

# Welcome to the course “Energy Conversion by Semiconductor Devices”

**Jun-Ho YUM**

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**Break on 22. Oct. 2024**

**No lecture on 16. Dec. 2024**

**15 min Presentation exam on 02 and 09. Dec. 2025**

**Oral exam in Jan. 2026:**

**6 – 7 questions and answers**

**20 min preparation and 20 min answer**

**Presentation topics:**

- 1. Working principle of a pn junction**
- 2. Exciton & working principle of organic photovoltaics**
- 3. Working principle of dye-sensitized solar cells**
- 4. Working principle of perovskite solar cells**
- 5. Working principle of of photoelectrochemistry**
- 6. Working principle of photocatalysis**
- 7. Novel materials, e.g. quantum dots, transition metal dichalcogenide, etc**
- 8. Characterization tools: EIS, TRPL, IMPV/IMVS, XRD, XPS, PL, TRPL, KPFM, Gas chromatography, etc**

**+**

**Applications (selection of a scientific article)**

**Total 15 mins:**

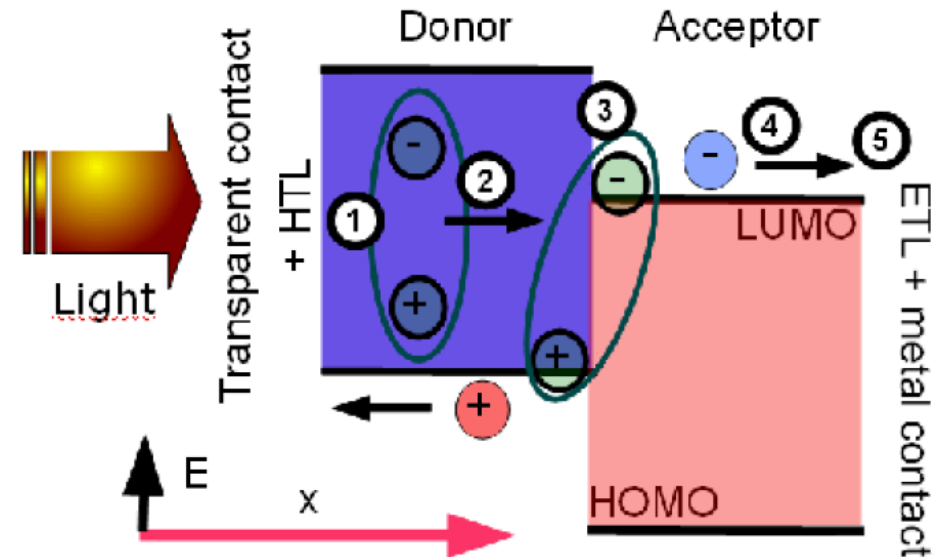
**Introduction 1 – 2 slides (1 – 3 mins)**

**Main body 3 – 4 slides (8 - 10 mins)**

**Conclusion 1 slides (1 min)**

## Organic Solar Cells

### 1. Working principle



## Elucidating the photodegradation pathways of polymer donors for organic solar cells with seven months of outdoor operational stability

Han Xu<sup>1,7</sup>, Jianhua Han<sup>1,2,7</sup>, Maxime Babics<sup>1</sup>, Luis Huerta Hernandez<sup>1</sup>, Diego Rosas Villalva<sup>1</sup>, Matteo Sanviti<sup>3,4</sup>, Jules Bertrand<sup>1</sup>, Yongcao Zhang<sup>1</sup>, Ye Liu<sup>1</sup>, Hu Chen<sup>1,5</sup>, Lingyun Zhao<sup>6</sup>, Joel Troughton<sup>1</sup>, Jaime Martin<sup>3,4</sup>, Frédéric Laquai<sup>1</sup>, Stefaan De Wolf<sup>1</sup> & Derya Baran<sup>1</sup>✉

### Motivations:

- photo- and thermal-induced degradation of polymer donors is still unclear.
- Lack of operational outdoor studies.

### Method:

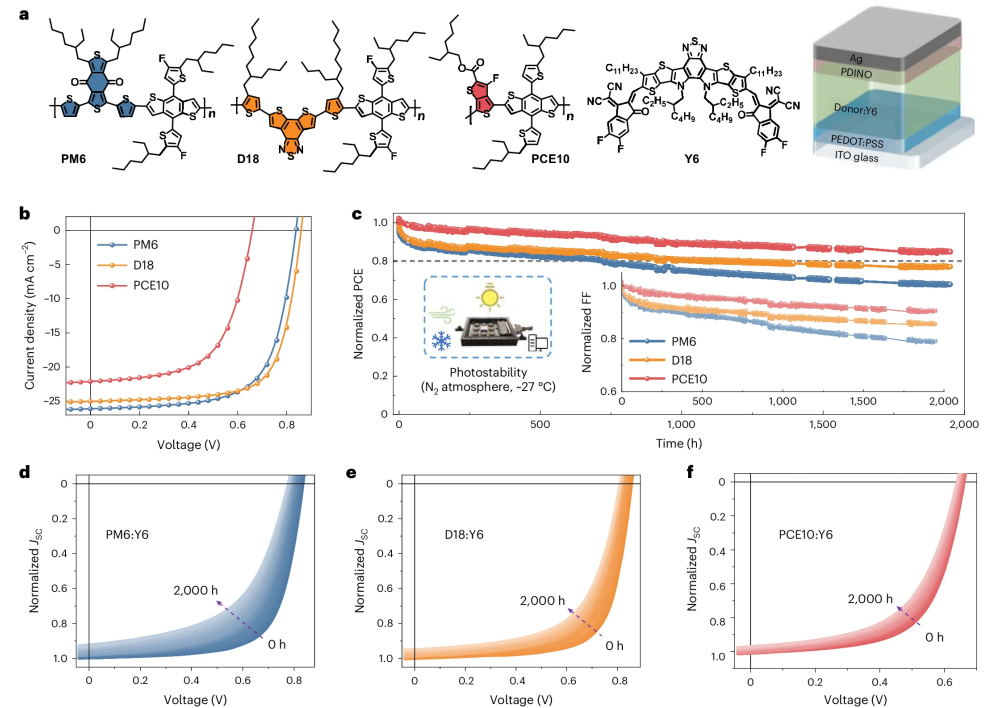
- Degradation studies in the lab of blends made with different donors.
- Trying to decouple morphology/ molecular degradation/interfacial degradations.
- Outdoor stability tests, effect of solar irradiance and heat stress.

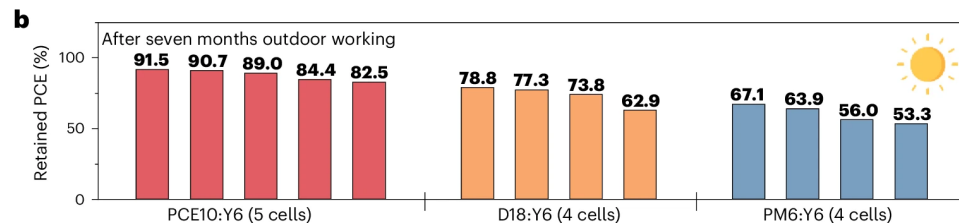
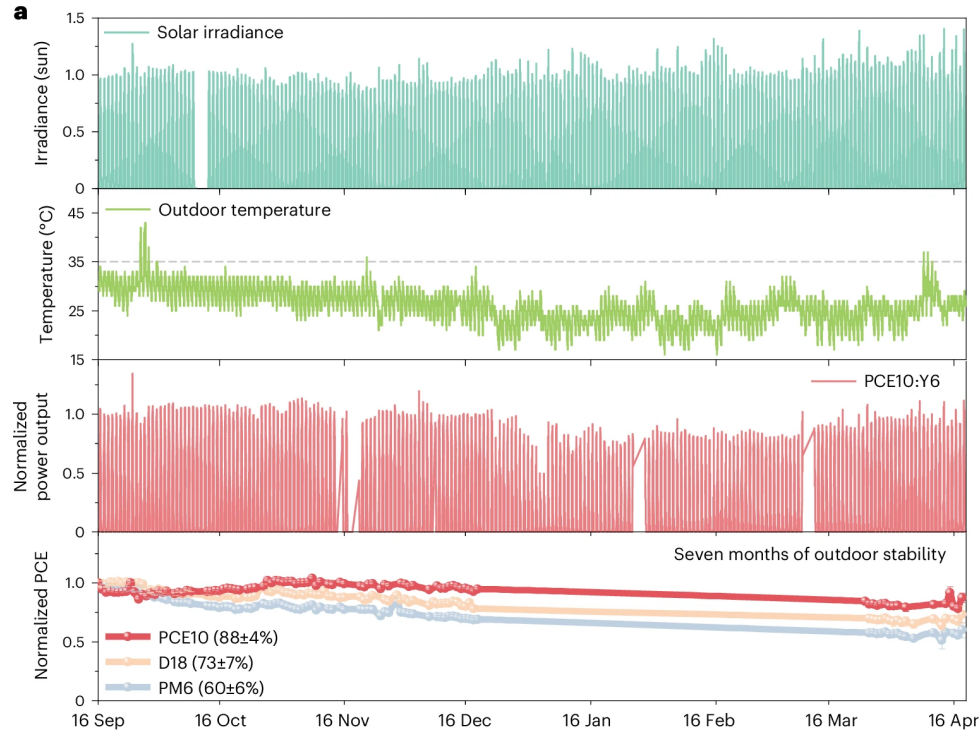
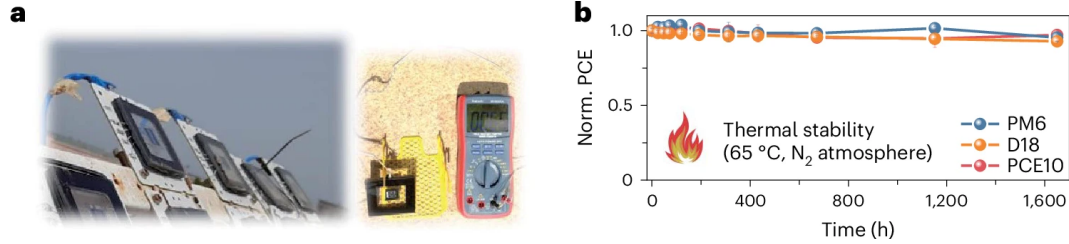
## Organic Solar Cells

### 2. One article about application:

- Motivation and Novelty

- Main Results





## 3. Conclusion and Criticism

- Motivates that stability is overlooked in OPV.
- Diverse characterizations.
- Good combination of experiments and theoretical calculation using Laplacian bond order.
- No really decoupling the change of morphology, mainly HR-TEM between different blends.
- Not convinced that they got any new insights from outdoor testing (just confirmation of lab results).
- Not convinced by their strategy to increase the performance by adding another polymer to the blend.

## Selection of papers

Some articles will be uploaded on the moodle link (Nov.).

Research articles published in 2025 but **no review articles**

Topics: Solar energy conversion, Solar Cells, Photoelectrochemistry, Photocatalysis, Water splitting or H<sub>2</sub> production, CO<sub>2</sub> reduction, Solar-driven NH<sub>3</sub> production, Optoelectronic applications, Nanomaterials, etc.

Journal recommendation: Nature and Nature family (Nature Mater., Nature Chem., Nature Photonics, Nature Energy, Nature Commun.), Science, RSC journals (Energy Environ. Sci., J. Mater. Chem.), ACS journals (JACS, ACS Nano, Nano Lett., ACS Energy Lett.), Wiley (Adv. Mater., Adv. Funct. Mater., Adv. Energy Mater., Angewandte), Cell Press (Joule, Matter)

**Exam will be scheduled  
alphabetically (Family  
name).**

**Please, send your selected topic and the title of  
your selected paper to [junho.yum@epfl.ch](mailto:junho.yum@epfl.ch) and  
by 28<sup>th</sup> November 2025!**

16/16 Name First Name

1 **Bedouelle Guillaume François  
Nicolas**

2 **Boos Angie Alice**

3 **Célérien Aurélie Fanny Marie**

4 **Contreras Fernandez Alba**

5 **Eggli Chloé**

6 **Fehler Amelie Antonia**

7 **Gajda Michal Jan**

8 **Gjeruldsen Hans Henrik**

9 **Krupa Mikolaj Piotr**

10 **Lorenzini Guillaume François**

11 **Martinelli Alyssa**

12 **Mennerat Marie Blandine Julie**

13 **Pan Ziyan**

14 **Qi Yangyi**

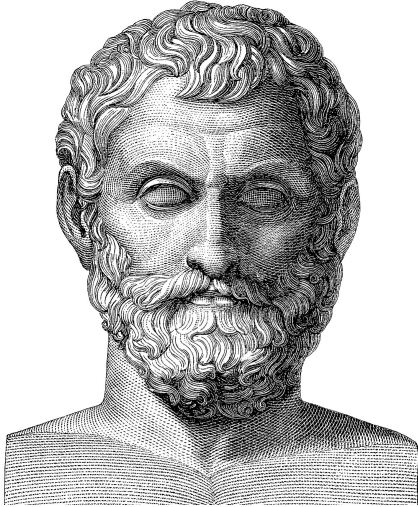
15 **Roobatjazi Seyednima**

16 **Rossboth Cédric Nathanaël**

- 1. The solar energy**
- 2. Light-Matter interaction**
- 3. The basic of semiconductors and junctions**
- 4. The basic of solar energy conversion and solar cells**
- 5. Solar cell technologies, pn junction solar cell, third generation solar cells**
- 6. The basic of electrochemistry**
- 7. Green water splitting by photoelectrochemistry**
- 8. Green water splitting by photocatalysis**

## Thales

(BC 626 – BC 548)

