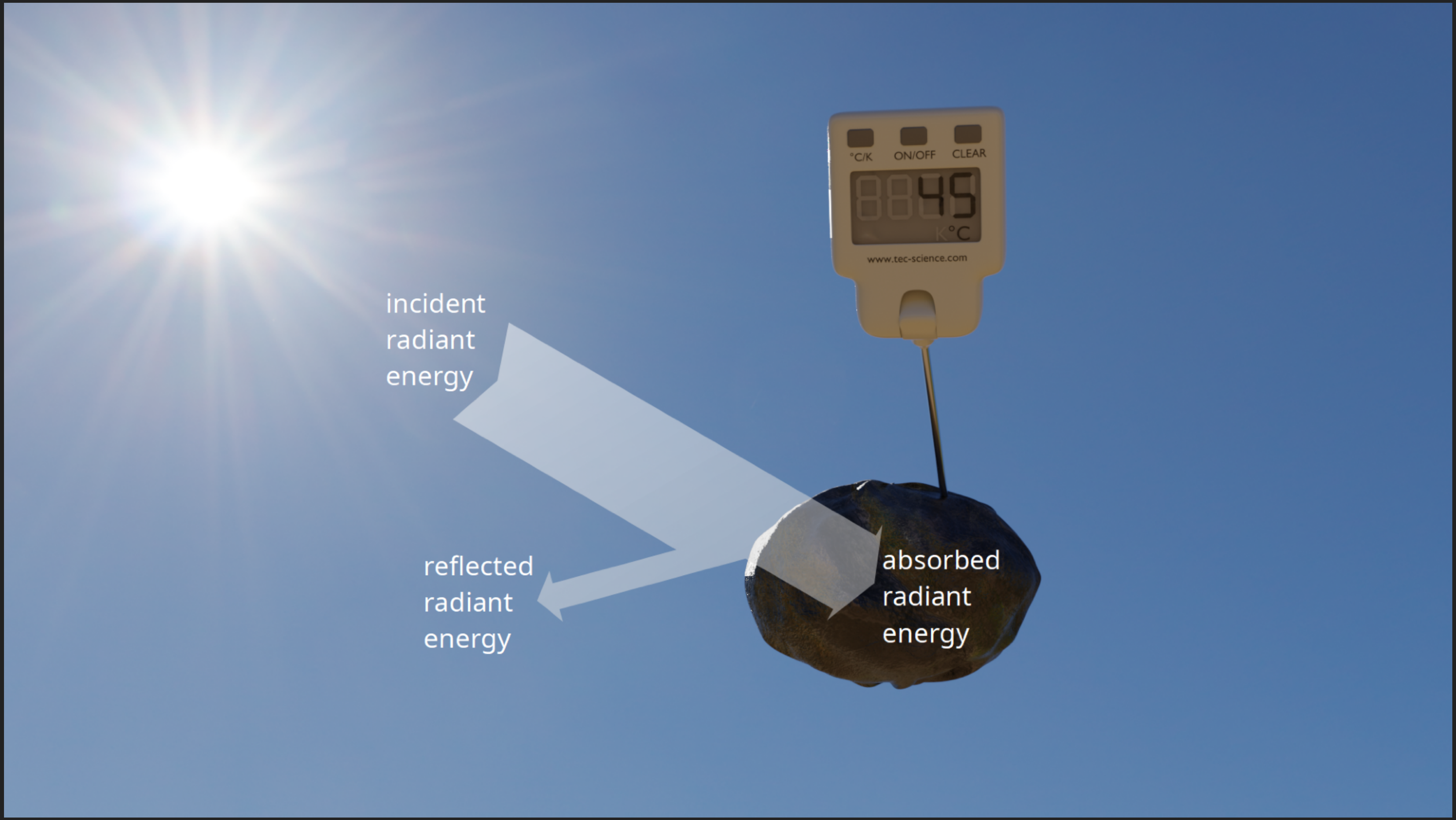
BLACKBODY RADIATION



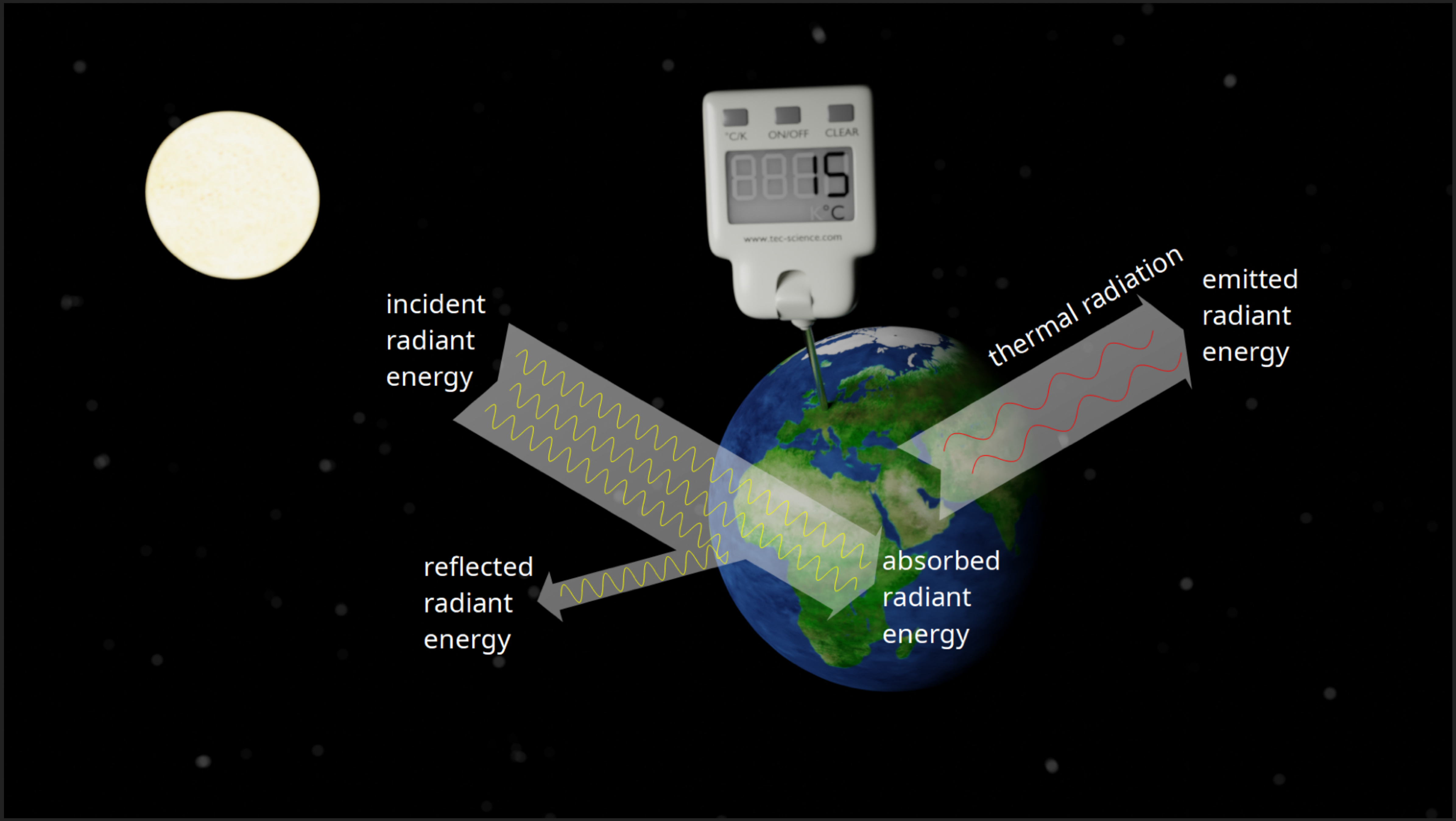
BLACKBODY RADIATION

- A blackbody is an idealized object that absorbs all incident electromagnetic radiation!

