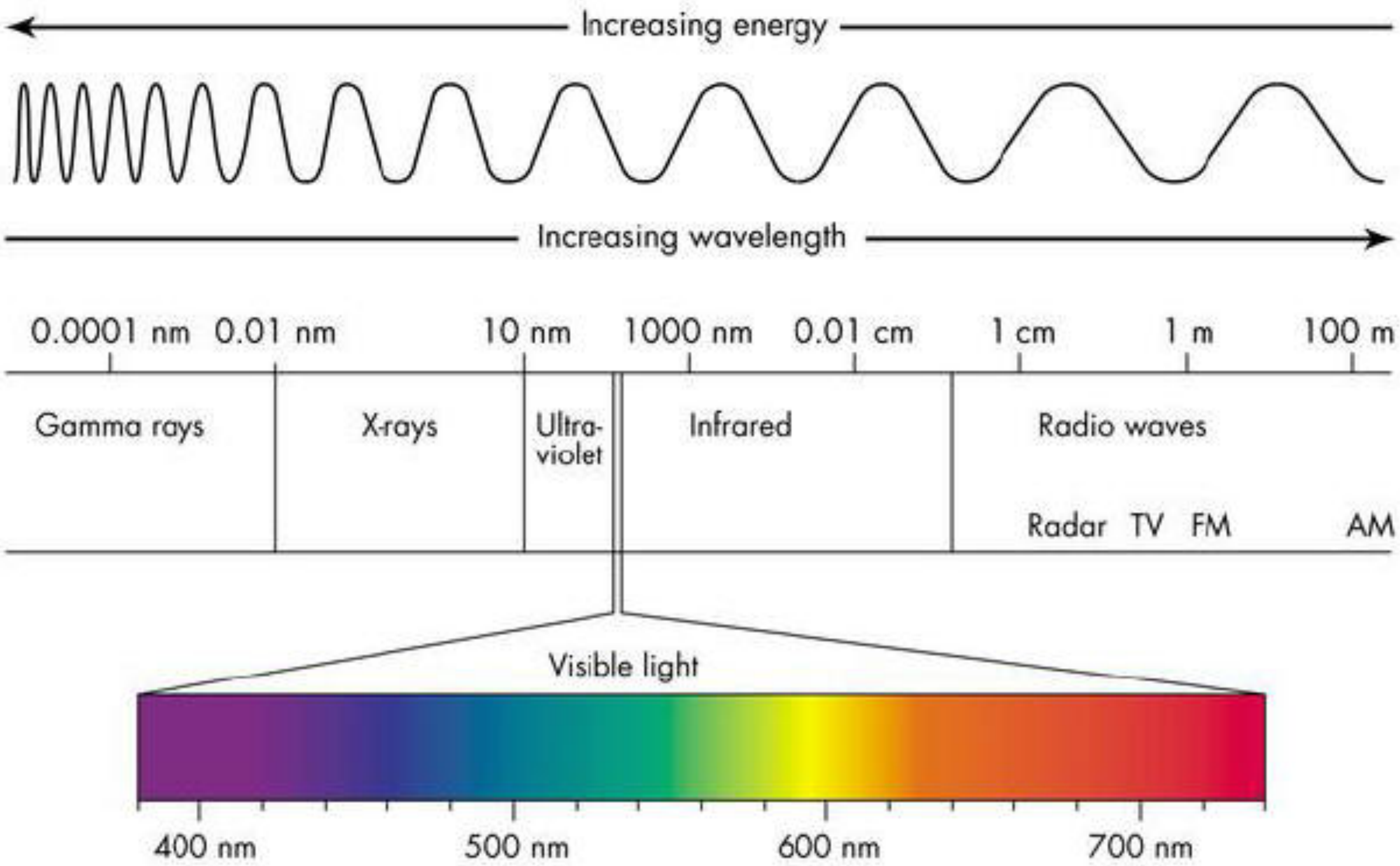
Infrared Imaging

Sensors and Applications

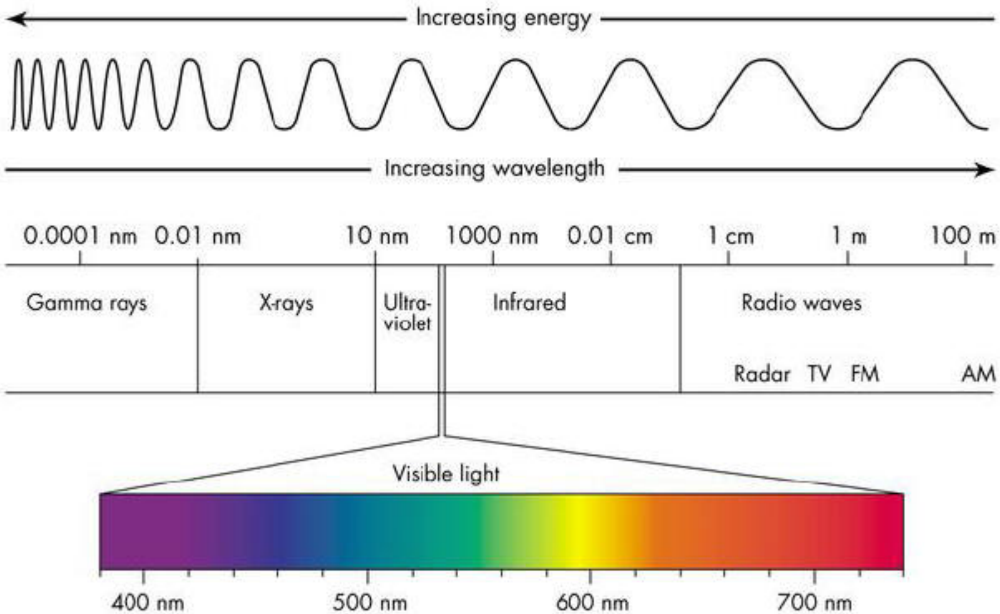
Master