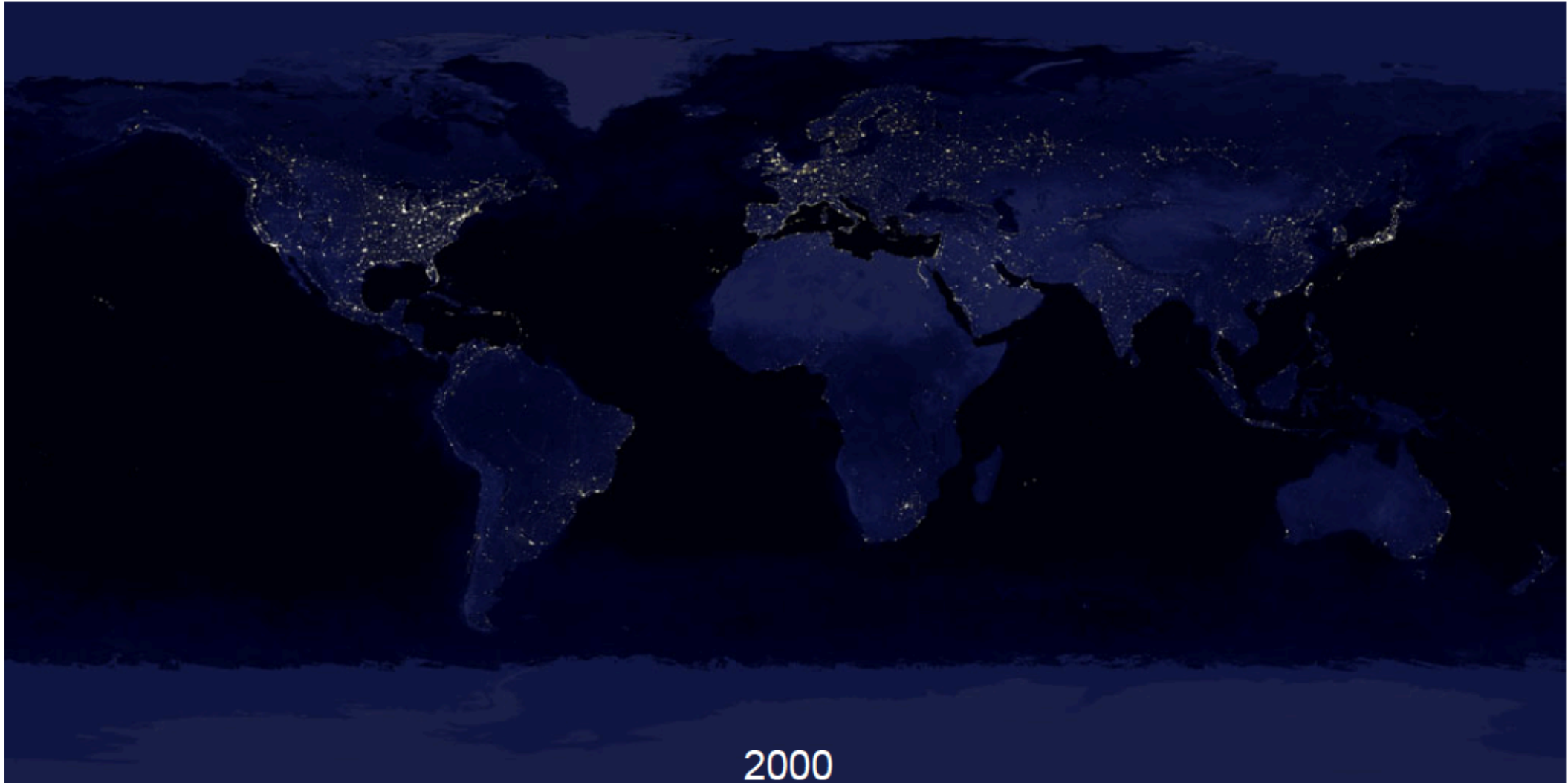


## William Gilbert

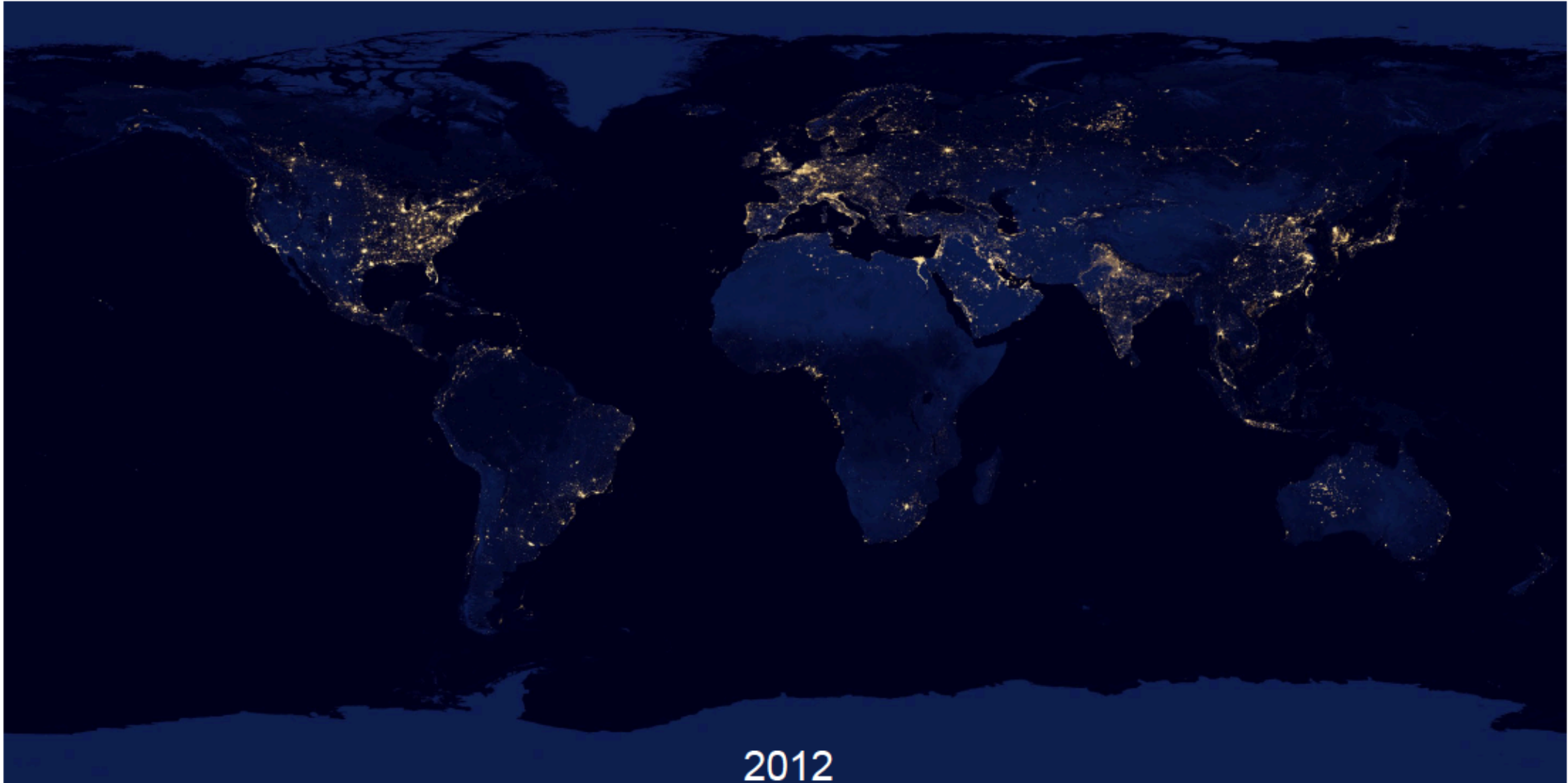
(1544 – 1603)



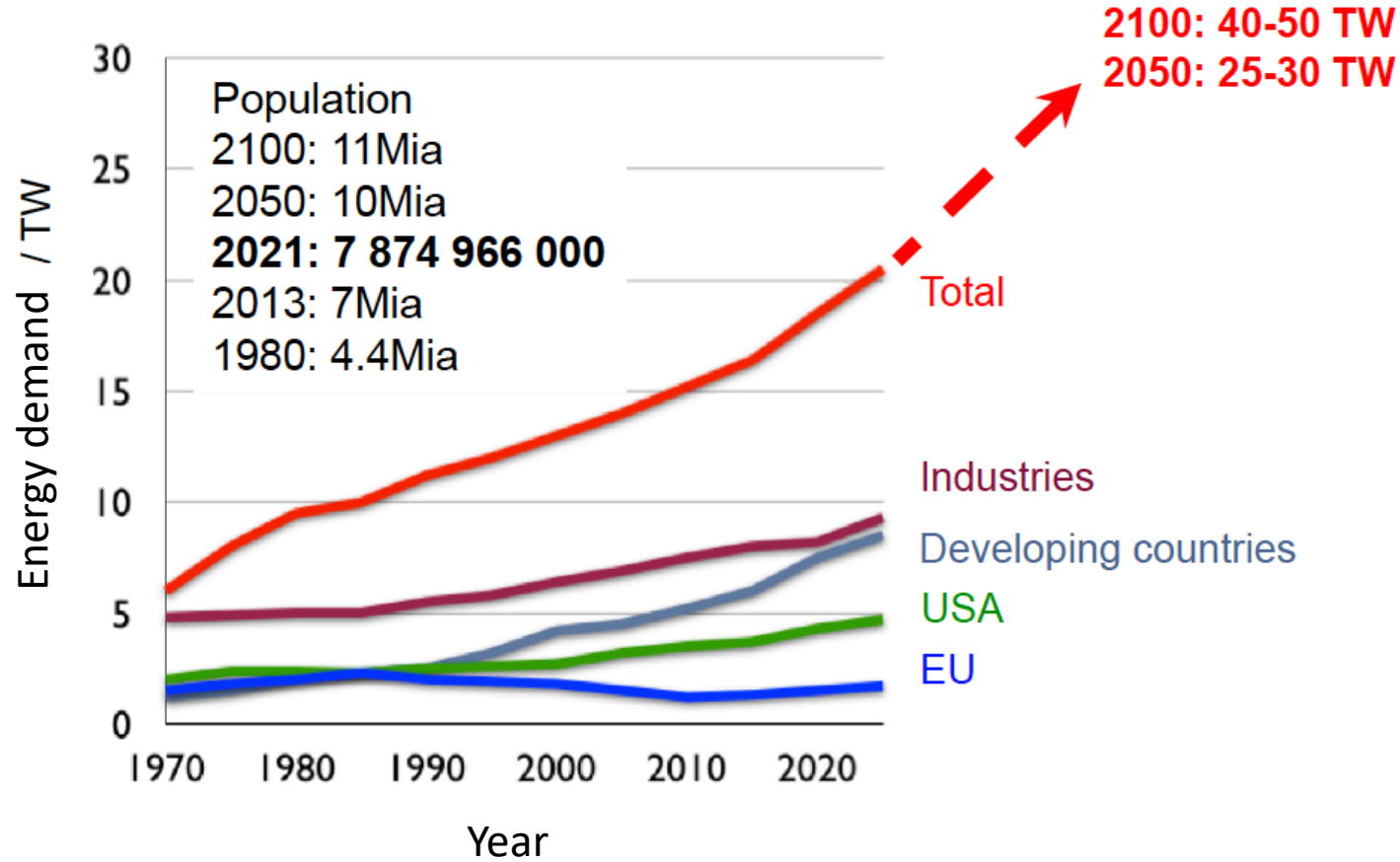
- The early Greek word for the Sun: ‘hlector’ (pronounced ‘elector’).
- In many ancient Greek writings that describe Thales’ work and ideas, amber is called “electron”.
- This was also used to describe the material amber because its colour reminded people of the Sun.
- William Gilbert was the first person to use the word “electricity”.



Source: <https://earthobservatory.nasa.gov/images/event/79869/earth-at-night>



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Source: <https://www.lifegate.com/greater-aletsch-glacier>

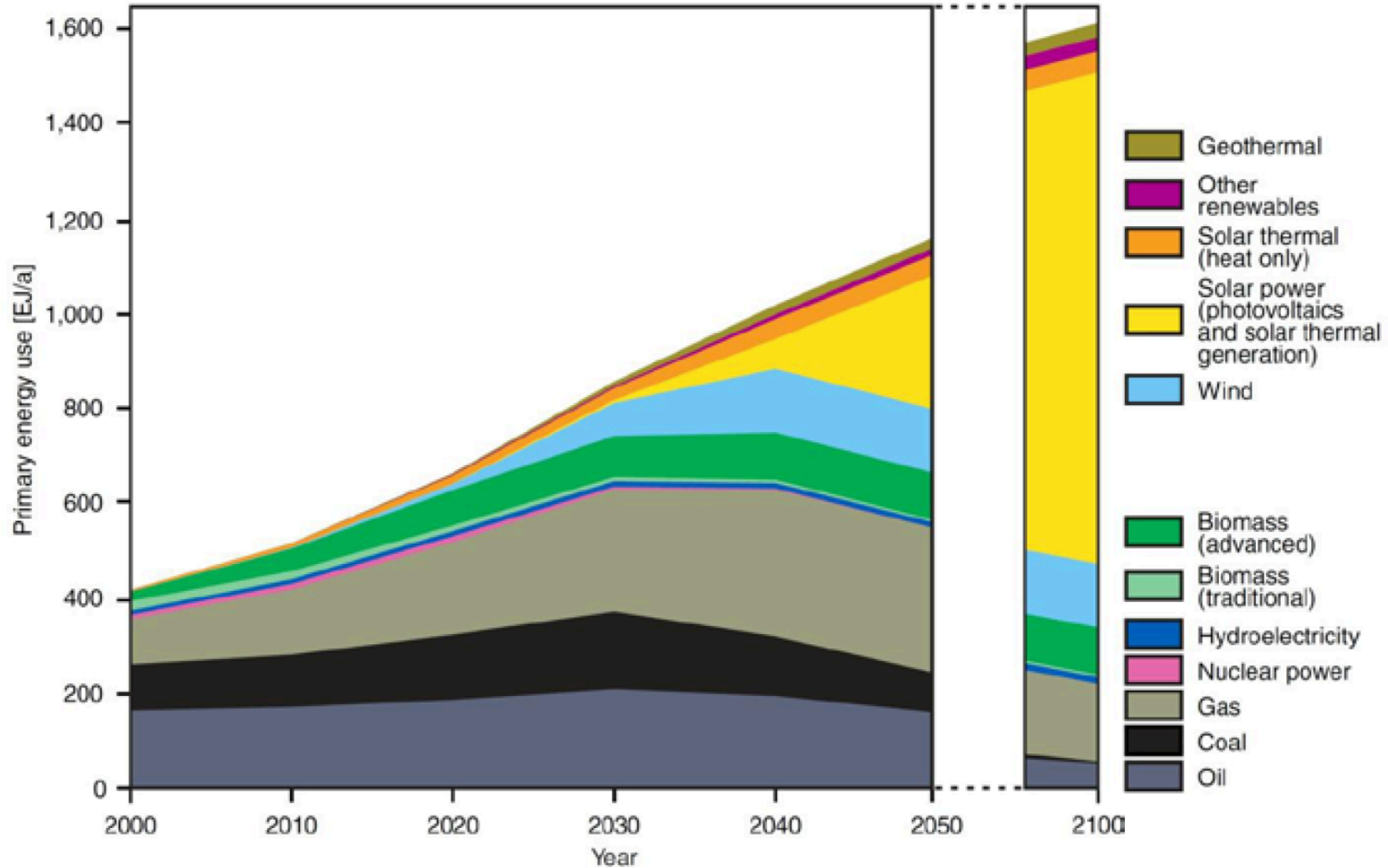
# Why Switzerland is among the ten fastest-warming countries in the world