THERMAL RADIATION



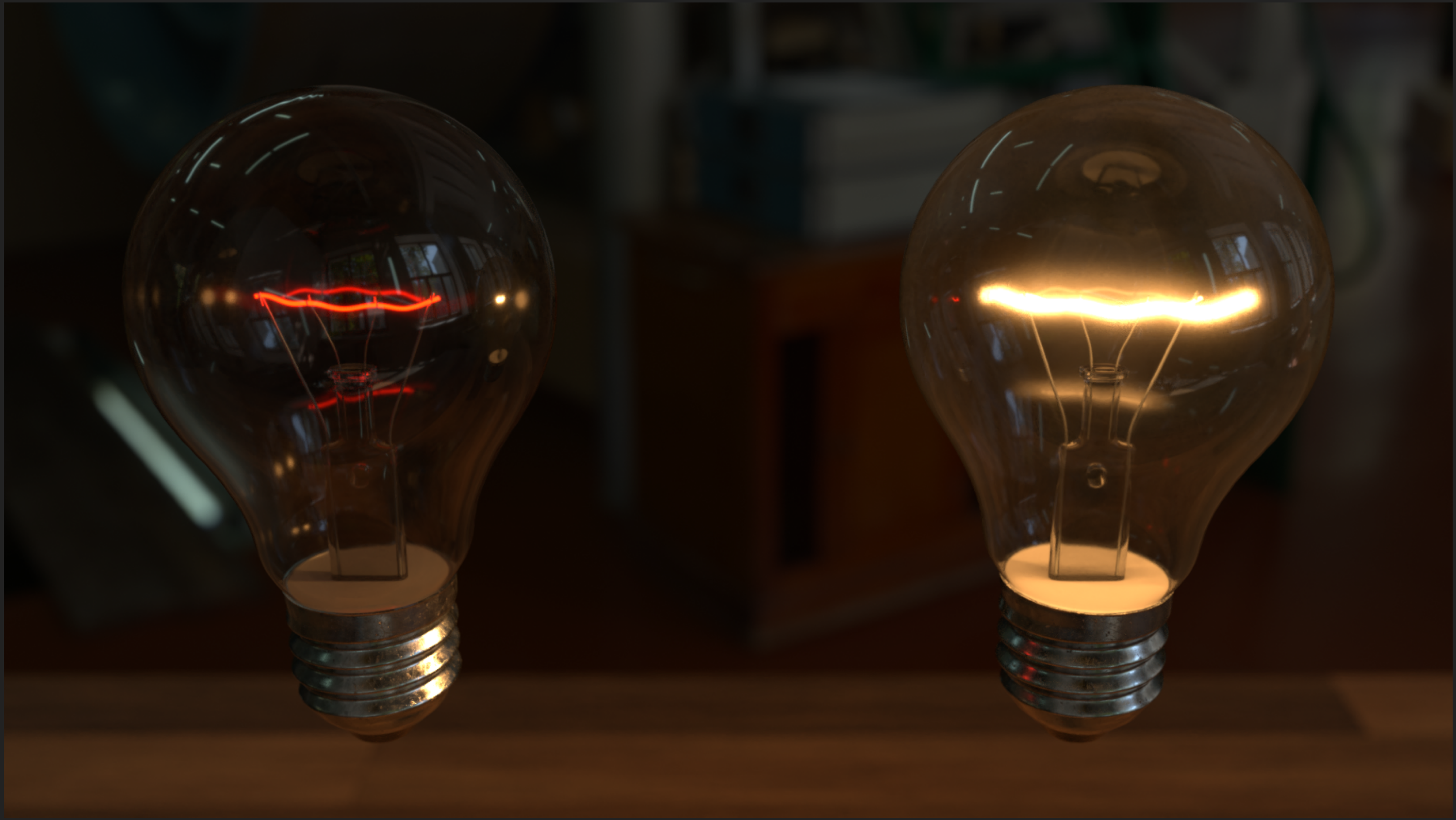
THERMAL RADIATION



THERMAL RADIATION

- Thermal radiation is the radiation emitted by a body in thermal equilibrium due to its temperature!

THERMAL RADIATION



- Thermal radiation comes from oscillations of the atoms!

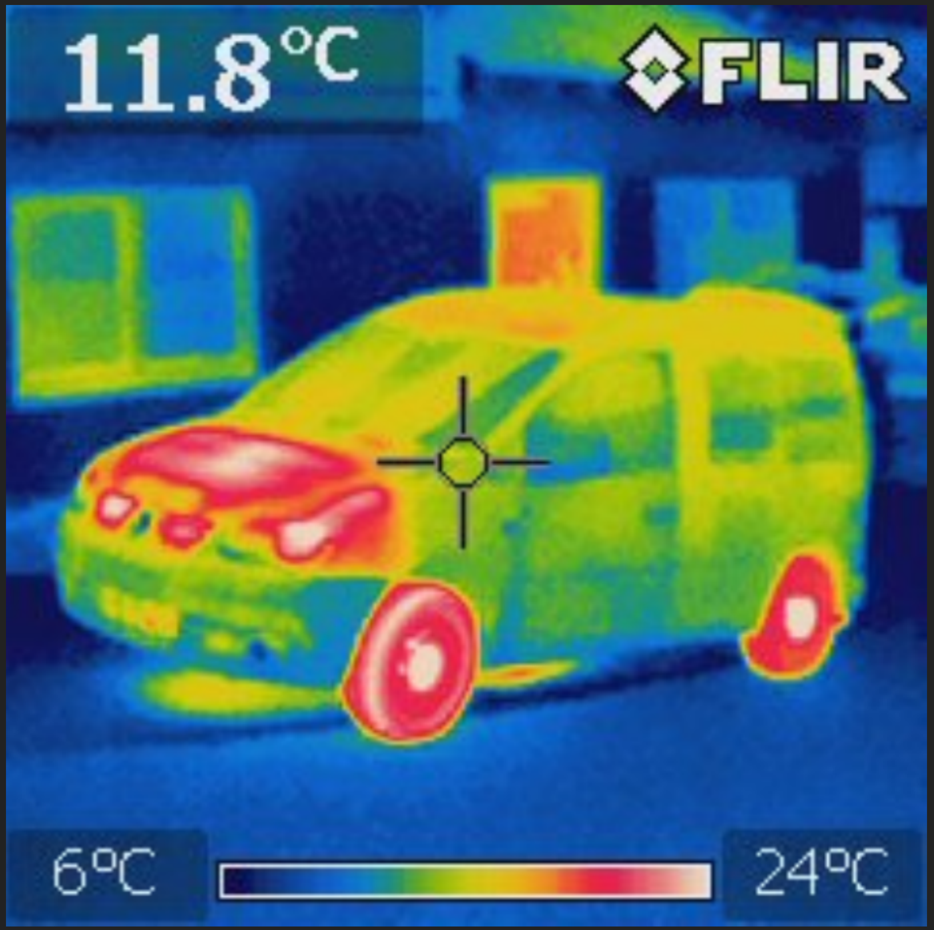
BLACKBODY RADIATION

- An ideal black body must emit thermal radiation. Even if by definition a blackbody absorbs all incident radiation, it still emits radiation. This is not reflected radiation, but radiation which the body emits “from inside” due to the oscillation of the atoms.
- All radiation is absorbed!
- Only if the temperature is increased very strongly and the body starts to glow, radiation in the visible wavelength range is emitted.
- Does not have to be black!

BLACKBODY RADIATION

- A blackbody is particularly suitable for the investigation of the spectral distribution of thermal radiation, since the radiation does not contain any reflecting parts of interference sources!

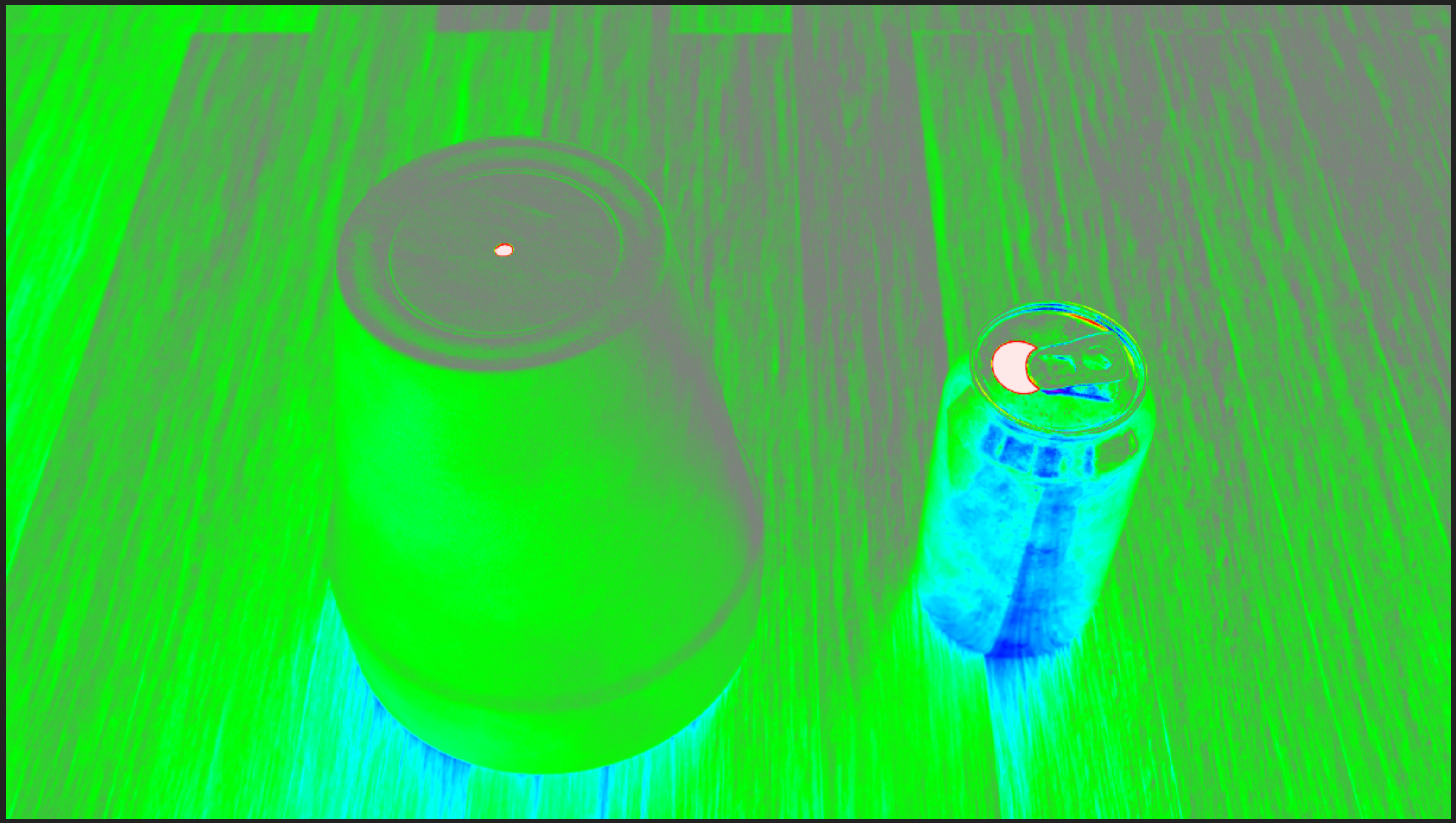
- The emitted thermal radiation of a black body is called blackbody radiation!