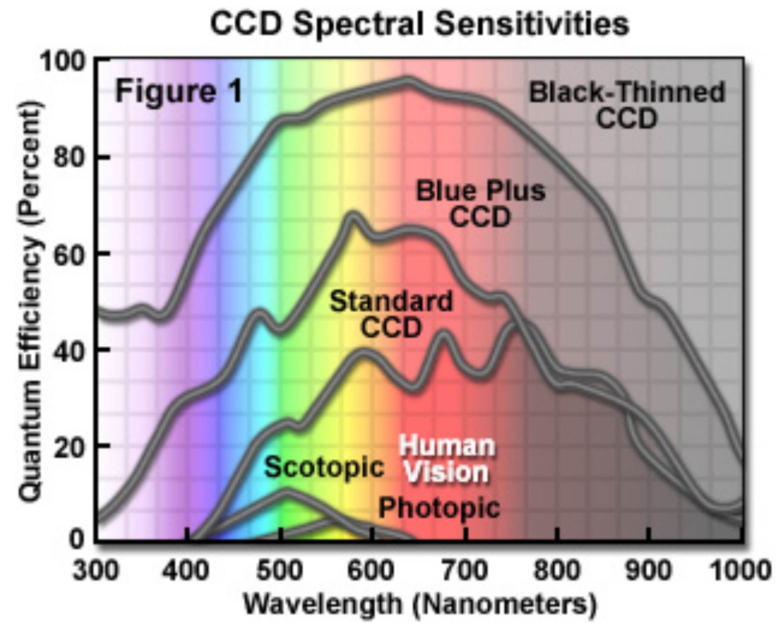
Electromagnetic spectrum



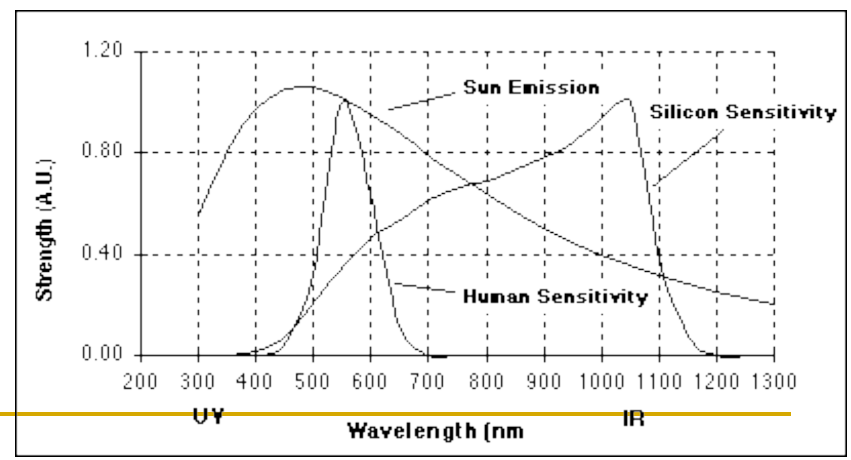
Visible image sensors

Silicon sensors