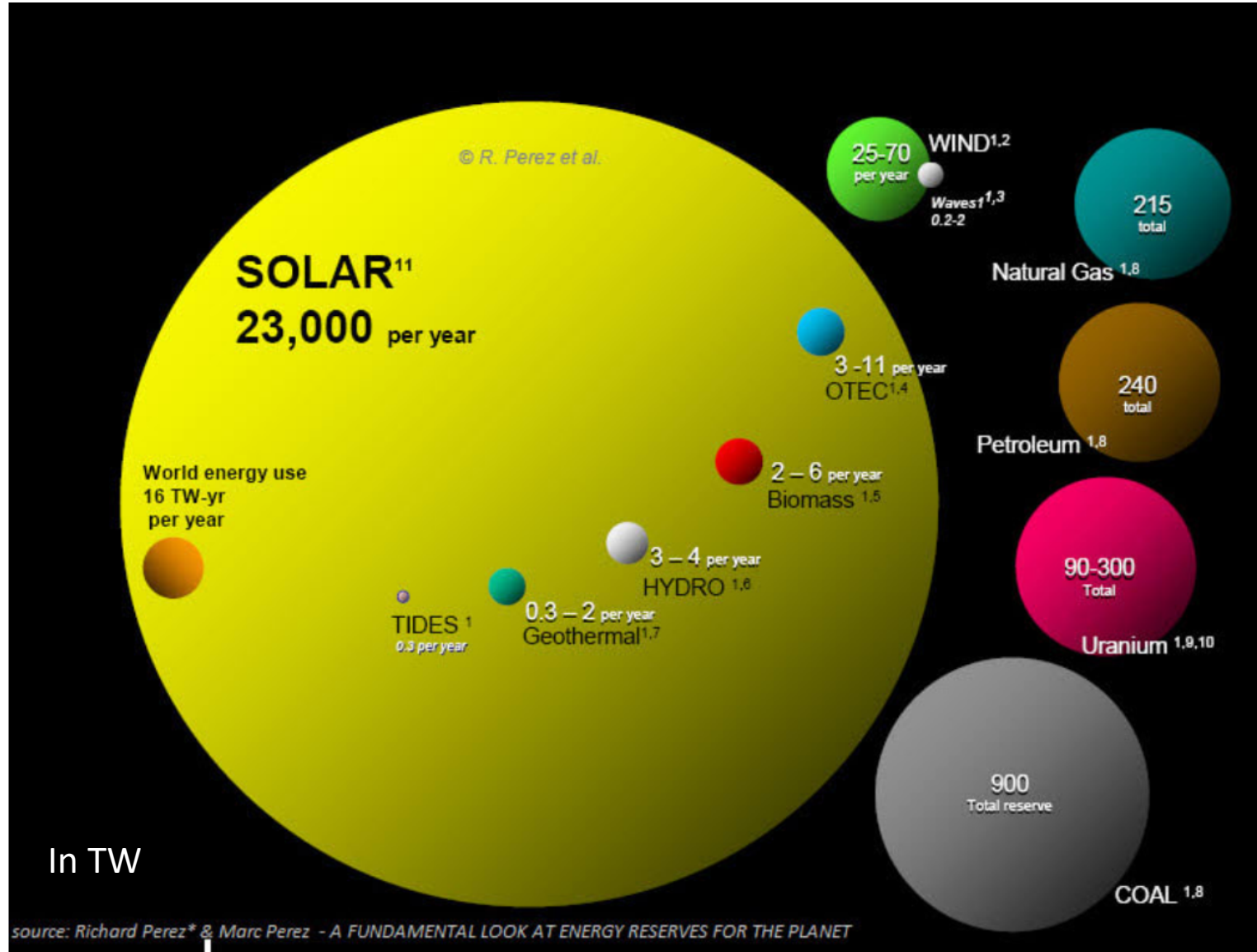


▲ A melted glacier lake in the Swiss Alps. Westend61 / A. Tamboly

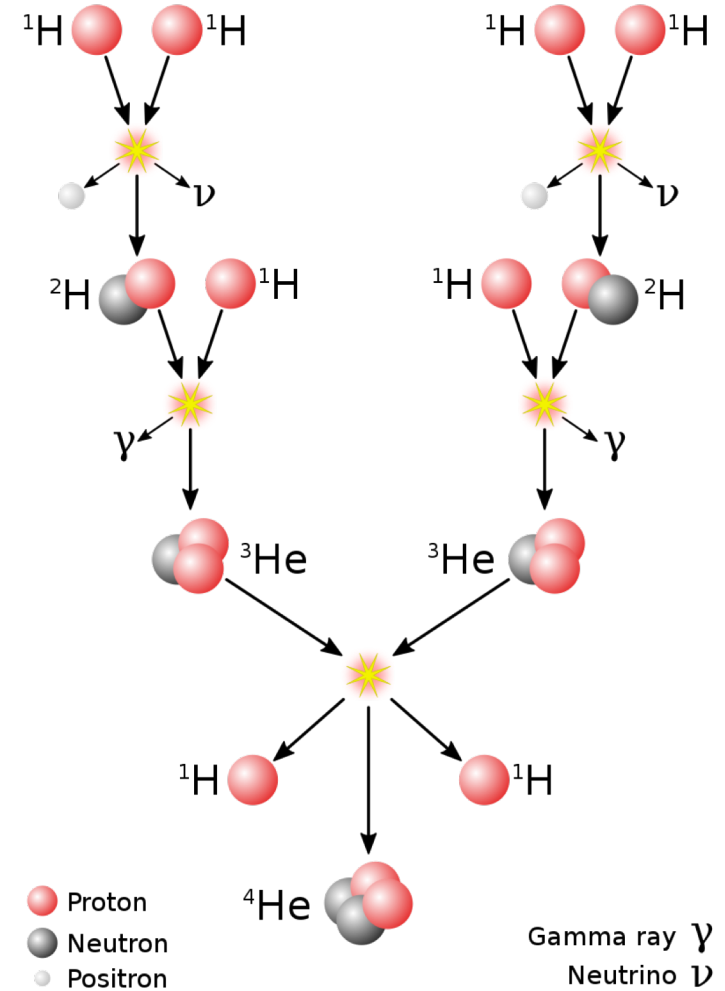
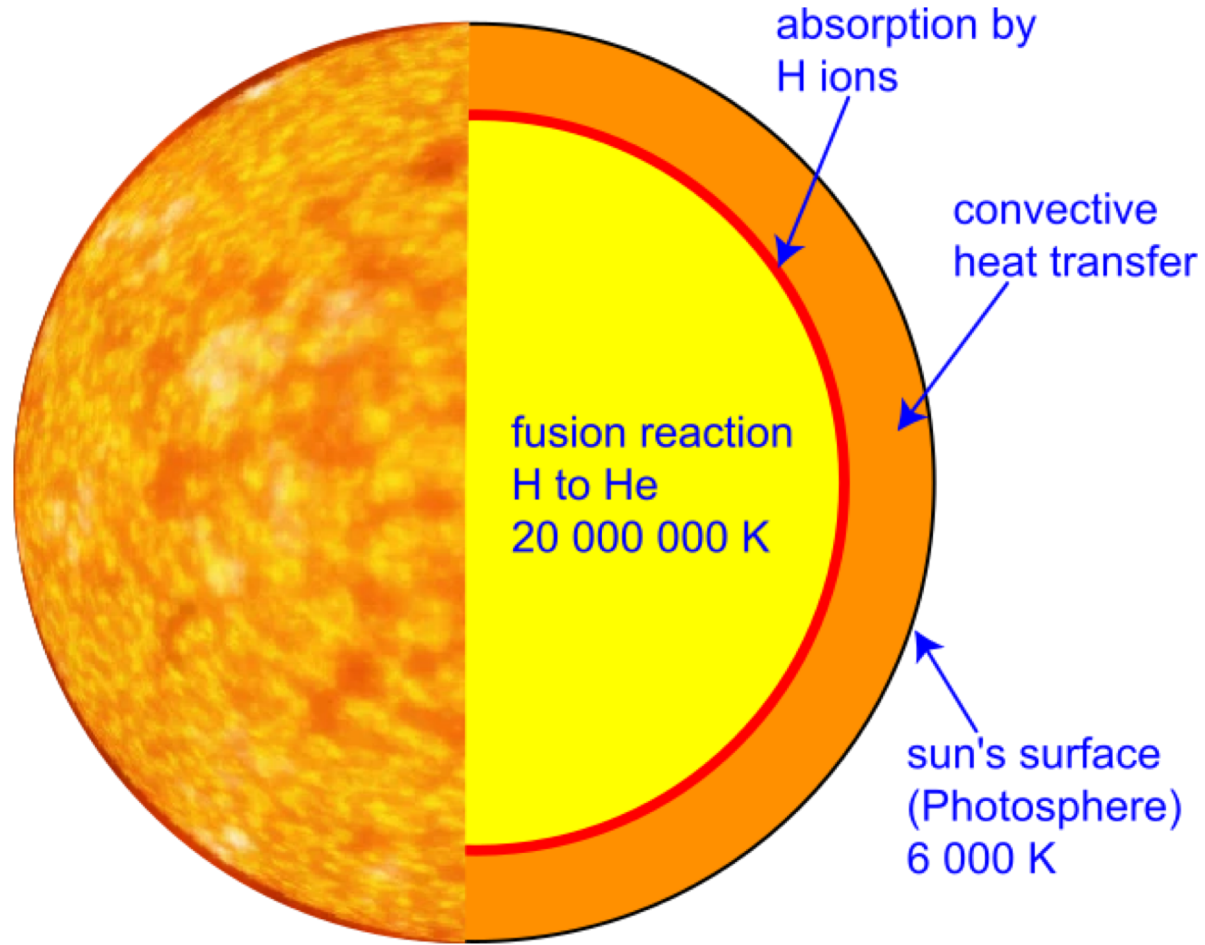


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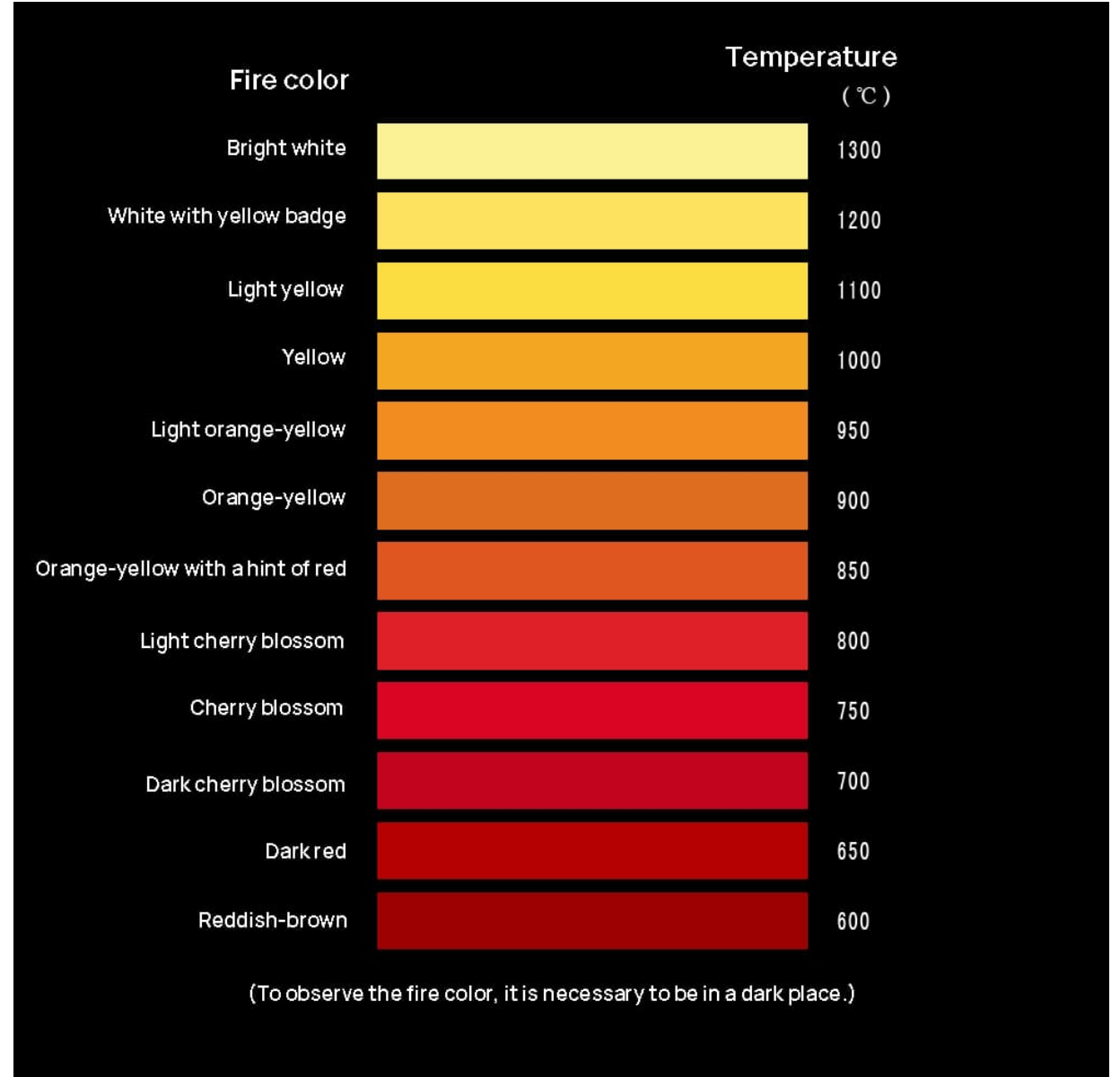
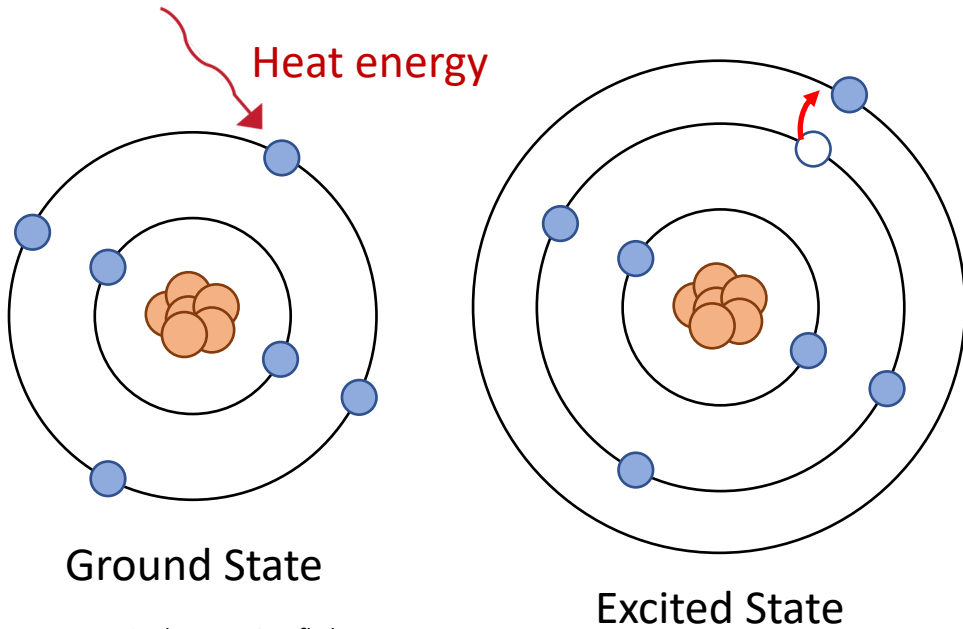