REALIZATION OF BLACKBODIES IN PRACTICE (CAVITY RADIATION)

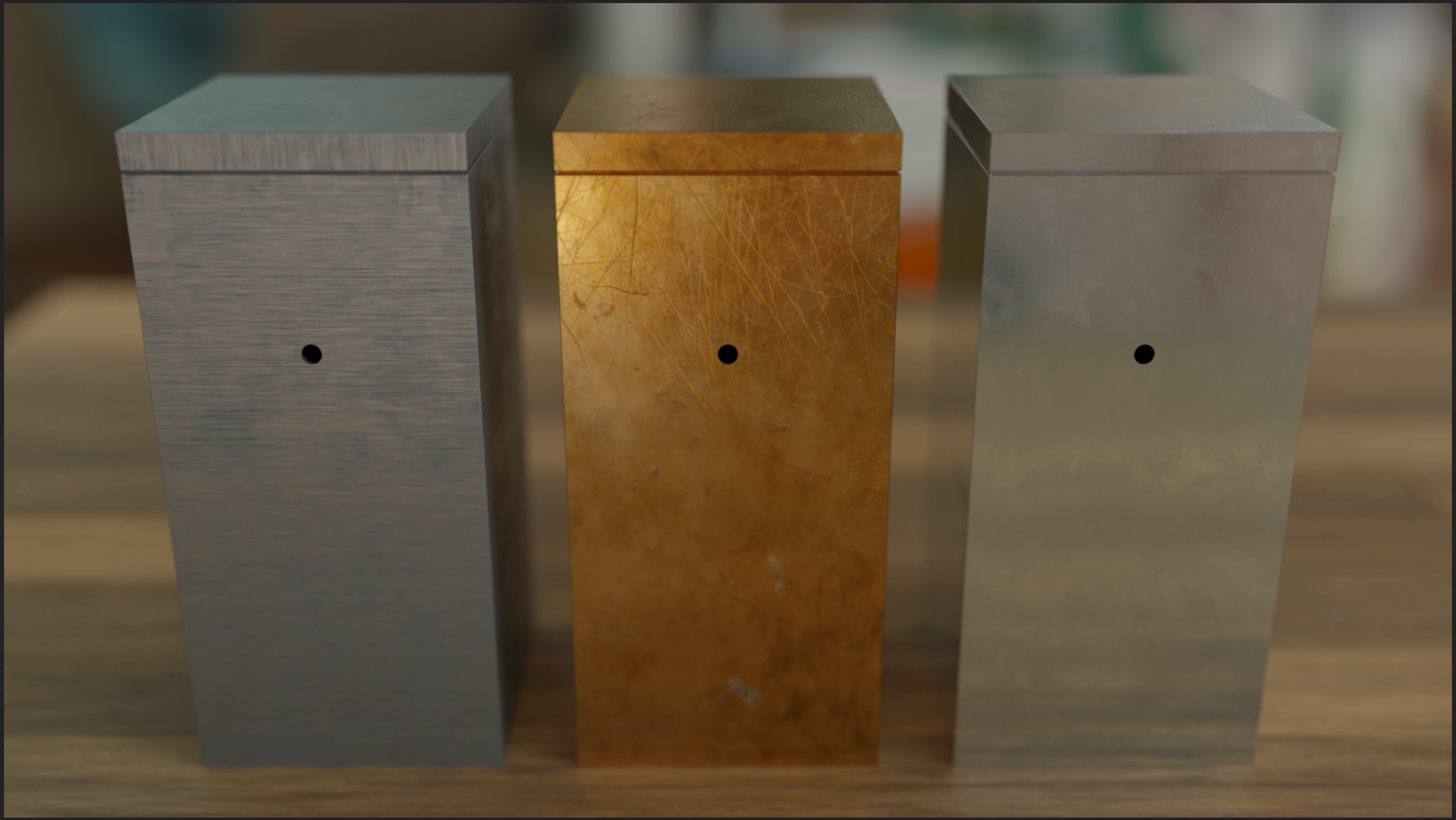
BLACKBODY RADIATION

- only the cavity or hole - not to the object itself!



SPECTRAL DISTRIBUTION OF BLACKBODY RADIATION (PLANCK SPECTRUM)

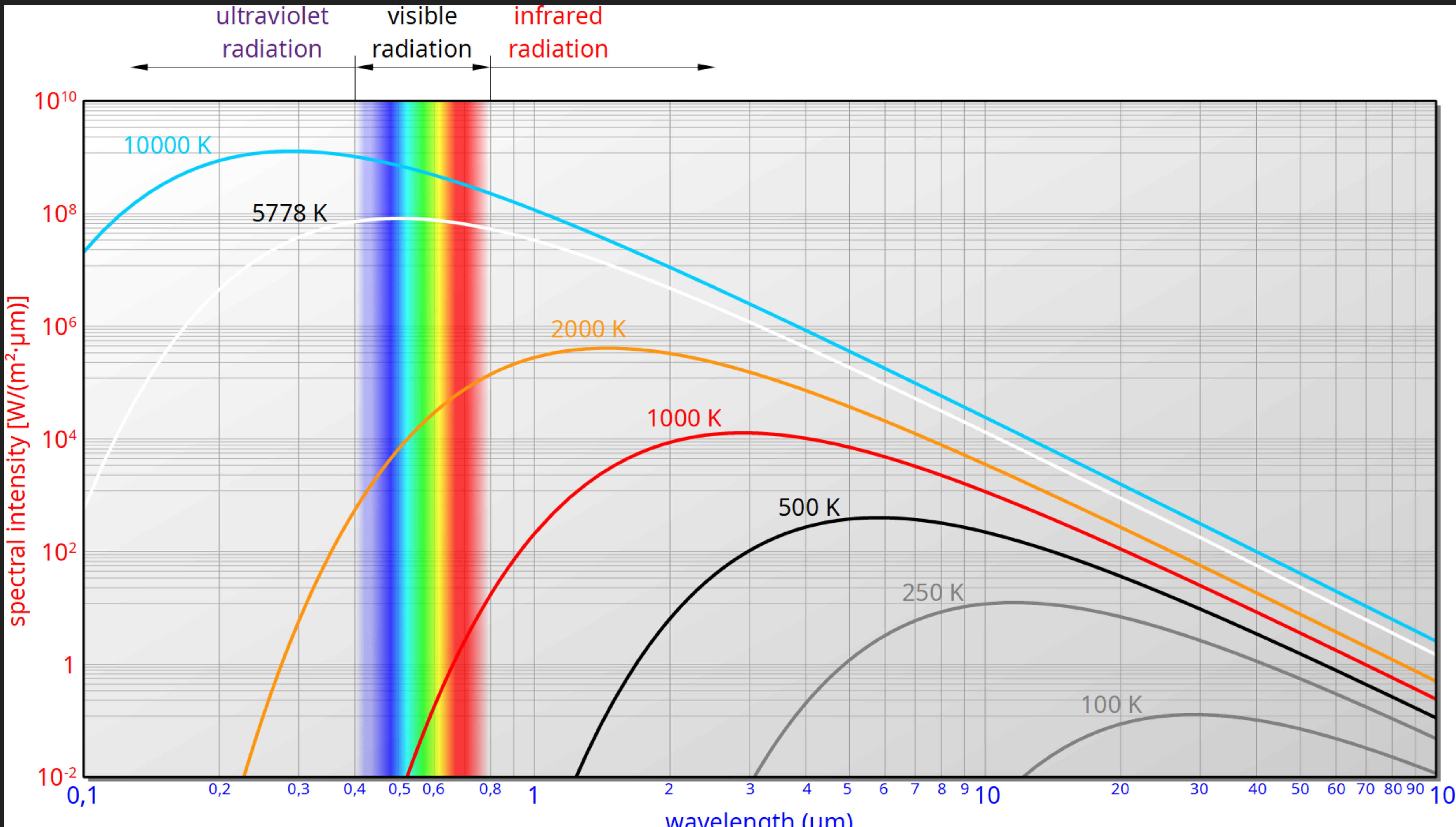
- Different materials at different temperatures.



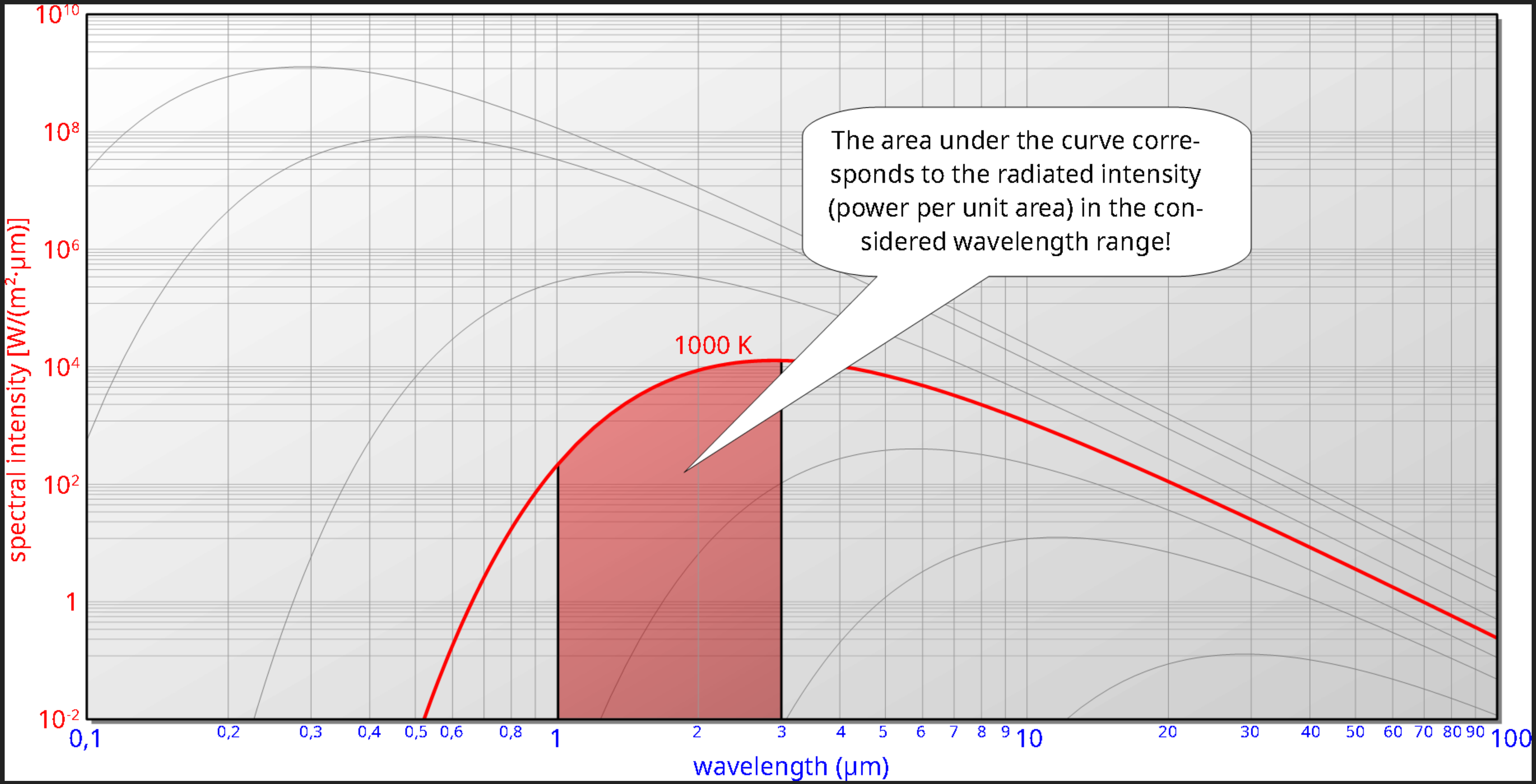
BLACKBODY RADIATION

- Radiation enters through a hole, but does not exit due to absorption.