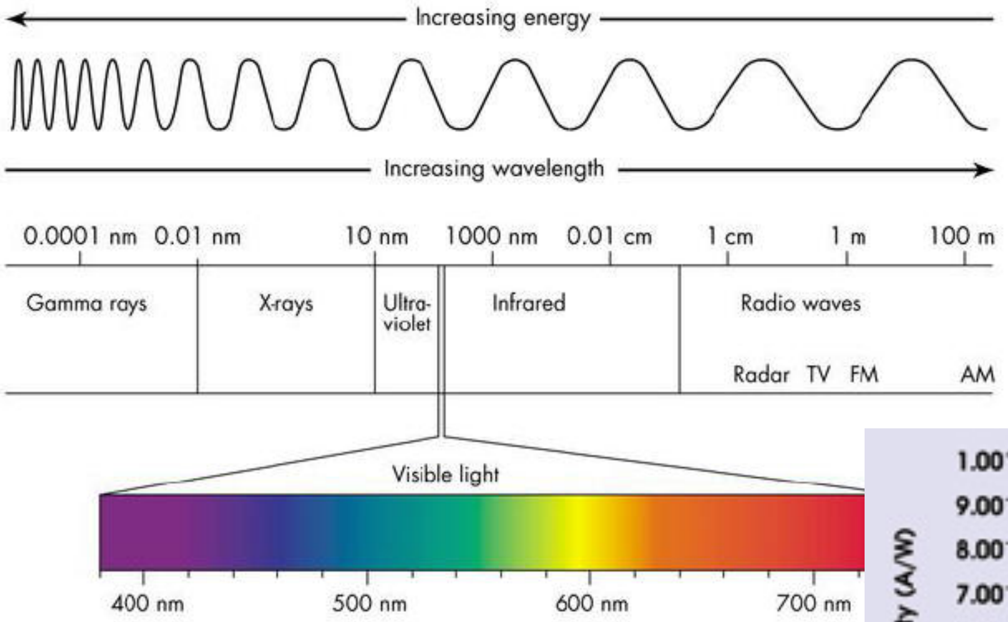




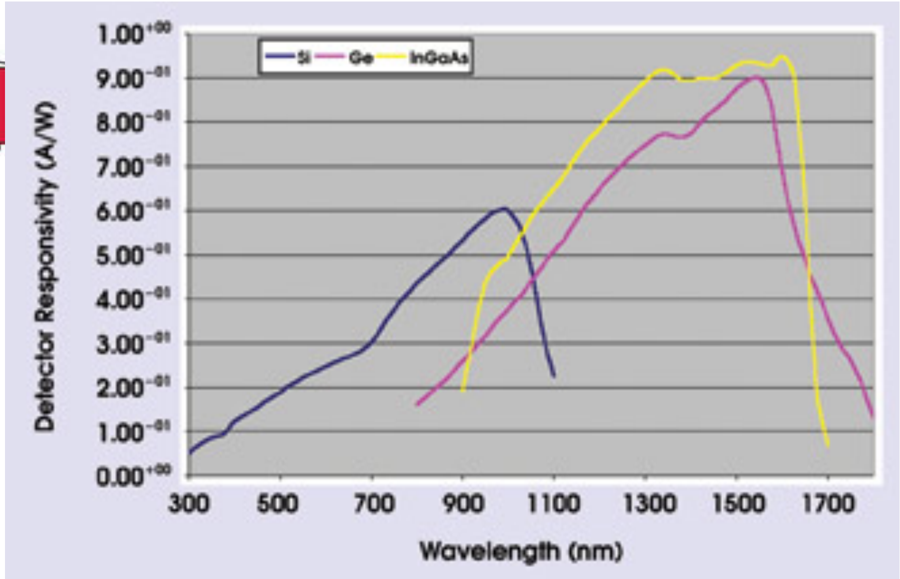
Sensitivity is limited by the spectral caracteristic of the silicon