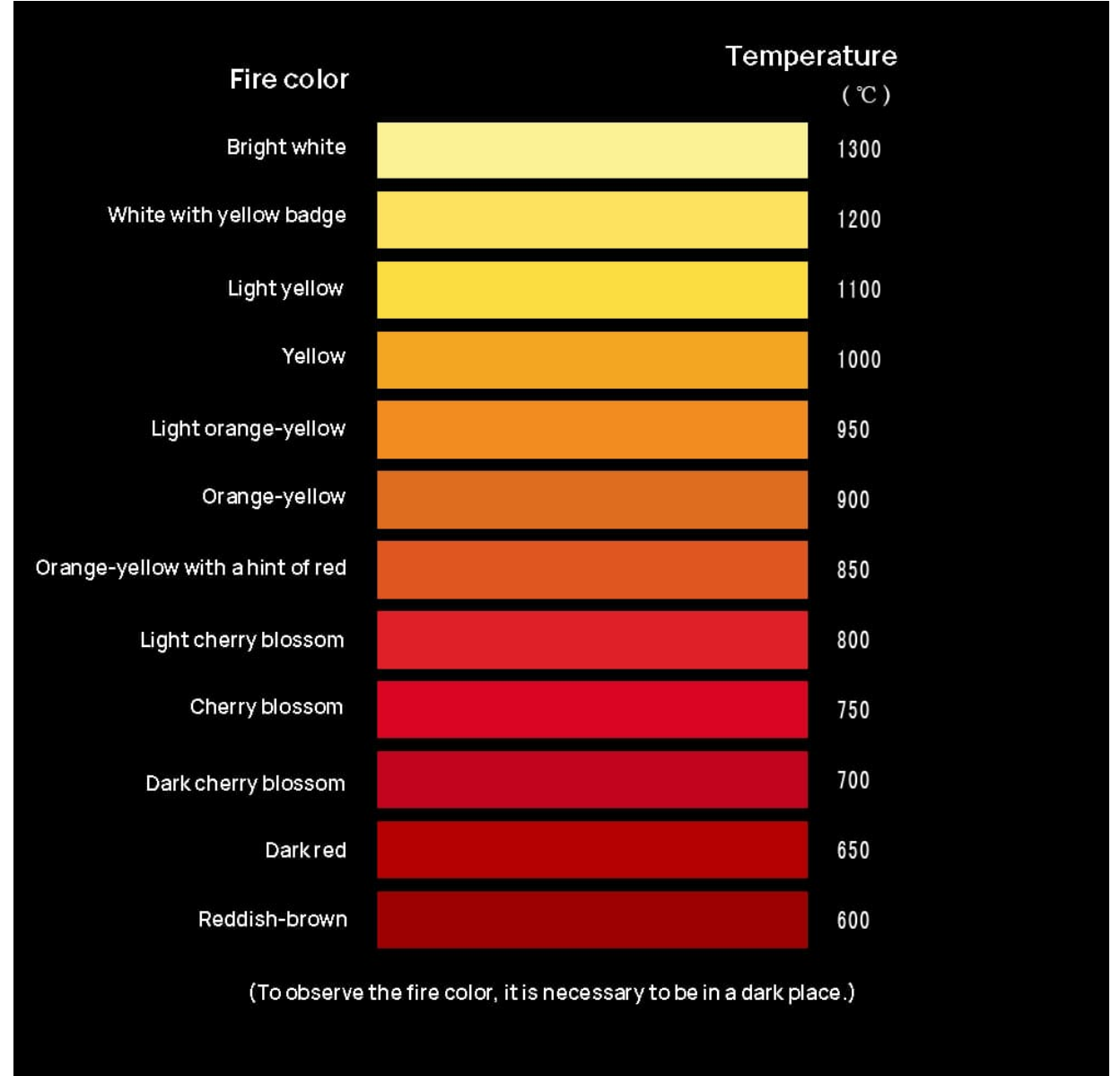
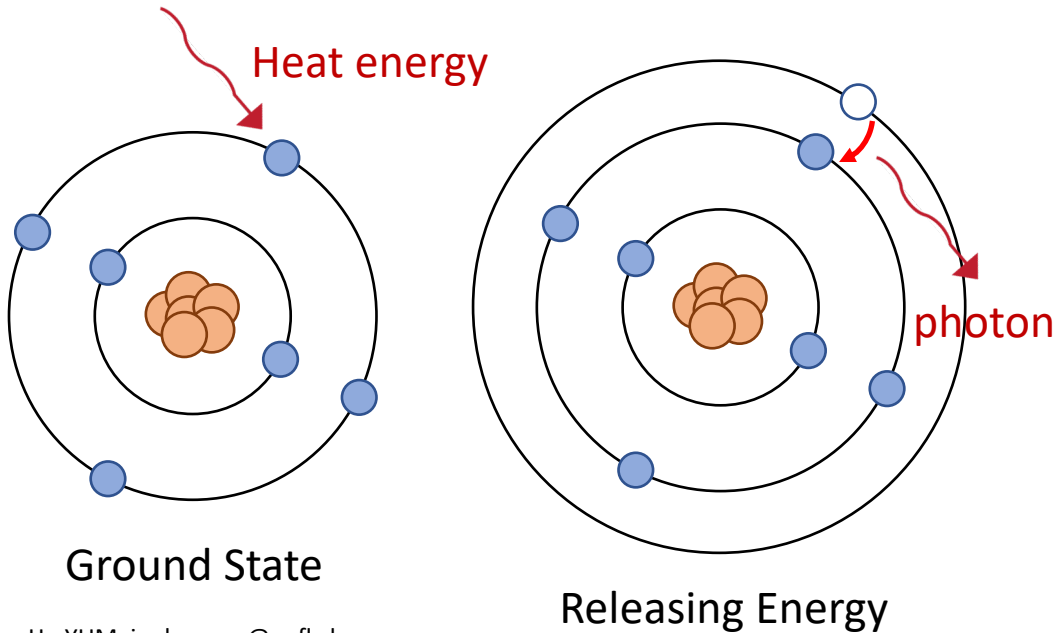
Perez, R. and M. Perez, (2009): A fundamental look at energy reserves for the planet. The International Energy Agency SHC Programme Solar Update, Volume 50, pp. 2-3, April 2009



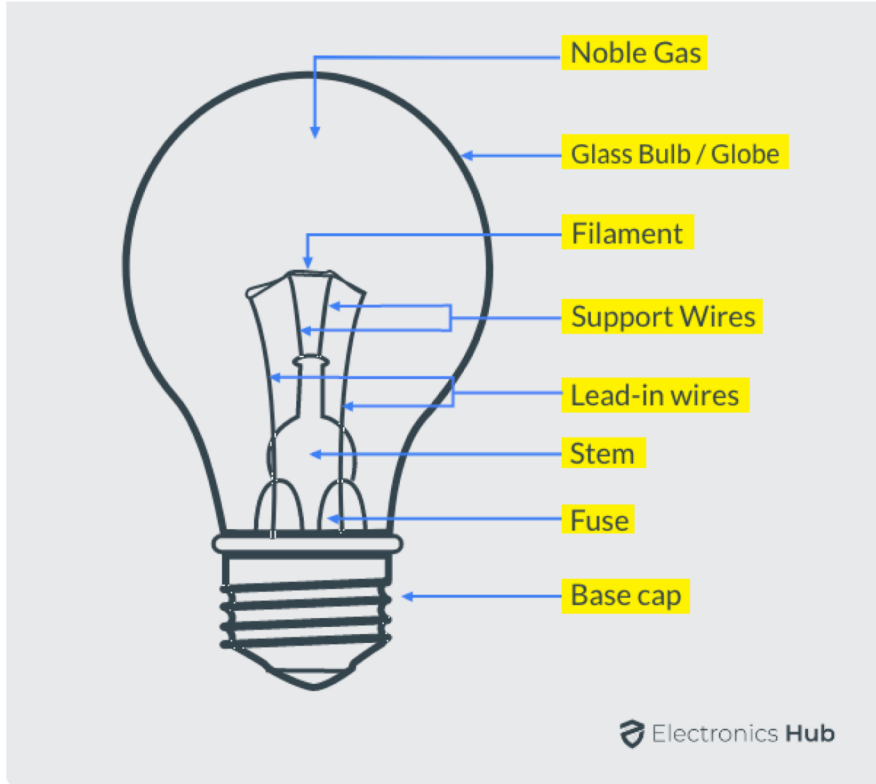
# Hot Object Emits Light!



# Hot Object Emits Light!



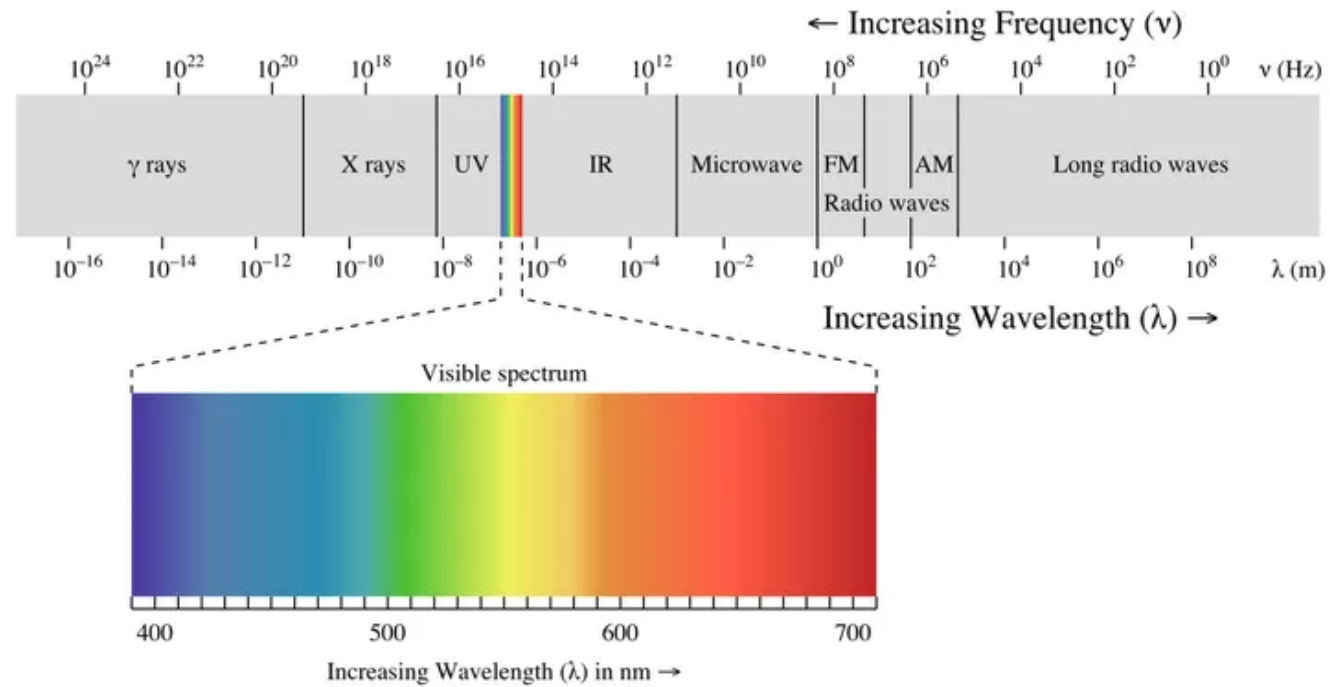
# EPFL Hot Object Emits Light!



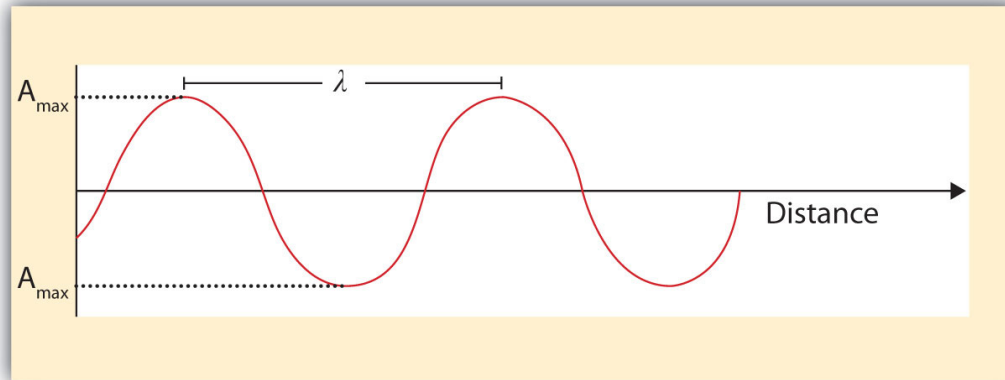
<https://www.usgs.gov/media/images/what-minerals-produce-colors-fireworks>

# EPFL Nature of Light: Electromagnetic Spectrum

An electromagnetic *spectrum* is a display of the component colors of a light beam, separated by their wavelengths.

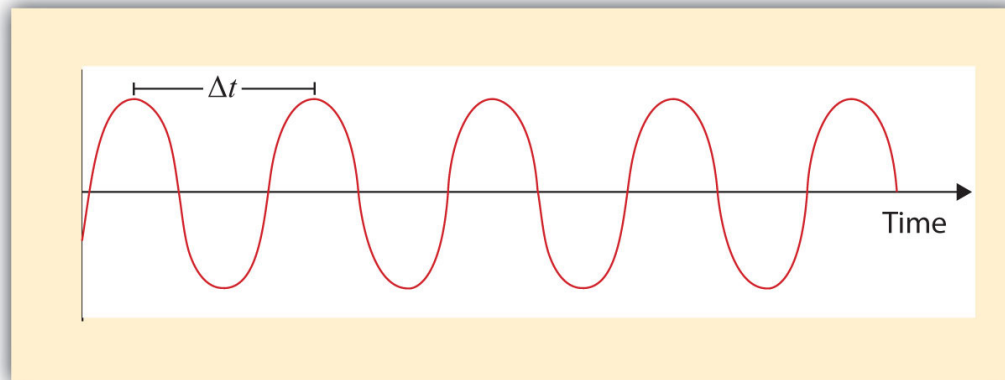


$$v = c/\lambda$$



**Wavelength ( $\lambda$ ):** the distance in the line of advance of a wave from any one point to the next point of corresponding phase.

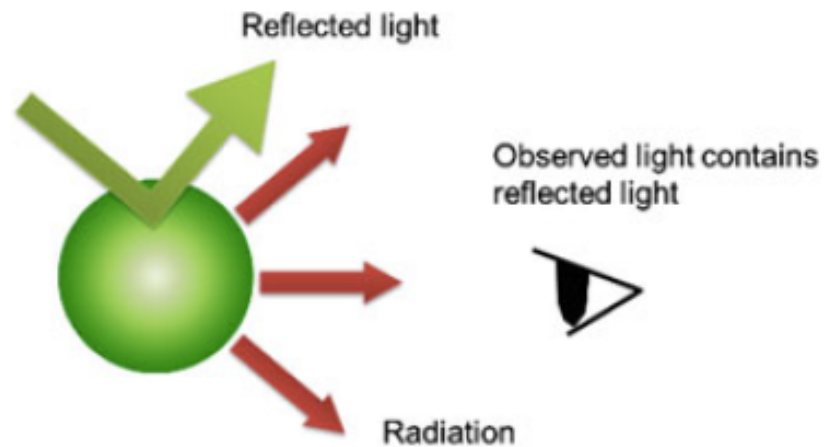
$$v = c/\lambda$$



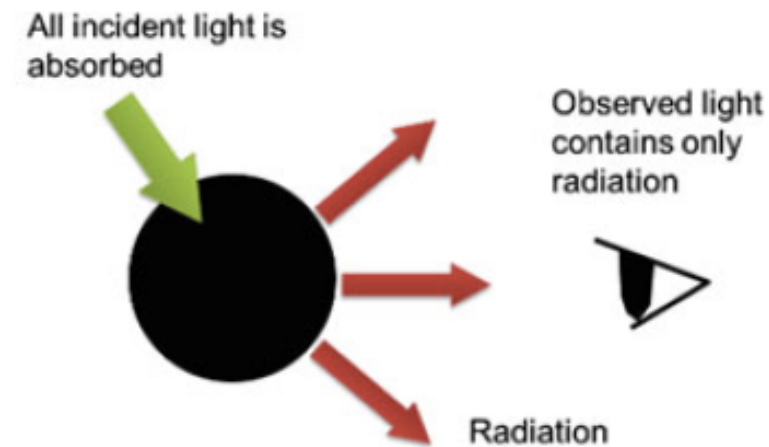
**Frequency ( $\nu$ ):** the number of cycles of light that pass a given point in one second.

# EPFL Black Body Radiation

Many commonly encountered light sources, including the sun, are closely modelled as "**blackbody**" emitters. A blackbody absorbs all radiation incident on its surface and emits radiation based on its temperature. Blackbodies derive their name from the fact that, if they do not emit radiation in the visible range, they appear black due to the complete absorption of all wavelengths.