BLACKBODY RADIATION

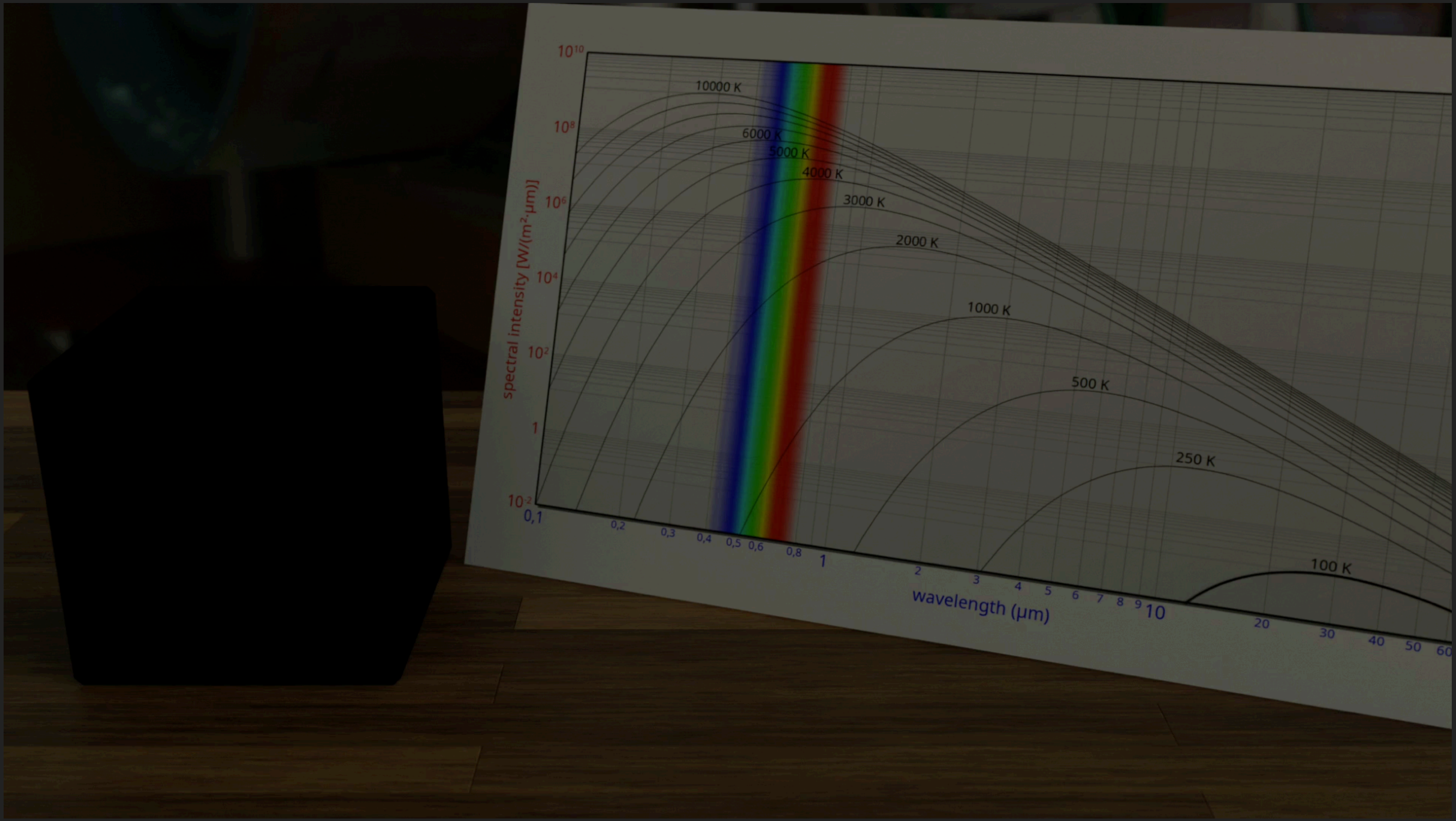


BLACKBODY RADIATION



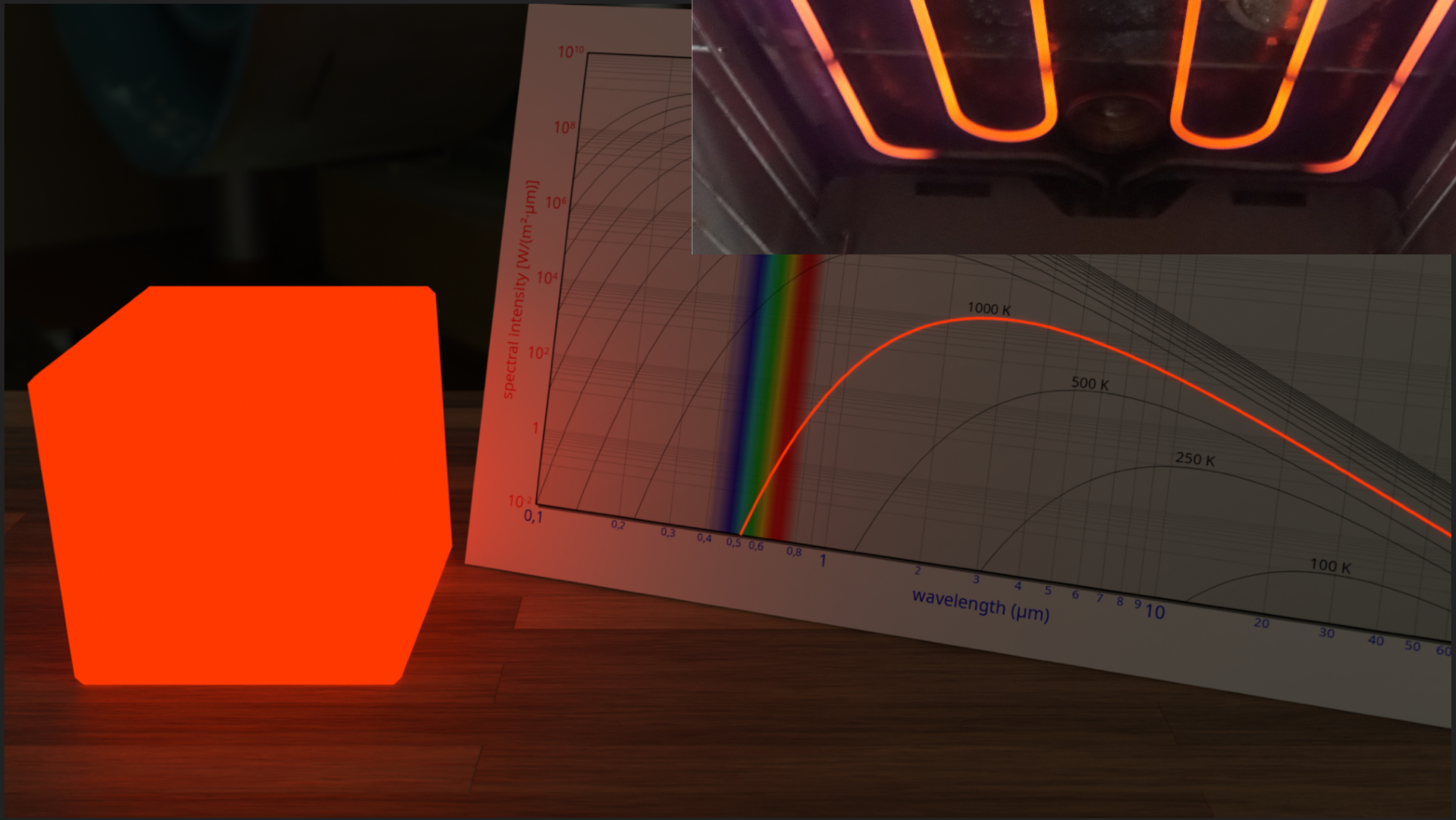
- The wavelength spectrum of blackbody radiation depends only on the temperature and not on the material!

BLACKBODY RADIATION



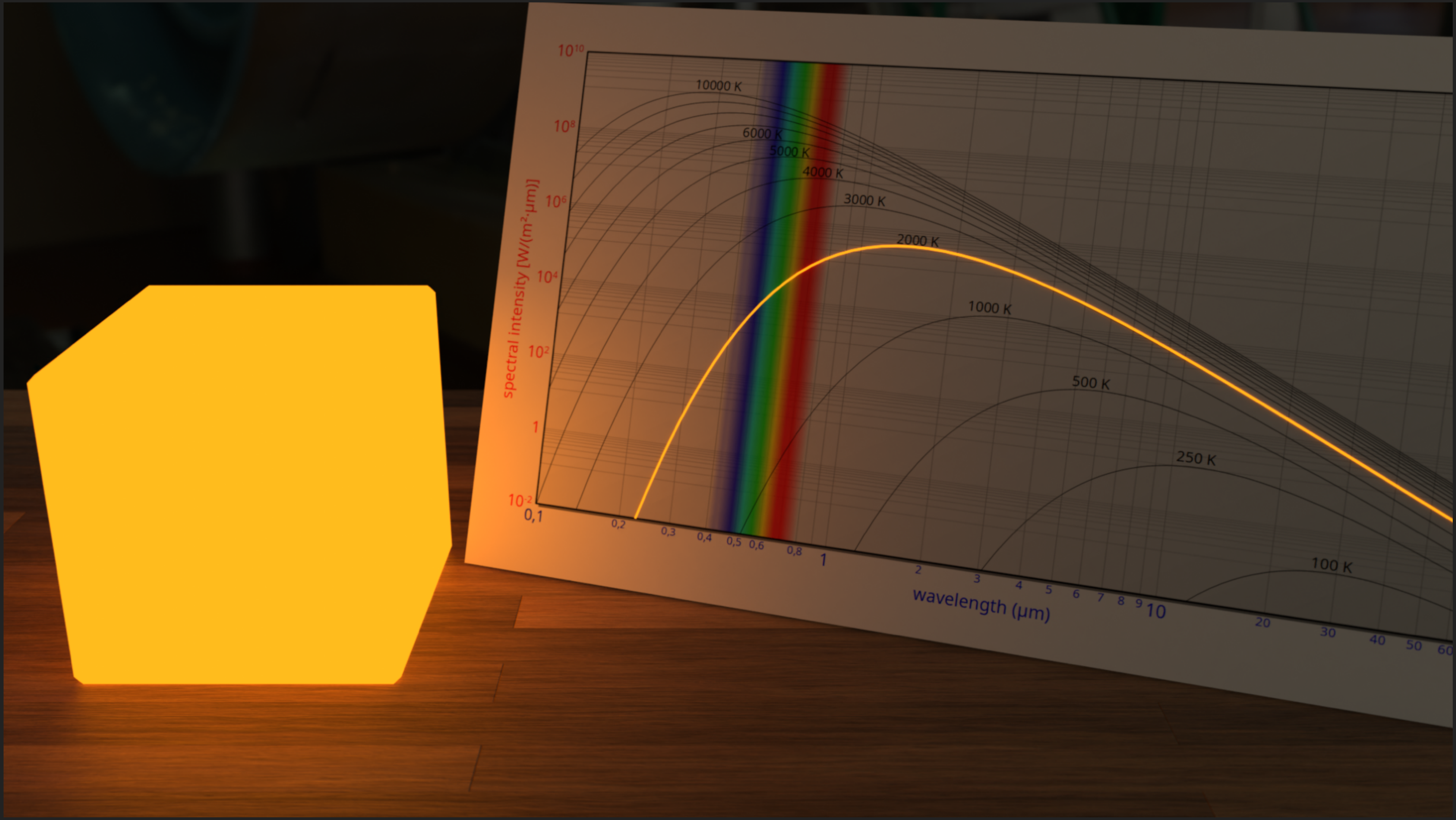
BLACKBODY RADIATION

- approx. 1000 K



BLACKBODY RADIATION

- 2000 K

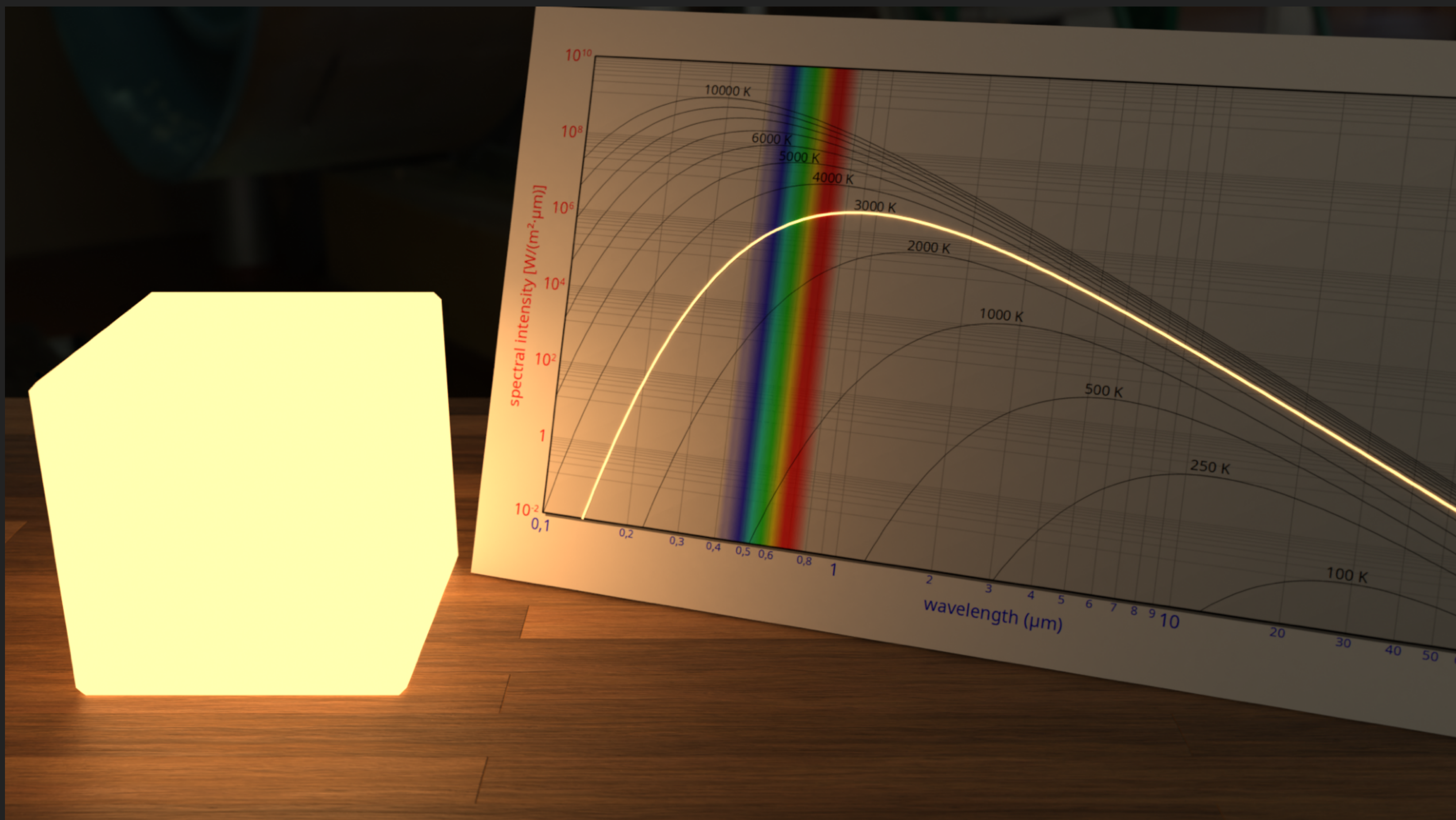


BLACKBODY RADIATION

- The white : over 3000 K

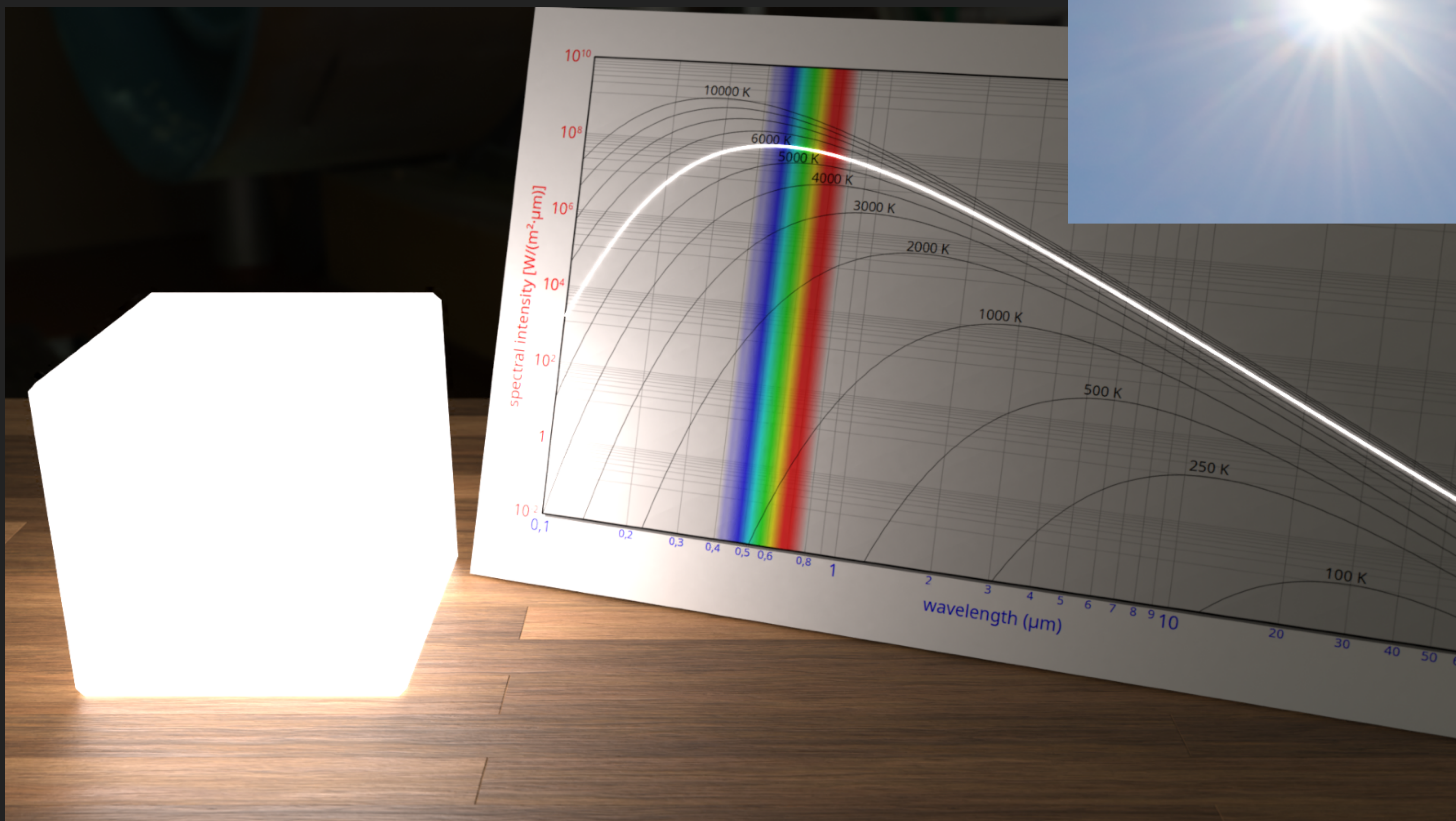
BLACKBODY RADIATION

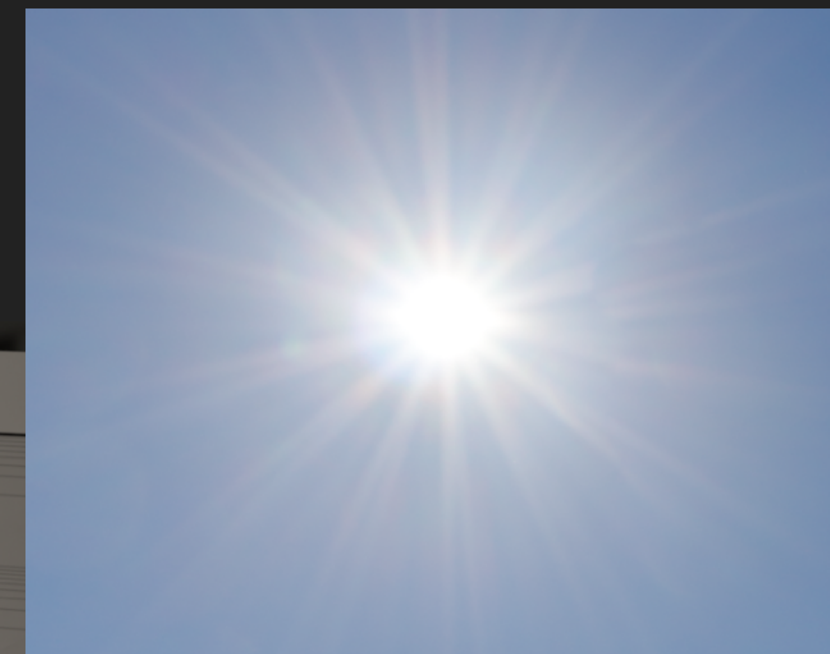
- over 3000 K more ultraviolet radiation (UV radiation)



BLACKBODY RADIATION