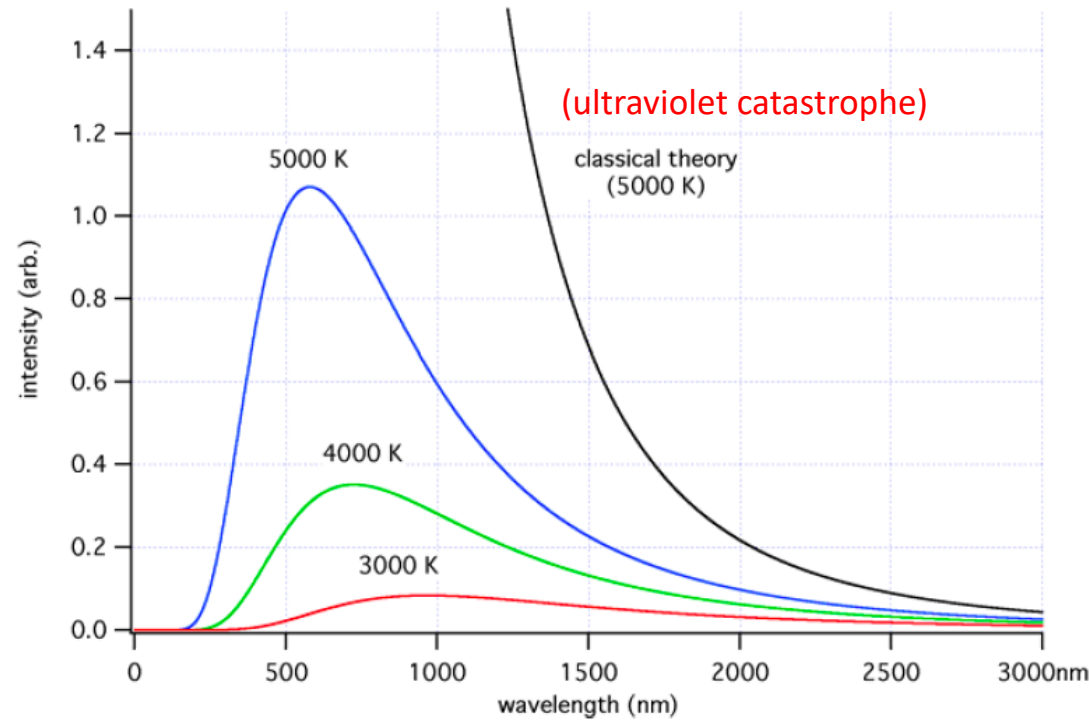
(a) General radiation



(b) Black-body radiation

# EPFL Black Body Radiation

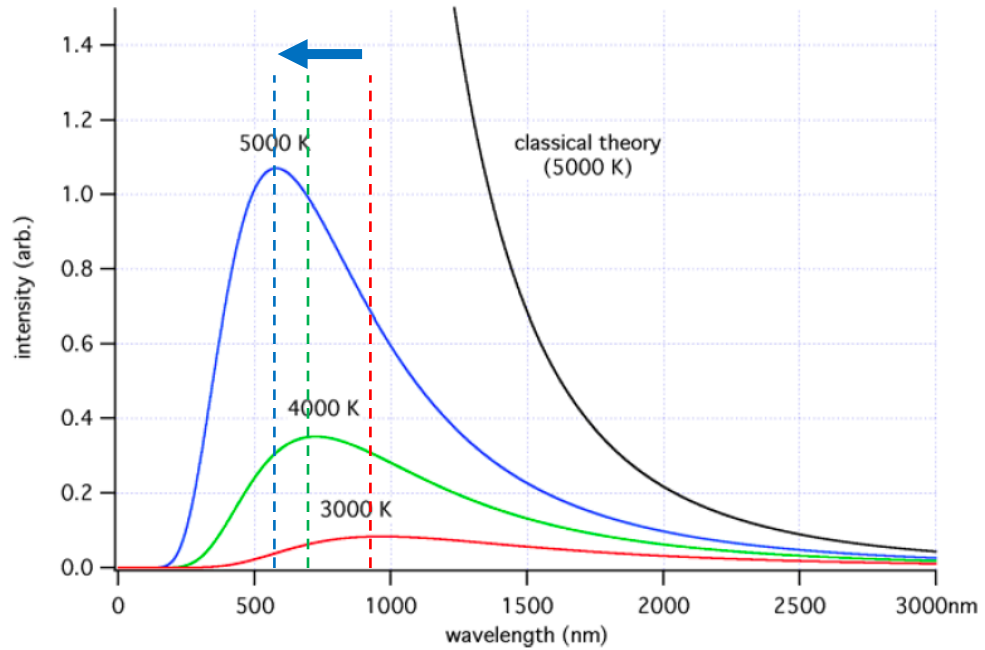
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energy of a quantum (photon) = (a calibration constant) x (frequency of vibration)

$$E = h\nu = hc/\lambda$$

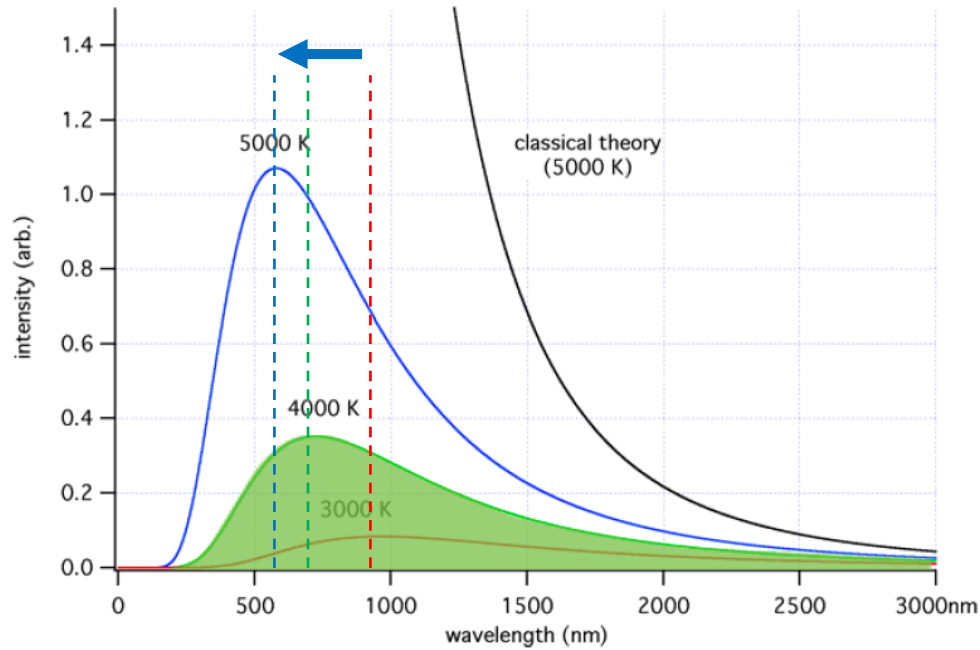
# EPFL Black Body Radiation



Wien's displacement law:  $\lambda_{peak} = \frac{b}{T}$

$$b = 2.898 \times 10^{-3} \text{ m} \cdot \text{K} \text{ or } 2898 \mu\text{m} \cdot \text{K}$$

# EPFL Black Body Radiation



The relationship given by Planck's radiation law shows that **with increasing temperature, the total radiated energy of a body increases and the peak of the emitted spectrum shifts to shorter wavelength.**

Wien's displacement law:  $\lambda_{peak} = \frac{b}{T}$

$$b = 2.898 \times 10^{-3} \text{ m} \cdot \text{K} \text{ or } 2898 \mu\text{m} \cdot \text{K}$$

Stefan-Boltzmann law:  $E = \sigma T^4$

*E is the energy radiated per unit area per unit time from the body*

$$\sigma = 5.670 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$$

Planck's Law (Planck's radiation law)

$$B(\lambda, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1} = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

*B(λ, T) is the spectral radiance of a body for wavelength λ at T  
= the power emitted per unit area of the body, per unit solid angle that the radiation is measured over, per unit λ (or ν)*

*ν is Frequency*

*k<sub>B</sub> is Boltzmann Constant*

*h is Planck's Constant*

*c is speed of light in vacuum*

# EPFL Different forms in Planck's Law

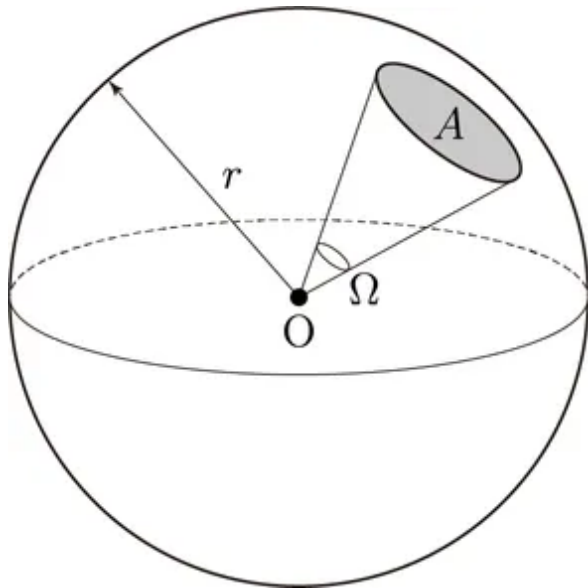
$$B(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$$

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

The SI units are  $W \cdot sr^{-1} \cdot m^{-2} \cdot Hz^{-1}$

The SI units are  $W \cdot sr^{-1} \cdot m^{-2} \cdot \mu m^{-1}$

$$\begin{aligned} \text{using } \lambda &= \frac{c}{\nu} \\ \Rightarrow \frac{d\lambda}{d\nu} &= -\frac{c}{\nu^2} \\ \Rightarrow \left| \frac{d\lambda}{d\nu} \right| &= \frac{c}{\nu^2} \end{aligned}$$



- The **solid angle** is like 2D angle but in a 3D space and is represented by **steradians (sr)**.
- The solid angle is used to calculate how much of an object is in the field of view of another object.

$$\Omega = \frac{A}{r^2}$$

$A$  = the projection area of the object (the area normal to radial lines at the distance  $r$ )

$r$  = the distance

# EPFL Solid Angle of The Sun

The solid angle of the sun from the viewpoint of the earth ( $\Omega_{se}$ )

$$= \frac{\text{the area of the sun projected onto a plane normal to the vector pointing from the Earth to the sun}}{(\text{the mean average distance from the earth to the sun})^2}$$

Sun and Earth:  $D_{sun} = 1.39 \times 10^9 \text{ m}$  and  $r = 1.49 \times 10^{11} \text{ m}$

Moon and Earth:  $D_{moon} = 3.47 \times 10^6 \text{ m}$  and  $r = 3.84 \times 10^8 \text{ m}$

$$\Omega_{se} = \frac{\pi \left(\frac{D}{2}\right)^2}{r^2} = \pi \times (2.18 \times 10^{-5}) = 6.84 \times 10^{-5} \text{ sr}$$

$f_\omega$  (Geometrical factor)  
↓

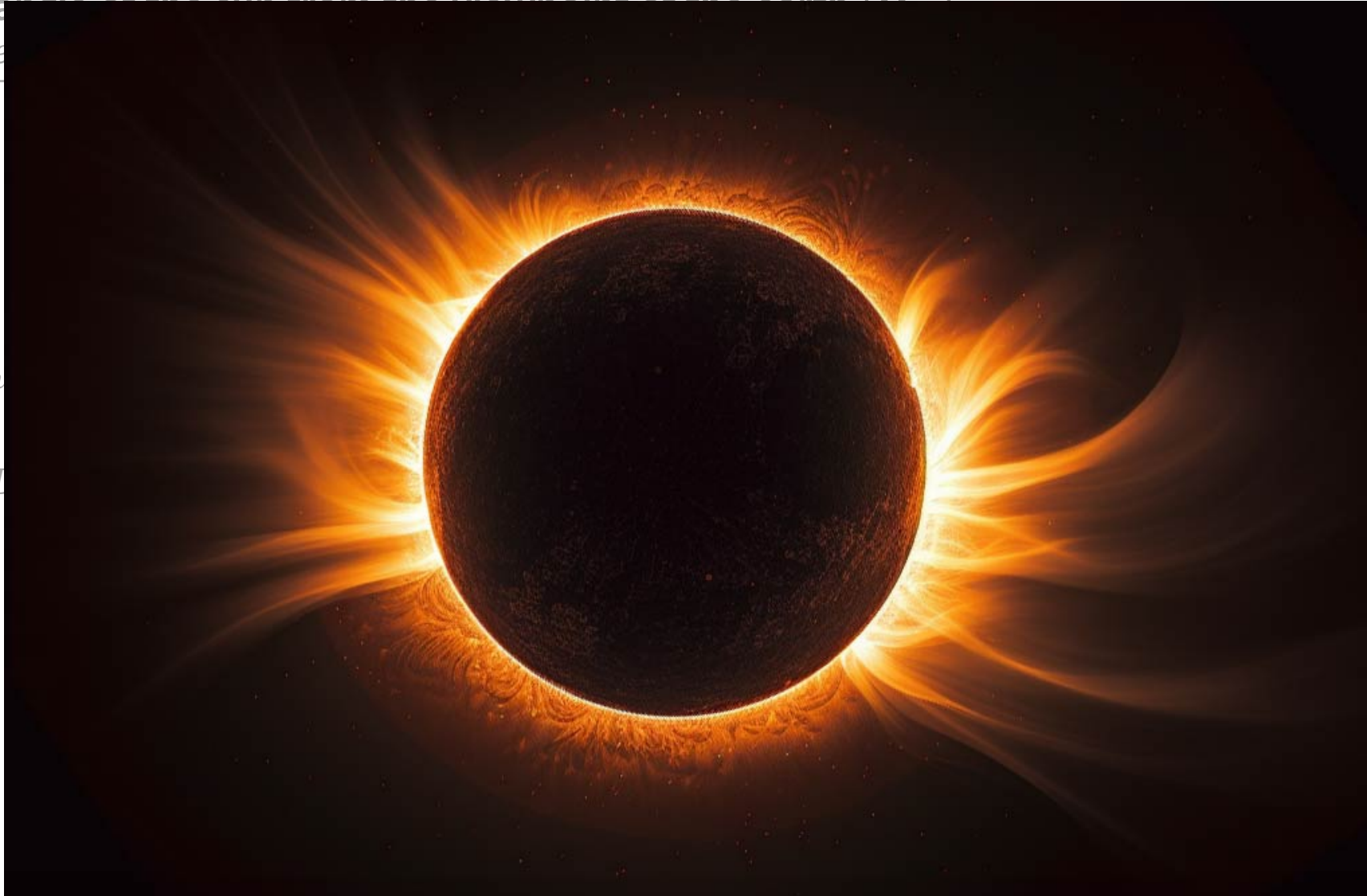
$$\Omega_{me} = 6.43 \times 10^{-5} \text{ sr}$$

*The Sun and Moon appear approximately the same size when viewed from the Earth.*

# EPFL Solid Angle of The Sun

The solid angle of the sun from the viewpoint of the earth ( $\Omega$ )

$$= \frac{\text{the area of the sun}}{\text{the distance from the earth to the sun}^2}$$



Sun and Earth:  $D_{sun}$

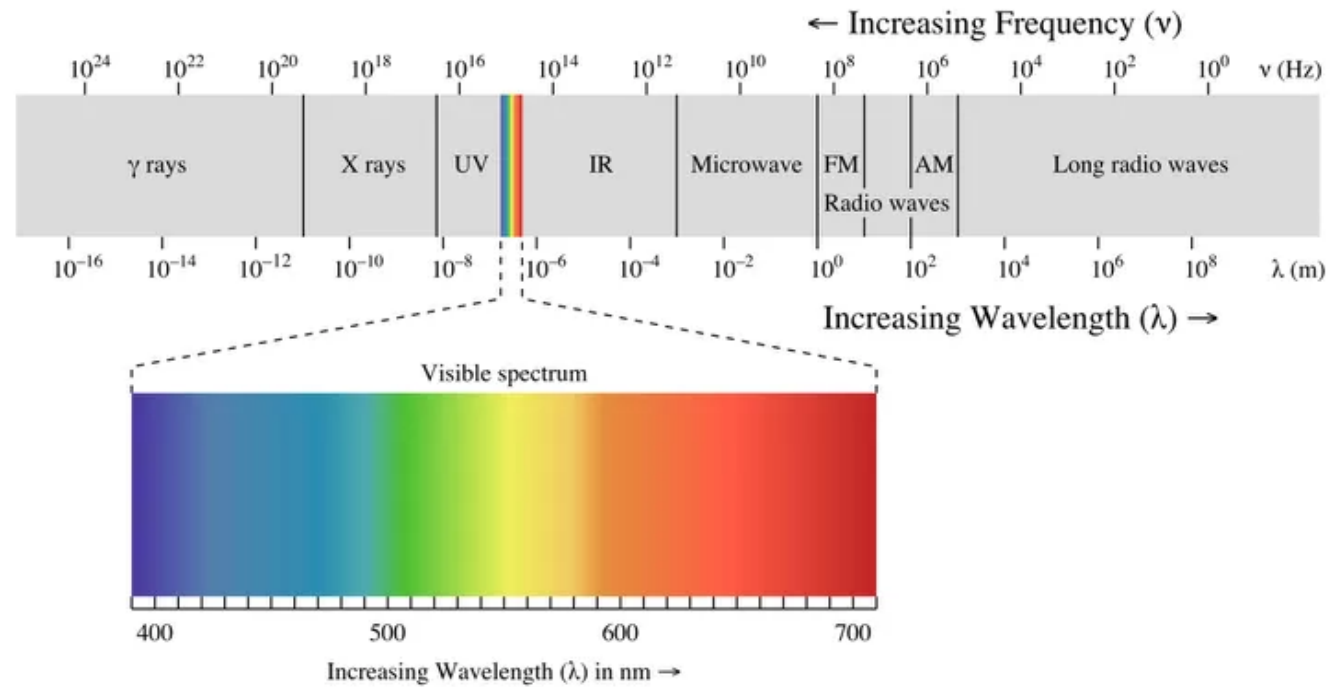
Moon and Earth:  $D_{moon}$

(symmetrical factor)

$$\Omega = 6.84 \times 10^{-5} sr$$

approximately the same as the solid angle of the Earth.