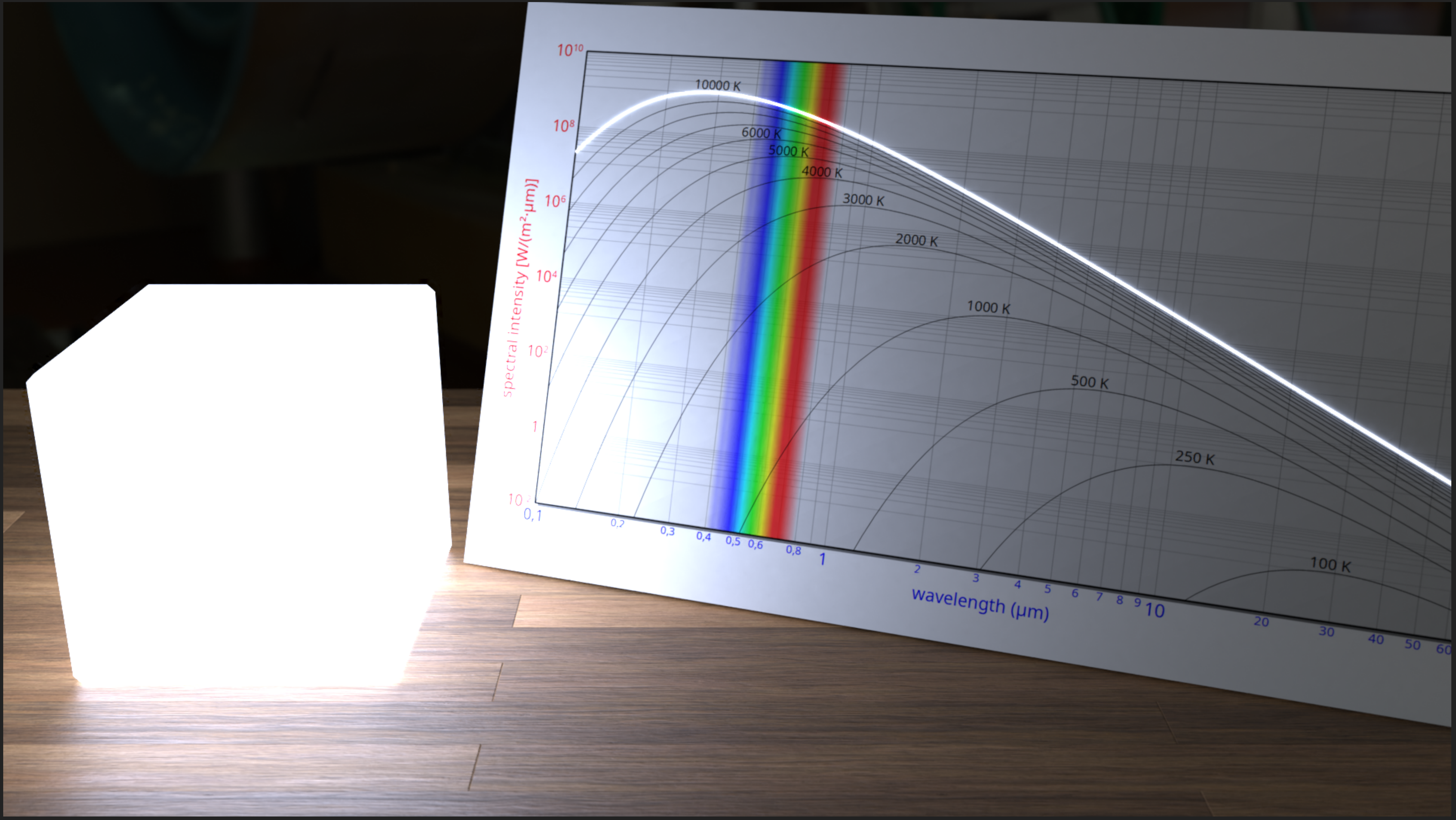
- about 6000 K





BLACKBODY RADIATION

- Blue giants more than 10,000 Kelvin.

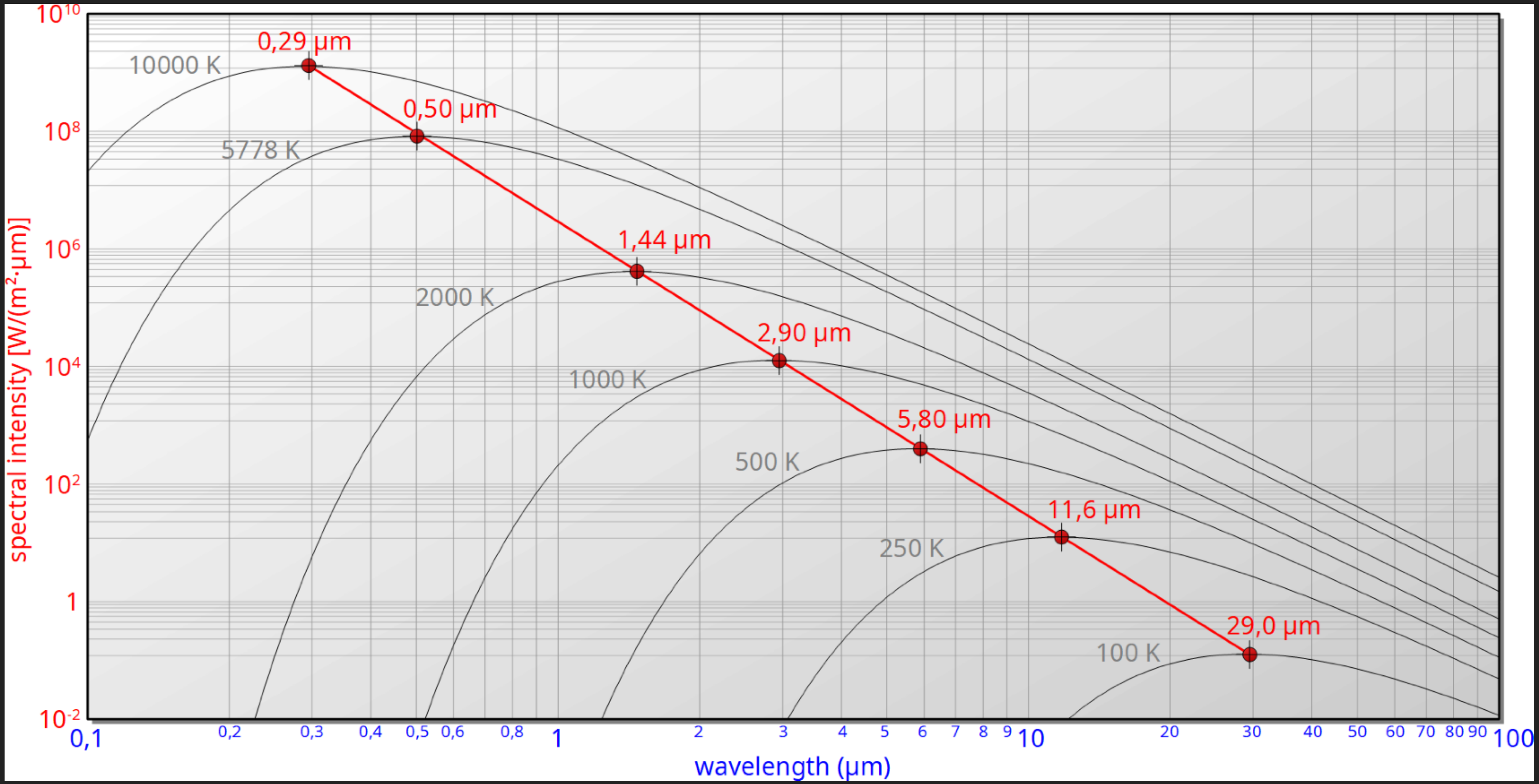


WIEN'S DISPLACEMENT LAW

- The maximum of the curve shifts with increasing temperature to ever shorter wavelengths.

$$\lambda_{max} = \frac{2897,8\ \mu m\ K}{T}$$

- The Wien's displacement law can be obtained by determining the maxima of Planck's law.

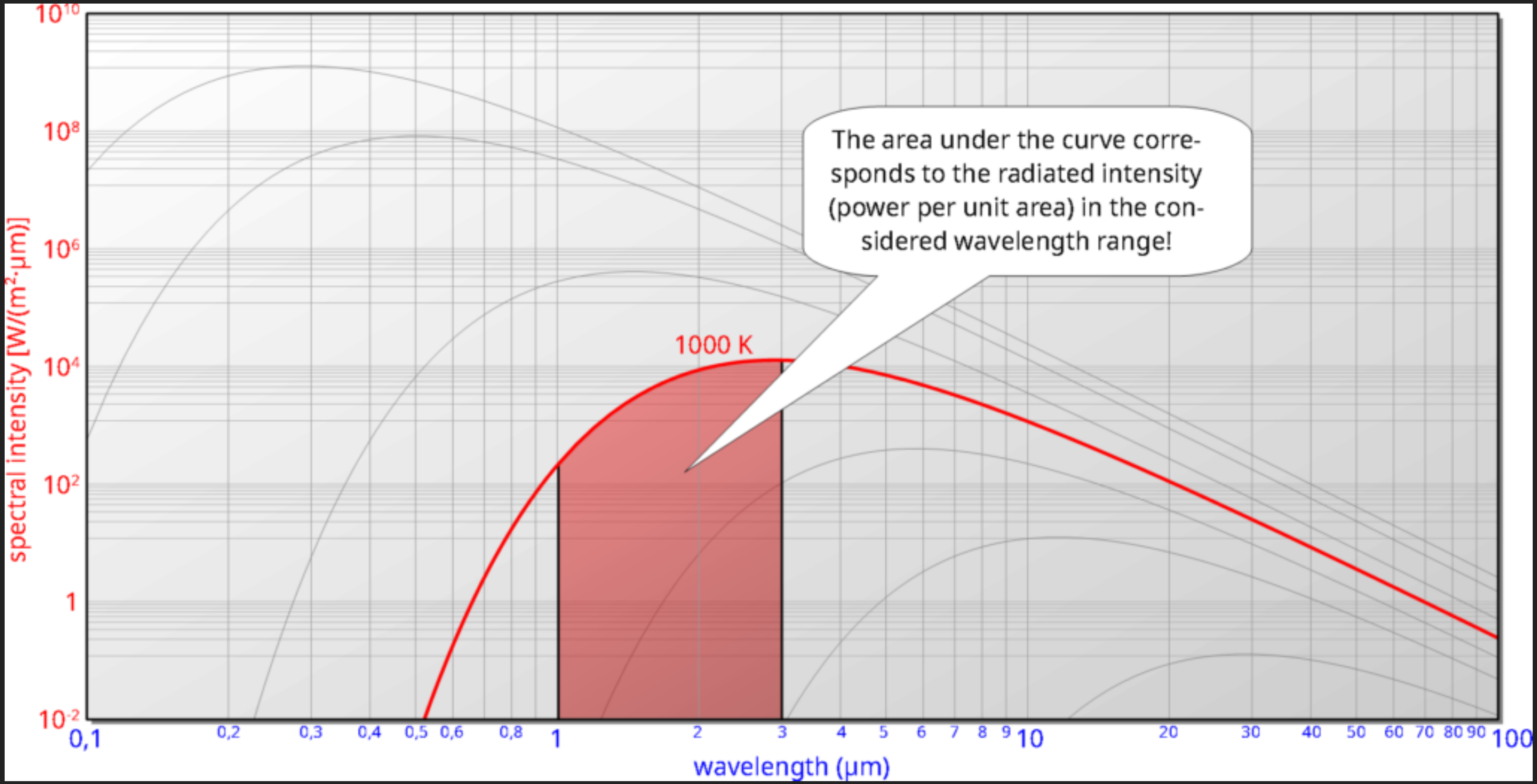


PLANCK'S LAW

- $c = \lambda \cdot f$

$$I_s(\lambda) = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

Planck's Law (wavelength form)



STEFAN - BOLTZMANN LAW

- The radiated intensity = the area under the spectral intensity distribution.
- Planck's law must be integrated over the entire wavelength range or frequency range.

$$\boxed{I = \sigma \cdot T^4} \quad \text{and} \quad \boxed{\sigma = \frac{2\pi^5 k_B^4}{15h^3c^2}} = 5,670 \cdot 10^{-8} \, \frac{\mathrm{W}}{\mathrm{m^2K^4}}$$

- The constant quantities can be combined to a new constant: Stefan-Boltzmann constant σ.
- The radiated intensity of a black body is only dependent on the temperature. It increases with the fourth power of the temperature. This is also called Stefan-Boltzmann law.

STEFAN – BOLTZMANN LAW

- The intensity of the blackbody radiation in thermal equilibrium is proportional to the fourth power of the temperature!

$$\boxed{I = \sigma \cdot T^4} \quad \text{and} \quad \boxed{\sigma = \frac{2\pi^5 k_B^4}{15h^3 c^2}} = 5,670 \cdot 10^{-8} \frac{\mathrm{W}}{\mathrm{m^2K^4}}$$

- The intensity I can be used to determine its energy emitted per unit time.

$$\boxed{\Phi(T, A) = \sigma \cdot A \cdot T^4}$$

EXERCISE

- In what wavelength region would you look for a star at T=1000 K?
  - Wien's Law

$$\lambda_{max} = \frac{2897,8\ \mu\text{m K}}{T}$$

$2{,}9 \times 10^{-6}$ m

- Your body is about 35C. What is your peak wavelength?
  - C → K

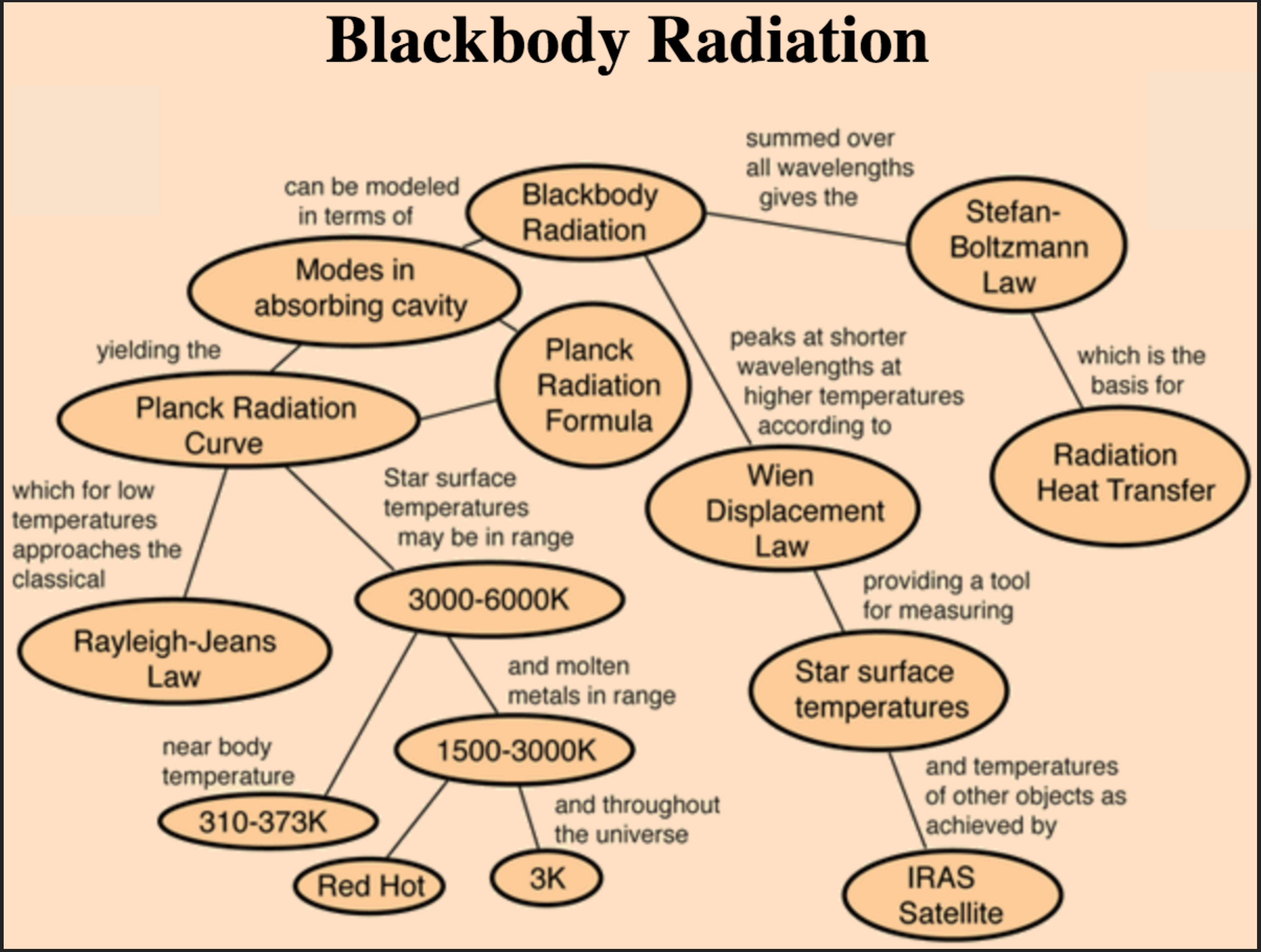
$$\lambda_{max} = \frac{2897,8\ \mu\text{m K}}{T}$$