**Photons are packets of energy!**  
**behave as particles and waves!**















$$E = h\nu = hc/\lambda$$

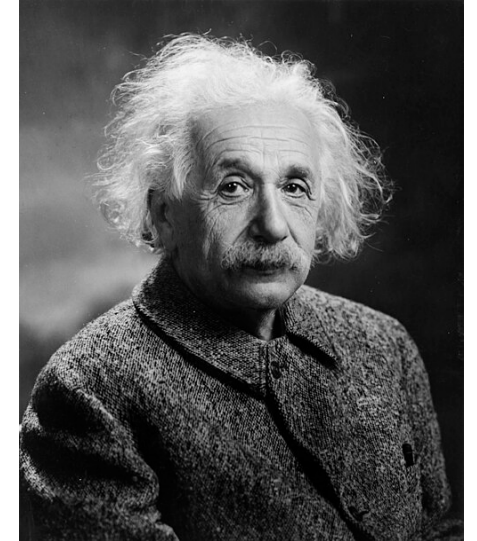
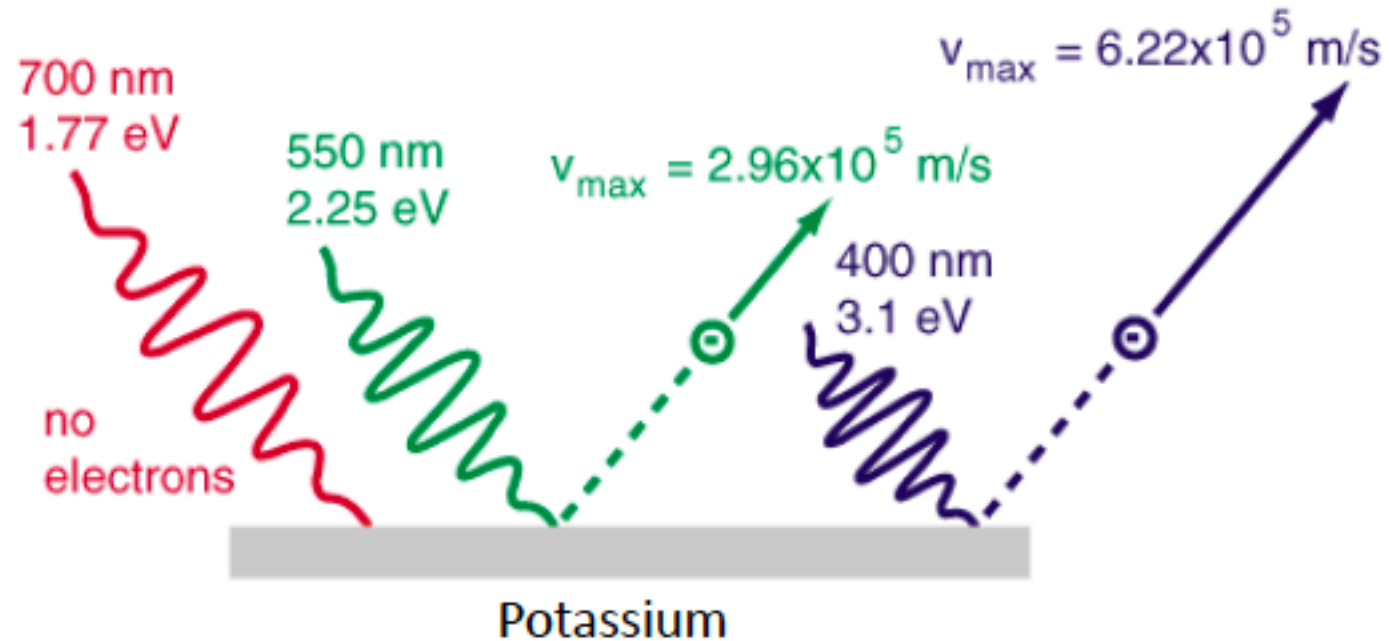
Increasing Energy



# EPFL Wave and Particle Nature of Light

| Phenomenon           | Wave explanation  | Particle explanation  |
|----------------------|---|---|
| Reflection           |    |    |
| Refraction           |    |    |
| Interference         |    |    |
| Diffraction          |    |    |
| Polarization         |   |   |
| Photoelectric effect |  |  |

# EPFL Energy Quantization: Photoelectric effect



Albert Einstein (1879 – 1955)

$$KE_{\max} = h\nu - W, \quad W = \text{work function of metal}$$

When light shines on the surface of a metallic substance, electrons in the metal absorb the energy of the light and they can escape from the metal's surface. This is called the **photoelectric effect**. Electrons emitted in this manner are called photoelectrons (Albert Einstein, the 1921 Nobel Prize in Physics).

Wavelength  $\longrightarrow$   $\lambda = \frac{h}{p}$   $\longleftarrow$  Planck's constant  
 $\longleftarrow$  Momentum = mass x velocity



**Louis de Broglie (1892 – 1987)**  
Nobel Prize in Physics 1929

Wavelength  $\longrightarrow$   $\lambda = \frac{h}{p}$   $\longleftarrow$  Planck's constant  
 $\longleftarrow$  Momentum = mass x velocity

### De Broglie wavelength of a football

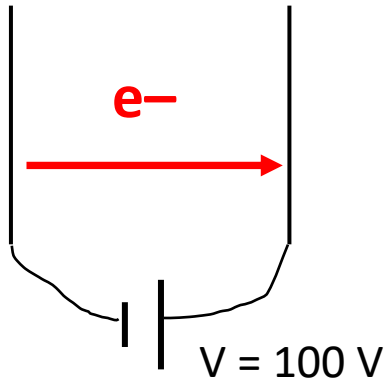


v: 210 km/h by Ronny Heberon but for simple calculation, 144 km/h (= 40 m/s)  
 m: 0.45 kg

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{0.45 \text{ kg} \times 40 \text{ m/s}} = 3.68 \times 10^{-35} \text{ m}$$

**Too small and the wave nature is not detectable!**

### De Broglie wavelength of an electron



v:  $5.9 \times 10^6$  m/s at a 100 V  
 m:  $9.1 \times 10^{-31}$  kg

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{9.11 \times 10^{-31} \text{ kg} \times 5.9 \times 10^6 \text{ m/s}} = 1.2 \times 10^{-10} \text{ m} (1.2 \text{ \AA})$$

- A photon is characterized by either a frequency ( $\nu$ ) or equivalently an energy, denoted by  $E$ . There is an inverse relationship between the energy of a photon ( $E$ ) and the wavelength of the light ( $\lambda$ ) given by the equation:

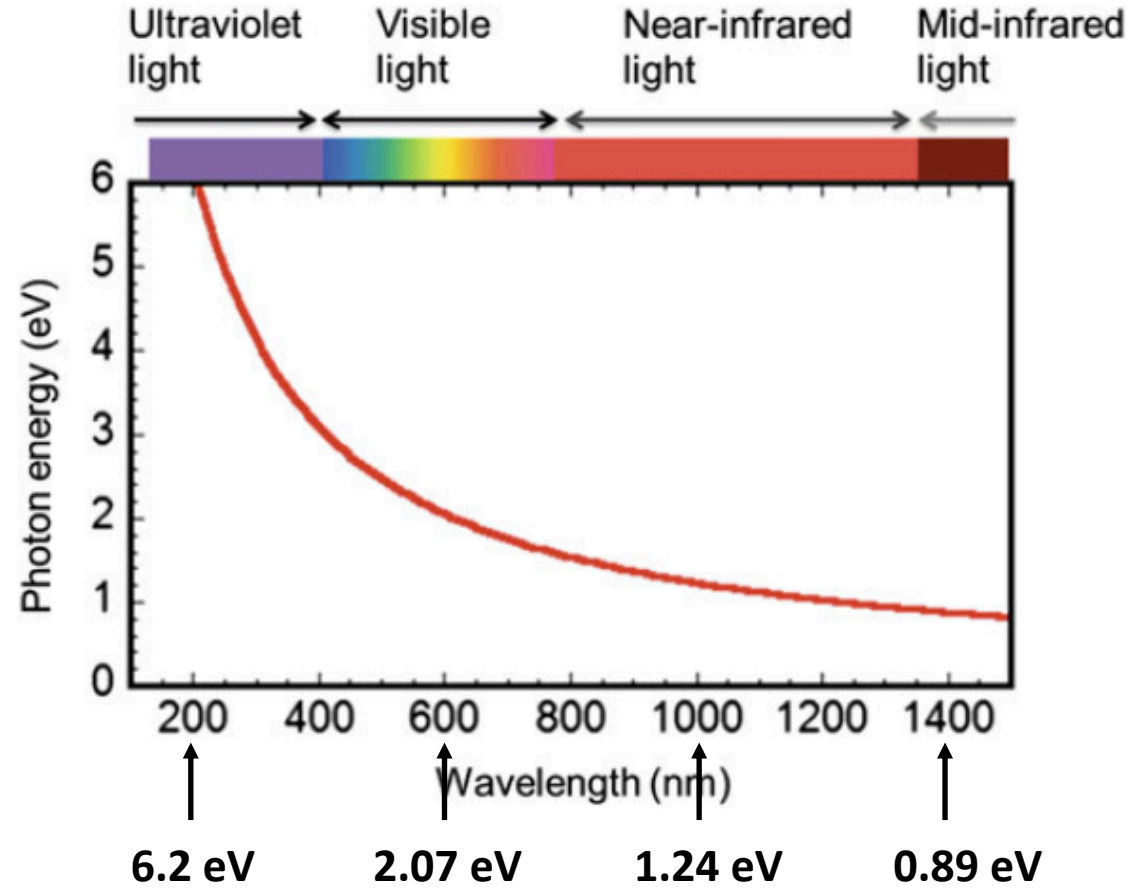
$$E(J) = h\nu = hc/\lambda$$

where  $h$  is Planck's constant and  $c$  is the speed of light:  $h = 6.626 \times 10^{-34}$  J·s and  $c = 2.998 \times 10^8$  m/s

- When dealing with "particles" such as **photons** or electrons, a commonly used unit of energy is the electron-volt (eV) rather than the joule (J).  
An electron volt is the energy required to raise an electron through 1 volt:  $1 \text{ eV} = 1.602 \times 10^{-19}$  J.
- Therefore, we can rewrite the above constant for  $hc$  in terms of eV:  $hc = (1.99 \times 10^{-25} \text{ J}\cdot\text{m}) \times (1 \text{ eV}/1.602 \times 10^{-19} \text{ J}) = 1.24 \times 10^{-6} \text{ eV}\cdot\text{m} = 1.24 \text{ eV}\cdot\mu\text{m} = 1240 \text{ eV}\cdot\text{nm}$

$$E(\text{eV}) = \frac{1240}{\lambda (\text{nm})}$$

$$E(eV) = \frac{1240}{\lambda (nm)}$$



# EPFL Photon Flux and Power Density

- The photon flux is defined as the number of photons per unit area per second:

$$\phi = \frac{\textit{number of photons}}{\textit{m}^2 \cdot \textit{sec}}$$

- The photon flux is important in determining the number of electrons which are generated from a solar energy conversion system: e.g. Incident Photon-to-Current Conversion Efficiency (IPCE) or External Quantum Efficiency (EQE).
- Since the photon flux gives the number of photons striking a surface in a given time, multiplying by the energy of the photons comprising the photon flux gives the energy striking a surface per unit time, which is equivalent to a power density.

$$\begin{aligned} H \left( \frac{W}{m^2} \right) &= \phi \times h\nu && \text{For frequency} \\ &= \phi \times q \frac{1240}{\lambda (nm)} && \text{For wavelength in nm} \\ &= \phi \times qE (eV) && \text{For energy in eV} \end{aligned}$$

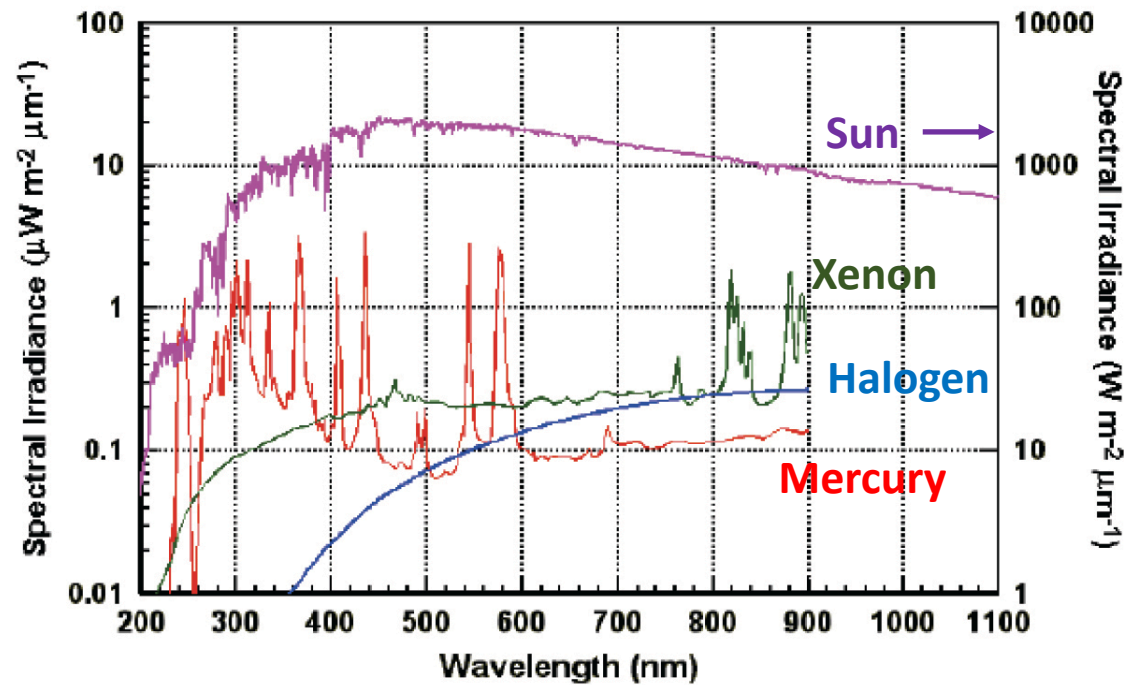
Photon flux of  $1E^{21} \text{ m}^{-2}\text{s}^{-1}$  with photon energy of 1.77 eV (700 nm)  $\rightarrow$  283 W/m<sup>2</sup>