$9{,}4 \times 10^{-6}$ m

SUMMARY

Property	Technique	Range of values
Distance	Trig Parallax	$1.3 \Rightarrow 80$pc
	Spect. Parallax	1 Mpc
Surface Temp.	Colors, Wein's Law Spectral Types	$3000K \Rightarrow 50000K$
Luminosity	Apparent brightness plus Distance*	$10^{-5} \Rightarrow 10^{6} L_{\odot}$
Radius	Stephan's Law	$0.01 R_{\odot} \Rightarrow 800 R_{\odot}$
Masses	Binary orbits	$0.08 M_{\odot} \Rightarrow 80 M_{\odot}$

PHYSICS BEHIND THE CLASSIFICATION



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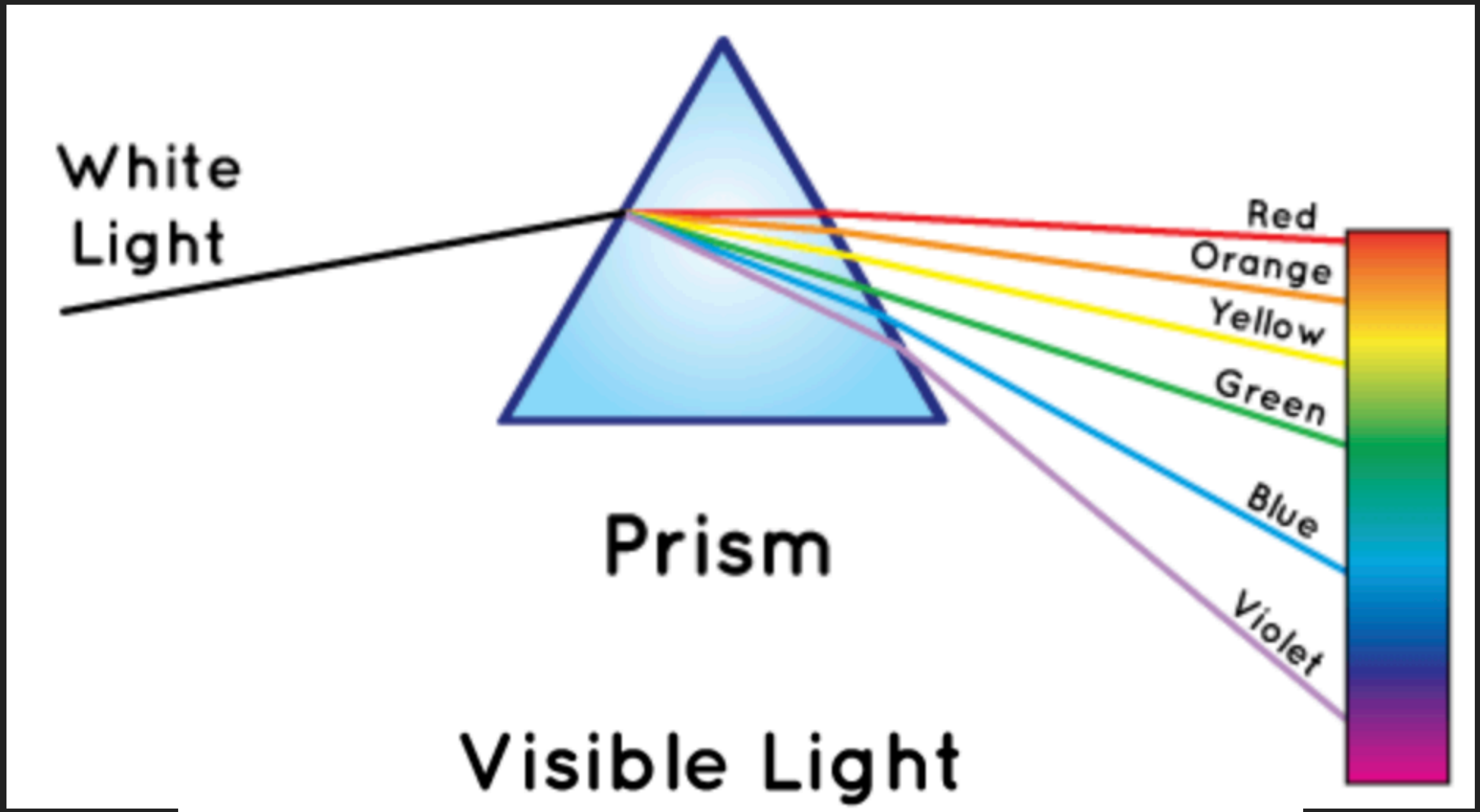

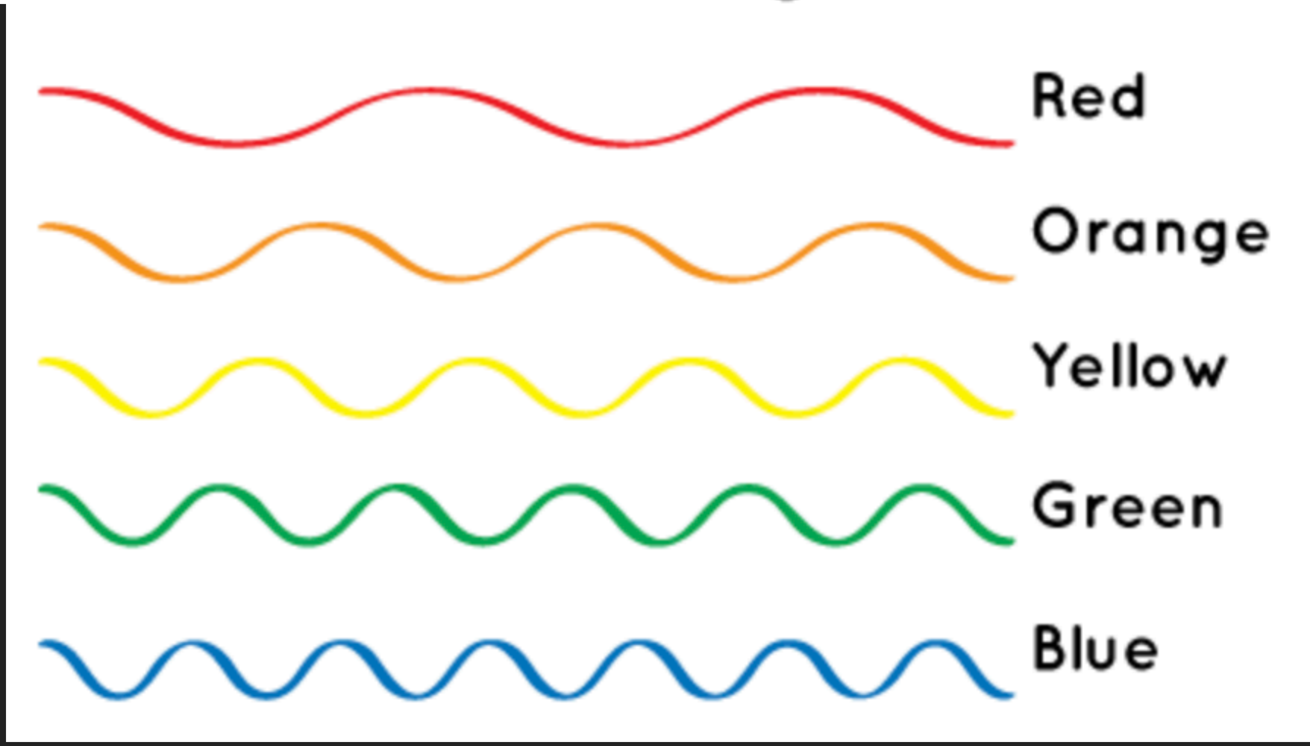

EXERCISE

Photon A

Photon A	Wavelength	Frequency	Energy	Velocity (in space)	Photon B
Red	larger the same smaller	larger the same smaller	larger the same smaller	larger the same smaller	**Blue**
Green	larger the same smaller	larger the same smaller	larger the same smaller	larger the same smaller	**Orange**
InfraRed	larger the same smaller	larger the same smaller	larger the same smaller	larger the same smaller	**Visual**
Visual	larger the same smaller	larger the same smaller	larger the same smaller	larger the same smaller	**Microwave**
X-rays	larger the same smaller	larger the same smaller	larger the same smaller	larger the same smaller	**Gamma-ray**

(Hint: the speed of *all* photons is the same.)

RESOURCES

- https://spaceplace.nasa.gov/blue-sky/en/
- http://hyperphysics.phy-astr.gsu.edu/hbase/bbcon.html
- https://www.tec-science.com/thermodynamics/temperature/black-body-radiation/
- https://www.tec-science.com/thermodynamics/temperature/plancks-law-of-blackbody-radiation/
- http://hosting.astro.cornell.edu/academics/courses/astro201/kirchhoff.htm
- http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html
- https://www.webassign.net/ncchem/bohr.html
- https://collection.sciencemuseumgroup.org.uk/objects/co3632/william-herschels-infrared-prism-prism-optical-demonstration
- https://cas.sdss.org/dr6/en/proj/basic/spectraltypes/lines.asp
- https://www.scienceinschool.org/2007/issue4/spectrometer
- http://www.cs.cmu.edu/~zhuxj/astro/html/spectrometer.html
- https://astro.unl.edu/naap/hydrogen/naap_hydrogen_sg.pdf
- https://astro.unl.edu/naap/hydrogen/hydrogen.html
- https://calgary.rasc.ca/stellarmagnitudes.htm
- https://www.youtube.com/watch?v=iwlMmJs1f5o
- https://earthsky.org/space/what-is-a-parsec
- https://www.astronomynotes.com/index.html

RESOURCES

- https://courses.lumenlearning.com/towson-astronomy-2/chapter/using-spectra-to-measure-stellar-radius-composition-and-motion/
- https://www.nobelprize.org/prizes/themes/how-the-sun-shines-2
- https://sites.ualberta.ca/~pogosyan/teaching/ASTRO_122/lect6/lecture6.html
- https://pages.uoregon.edu/jimbrau/astr122/Notes/Chapter4.htm
- https://thecuriousastronomer.wordpress.com/tag/spectra/
- https://docs.kde.org/trunk5/en/extragear-edu/kstars/ai-colorandtemp.html
- https://www.handprint.com/ASTRO/specclass.html