Photon flux of  $1E^{21} \text{ m}^{-2}\text{s}^{-1}$  with photon energy of 1 eV (1240 nm)  $\rightarrow$  160 W/m<sup>2</sup>

# EPFL Spectral Irradiance

- The spectral irradiance, denoted by  $F$ , gives the power density at a particular wavelength.
- The units of spectral irradiance are in  $\text{Wm}^{-2}\mu\text{m}^{-1}$ .
- The spectral irradiance is the most common way of characterizing a light source.

$$F(\lambda) = H \times \frac{1}{\lambda}$$



The spectral irradiance of artificial light sources (left axis) compared to the spectral irradiance from the sun (right axis).  
Elsarrag, E. *et al. Renew. Wind. Water Solar*, 2(16), (2015)

# EPFL Solar Energy to The Earth

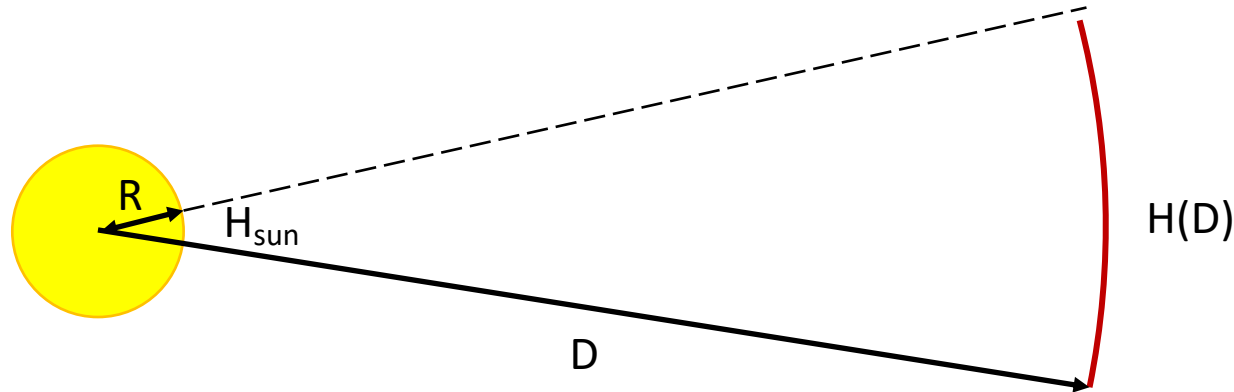
- The solar energy on an object some distance D from the sun is found by dividing the total power emitted from the sun by the surface area over which the sunlight falls.

$$H(D) = \frac{4\pi R_{sun}^2}{4\pi D^2} H_{sun} = \frac{R_{sun}^2}{D^2} H_{sun}, H_{sun} \text{ by Stefan Boltzman equation } (\sigma T_s^4) \text{ and } \mathbf{H_{Earth} = 1366 W/m^2}$$

$$\sigma = 5.670 \times 10^{-8} W m^{-2} K^{-4}$$

$$E_{Earth} = 1366 \times \pi R_{Earth}^2 = 1366 \times 1.275 \times 10^8 km^2 = 174 PW$$

$$\text{measured value} = 1361 - 1362 W/m^2$$

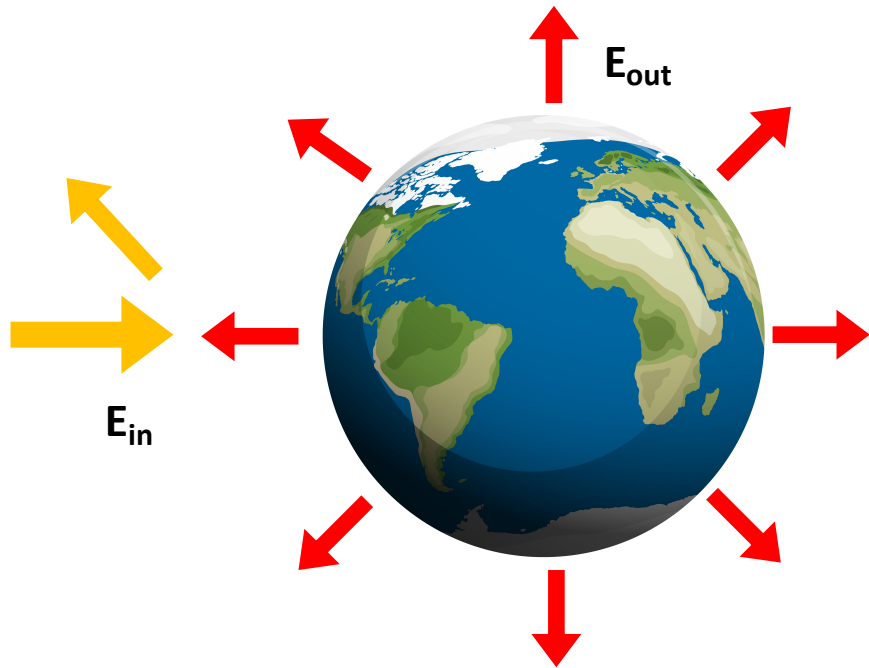


- Solar Constant:** the rate at which solar energy arrives at the top of the atmosphere = the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the planet from the sun

| Planet  | Distance (x 10 <sup>9</sup> m) | Solar Constant (W/m <sup>2</sup> ) | Radius (m) | Solar Radiation (PW) |
|---------|--------------------------------|------------------------------------|------------|----------------------|
| Mercury | 58                             | 9087                               | 2440       | 170                  |
| Venus   | 108                            | 2620                               | 6050       | 302                  |
| Earth   | 150                            | 1366                               | 6370       | 174                  |
| Mars    | 228                            | 588                                | 3390       | 21                   |

# EPFL The Earth Temperature

Energy Balance,  $E_{in} = E_{out}$



$$E_{Earth} = 1366 \times \pi R_{Earth}^2 = 1366 \times 1.275 \times 10^8 \text{ km}^2 = 174 \text{ PW}$$

$$E_{in} = E_{Earth} \times (1 - A)$$

A (Albedo) = the fraction of light that a surface reflects = 0.33

$$E_{out} = \sigma T_{earth}^4 \times (4\pi R_{Earth}^2)$$

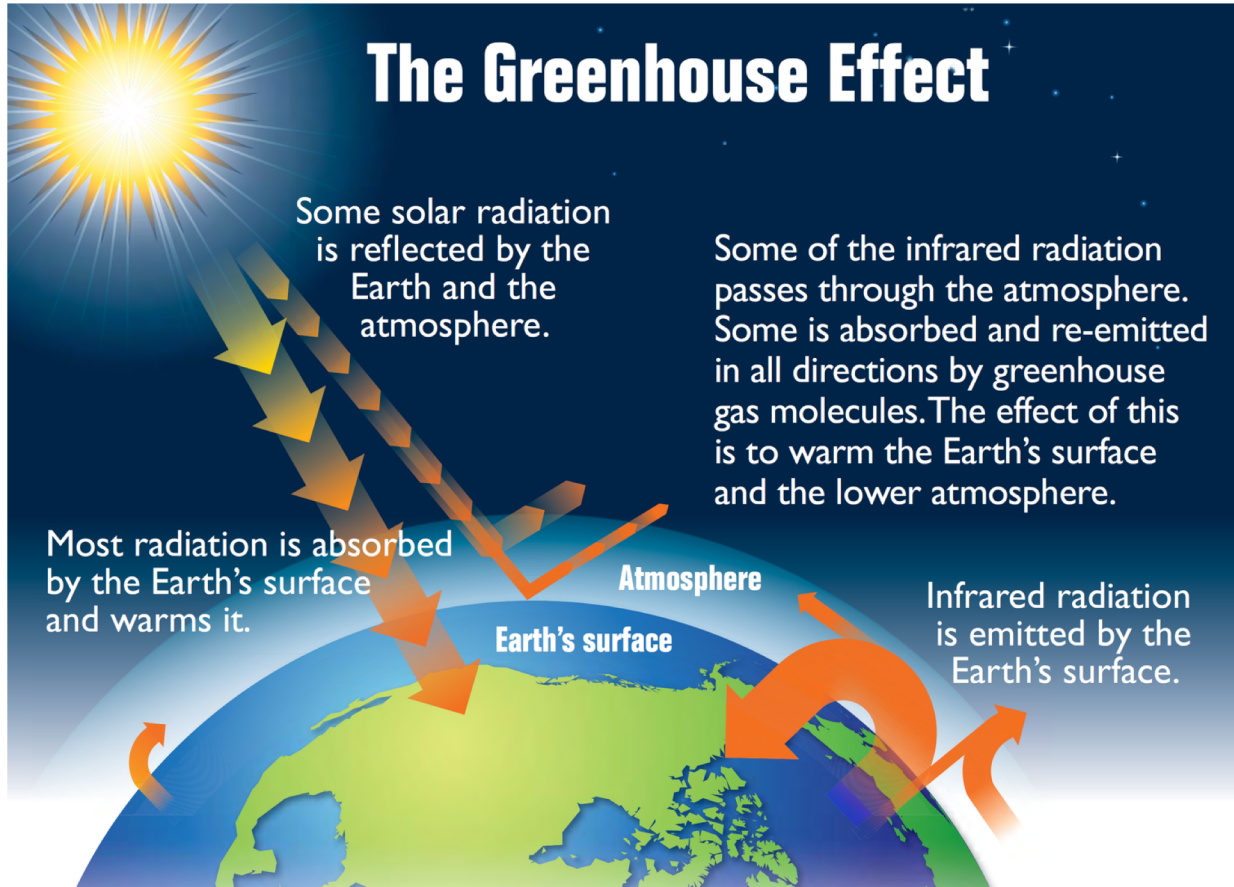
$$1366 \times \pi R_{Earth}^2 \times (1 - 0.33) = \sigma T_{earth}^4 \times (4\pi R_{Earth}^2)$$

$$T_{earth} = \left[ \frac{1366 \text{ W/m}^2 \times 0.67}{4\sigma \text{ Wm}^{-2}\text{K}^{-4}} \right]^{1/4}$$

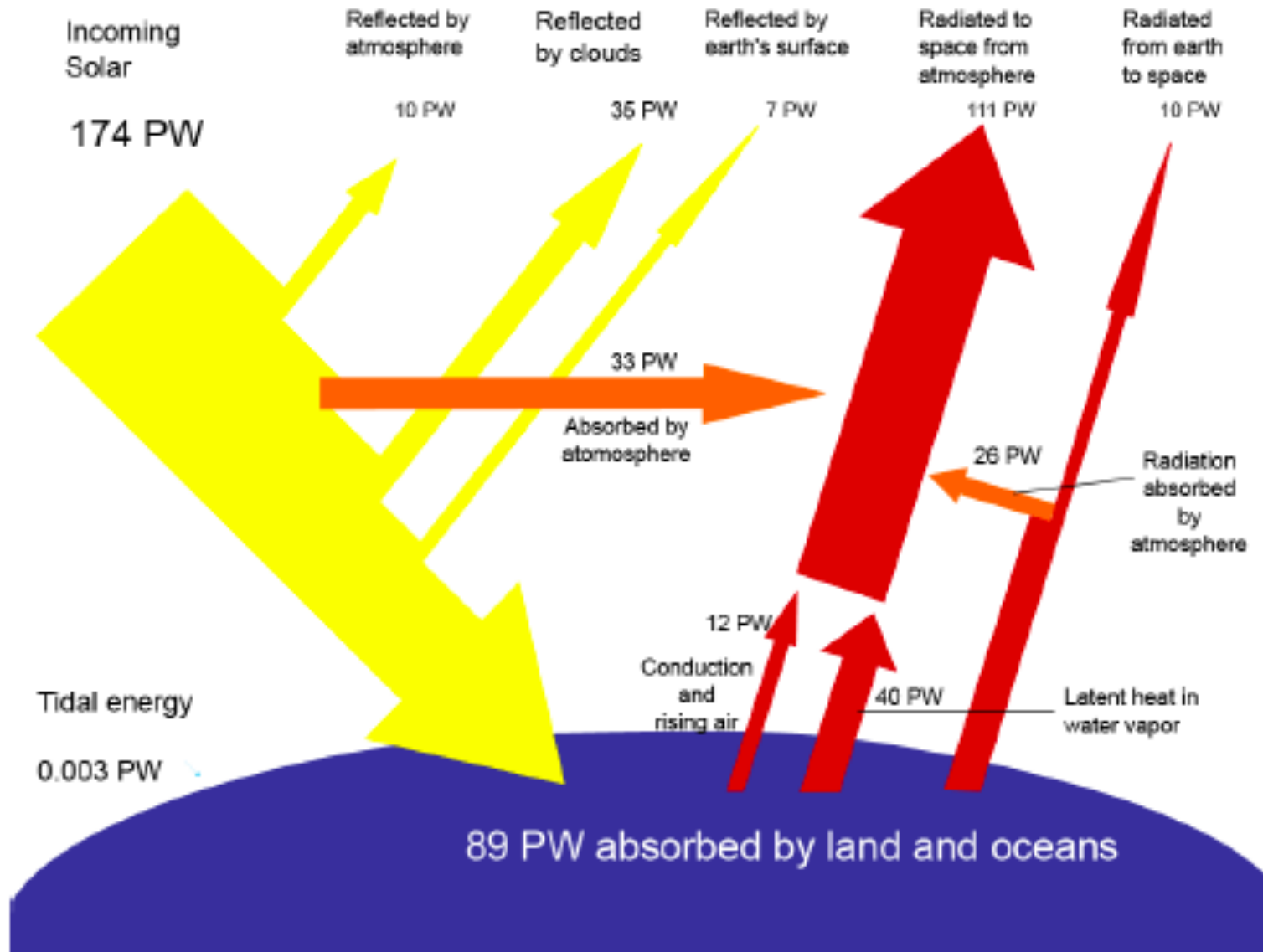
$$T_{earth} = 252 \text{ K} = -21^\circ\text{C}$$



The observed ground temperature is 15 °C



- The Earth is 33 °C warmer than expected based on black body calculations and the known input of solar energy.
- This extra warmth is what we call the **greenhouse effect**.
- It is a result of warming of the Earth's surface by the absorption and re-emission of IR radiation by molecules in the atmosphere.
- The greenhouse gases for the earth: methane, carbon dioxide, water vapour.
- The atmosphere is warm at the surface (15 °C), cold in the middle (-4 °C), and extremely cold near the top (-100 °C).

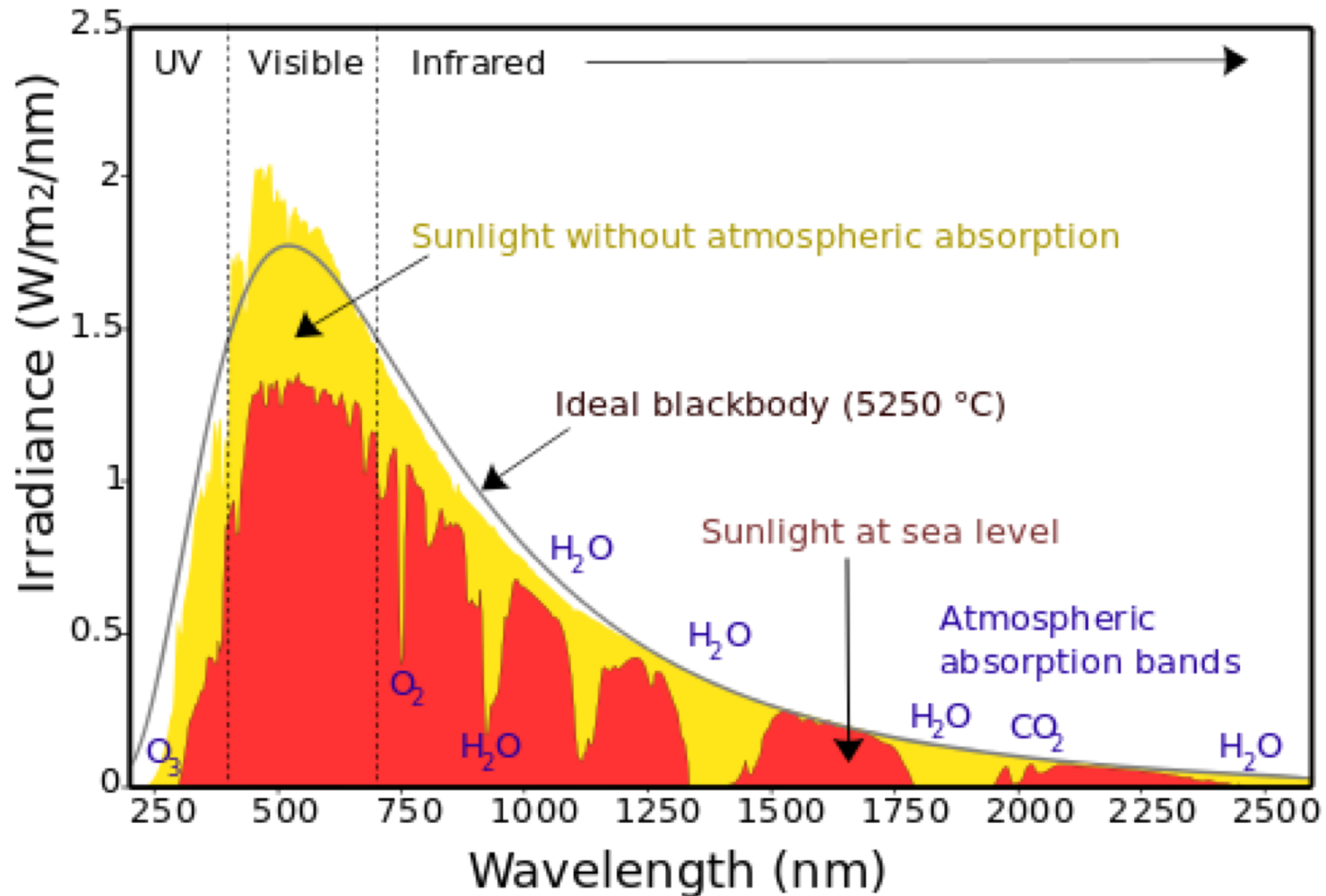


**Global energy consumption = 0.02 PW**

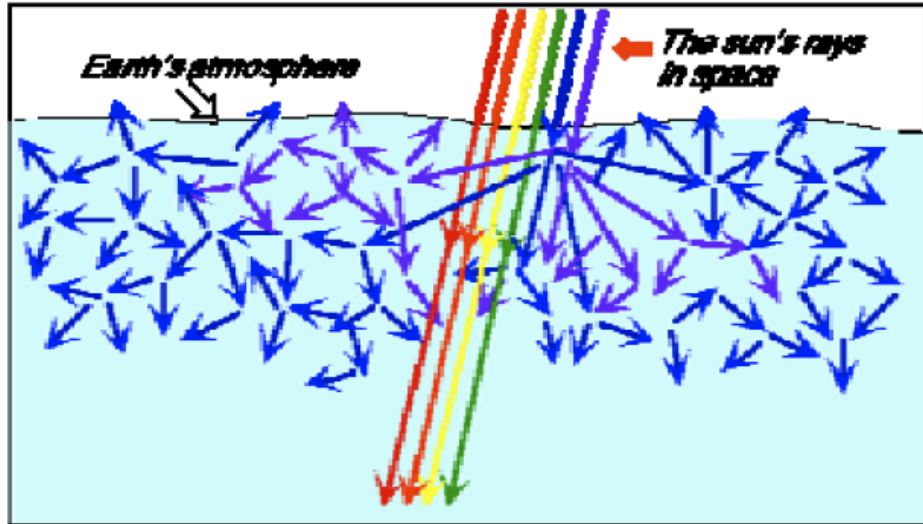
## Atmospheric effect

- Absorption, scattering, reflection in the atmosphere.
- A reduction in the power of the solar radiation.
- A change in the spectral content.
- Diffuse component into the solar spectrum.
- Local variations (clouds, sun hours).

### Spectrum of Solar Radiation (Earth)



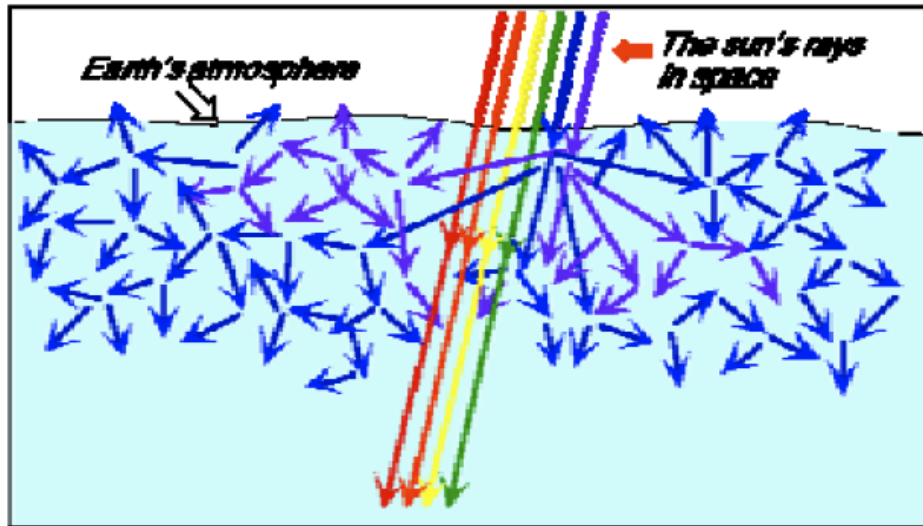
# EPFL Solar Energy: Scattering and Variations



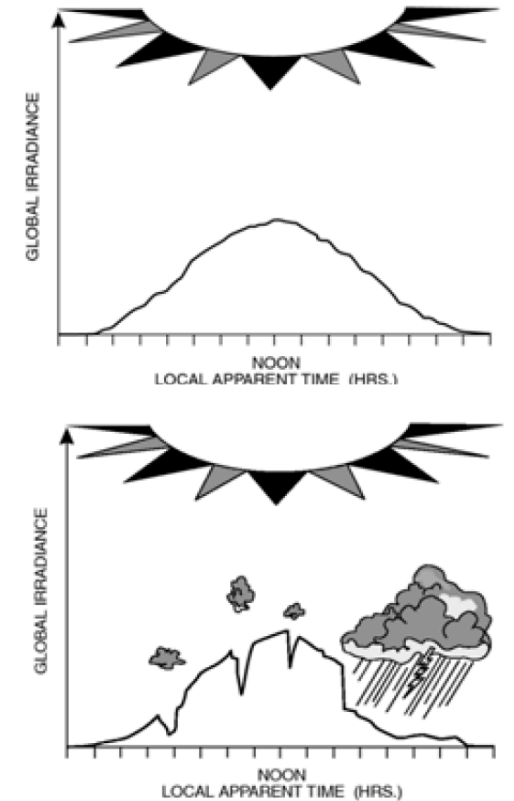
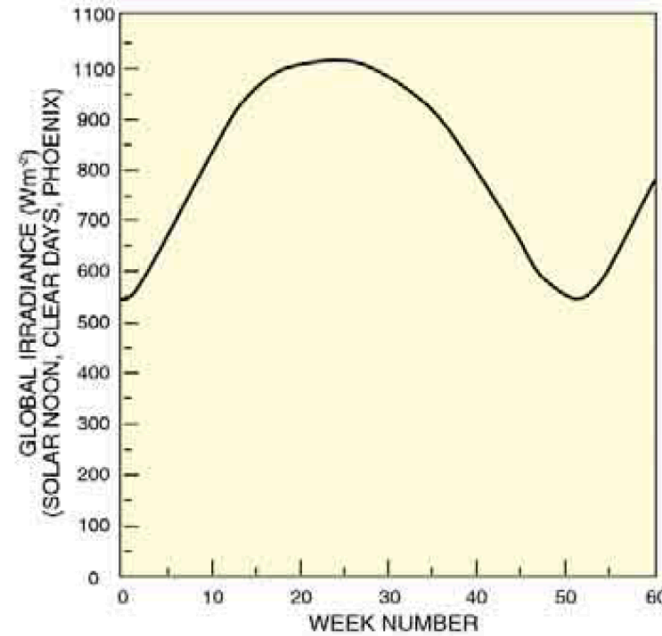
- Rayleigh scattering by molecules,  $I \propto 1/\lambda^4$
- Mie Scattering by water droplets and aerosols, almost independent of wavelength in the visible range, ex) white clouds



# EPFL Solar Energy: Scattering and Variations



- Rayleigh scattering by molecules,  $I \propto 1/\lambda^4$
- Mie Scattering by water droplets and aerosols, almost independent of wavelength in the visible range, ex) white clouds



- Total terrestrial irradiance depends on location (north, south ..), hours/days of sun, cloud coverage, etc.
- When averaged over one day: Clear  $\sim 590 - 1000 \text{ W/m}^2$   
Cloudy days  $\sim 120 \text{ W/m}^2$

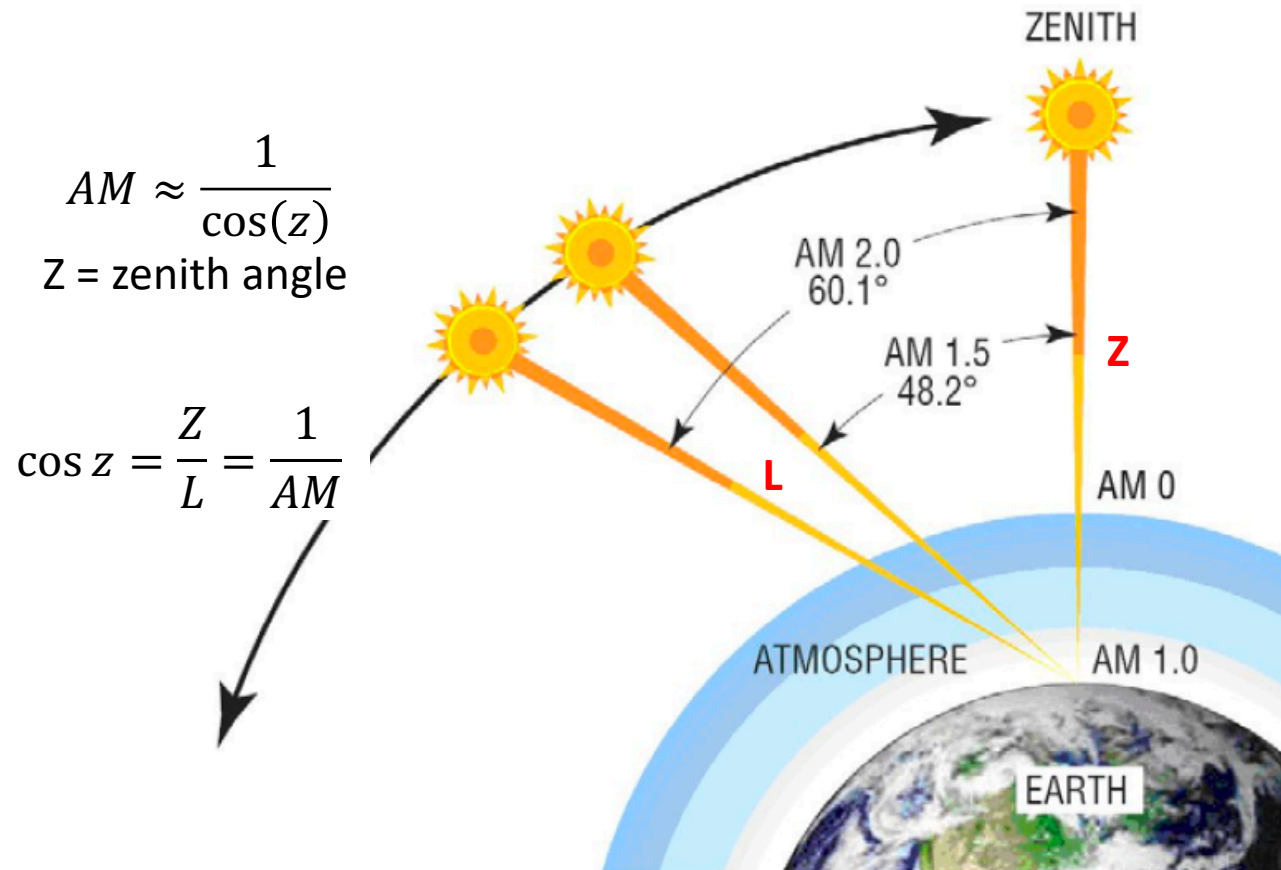
$$H \left( \frac{W}{m^2} \right) = \phi \times h\nu$$

$$\phi = \frac{1366 \text{ W/m}^2}{1.48 \text{ eV}} \times \frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}} = 5.8 \times 10^{17} \text{ cm}^{-2} \text{ s}^{-1}$$

| AM | Comments                                  | Solar constant (W/cm <sup>2</sup> ) | $h\nu_{av}$                           | $N_{ph}$ (cm <sup>-2</sup> sec <sup>-1</sup> ) |
|----|---|-------------------------------------|---------------------------------------|--|
| 0  | Outside atmosphere                        | 1366                                | 1.48 eV (838 nm)                      | $5.8 \times 10^{17}$                           |
| 1  | Sea level, sun at zenith                  | 1040                                | 1.32 eV (939 nm)<br><b>Red shift</b>  | $5.0 \times 10^{17}$                           |
| 2  | Sea level, sun at 60 degree from zenith   | 840                                 | 1.28 eV (969 nm)<br><b>Red shift</b>  | $4.3 \times 10^{17}$                           |
| 3  | Sea level, sun at 70.5 degree from zenith | 750                                 | 1.21 eV (1025 nm)<br><b>Red shift</b> | $3.9 \times 10^{17}$                           |
| 1  | Cloudy weather, Sea level, sun at zenith  | 120                                 | 1.44 eV (861 nm)<br><b>Blue shift</b> | $5.2 \times 10^{16}$                           |

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length that is, when the sun is directly overhead.

Hence, the Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.



Neglect the curvature of the earth!

$$AM \approx 1/\cos(z)$$

This is reasonably accurate for value of z up to around 75 degree.

$$AM = \sqrt{(r\cos(z))^2 + 2r + 1} - r\cos(z)$$

Modelling the atmosphere as a simple spherical shell provides a reasonable approximation<sup>(1)</sup>

(1) Schoenberg, E. Theoretische Photometrie, g) Über die Extinktion des Lichtes in der Erdatmosphäre. In *Handbuch der Astrophysik*. Band II, erste Hälfte. Berlin: Springer (1929).

$r$  = the radius of the Earth/the effective height of the atmosphere = 6371/9

| z (degree) | Flat Earth | Spherical shell | Global irradiance (W/m <sup>2</sup> ) |
|------------|------------|-----------------|---------------------------------------|
| 0          | 1.0        | 1.0             | 1366                                  |
| 60         | 2.0        | 2.0             | 840                                   |
| 70         | 2.9        | 2.9             | 710                                   |
| 75         | 3.9        | 3.8             | 620                                   |
| 80         | 5.8        | 5.6             | 470                                   |
| 85         | 11.5       | 10.6            | 254                                   |
| 88         | 28.7       | 20.3            | 96                                    |
| 90         | ∞          | 37.6            | 20                                    |

- AM Global = AM Direct + AM Diffuse