Infrared Sensors



Example : Germanium



If the sensor is realised with an other material, the spectral sensitivity is different

Infrared Sensors

- **Photonic Sensors**

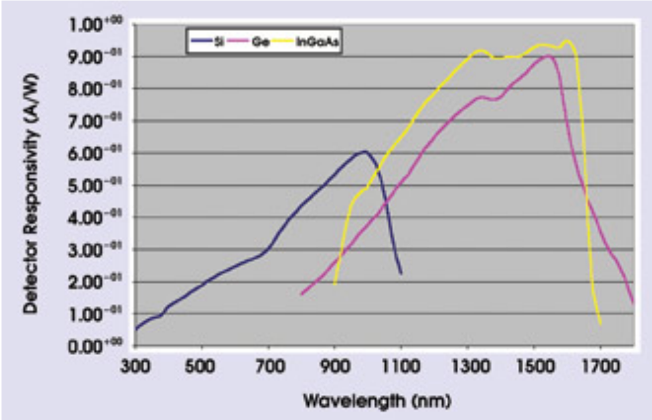
The amplitude of the signal is proportional to the photon flux expressed as the number of photons per second.

- **Thermal detectors**

The amplitude of the electrical signal id proportionnal to the radiant energy expressed in watts.

Infrared Sensors

Photonic Sensors : photodiodes, photocell…

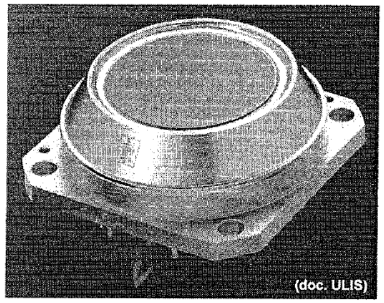


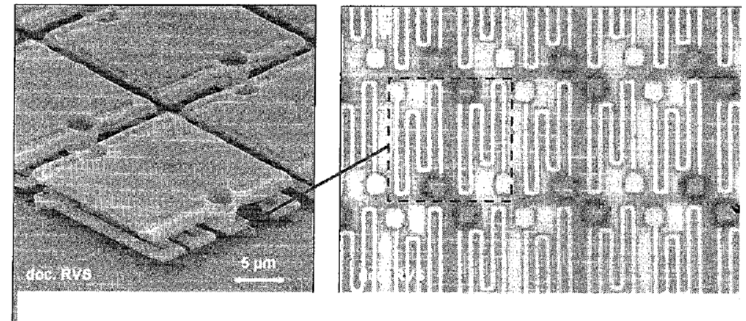
Thermal sensors : Thermocouples, Bolometers

The sensors is thermally affected by the heat

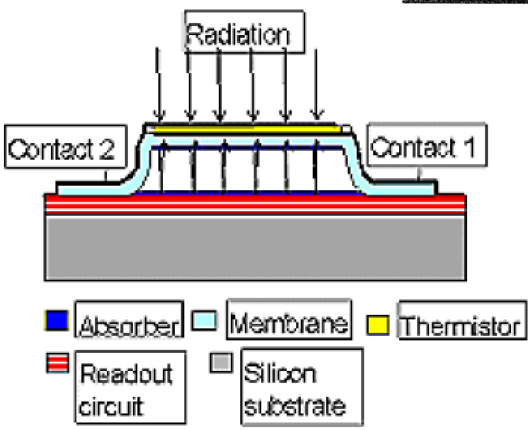
Infrared Sensors

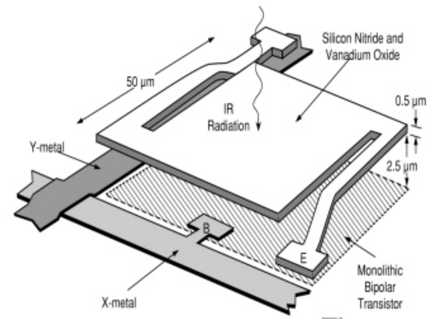
Bolometers





Scheme of micro-bolometer in cross





$$\frac{dR}{R} = \beta dT_d$$

β temp coefficient of the bolometer (K^{-1})

Metallic resitance

$$R = R_0(1 + \alpha_m T_d)$$

Ro, R at 0 K

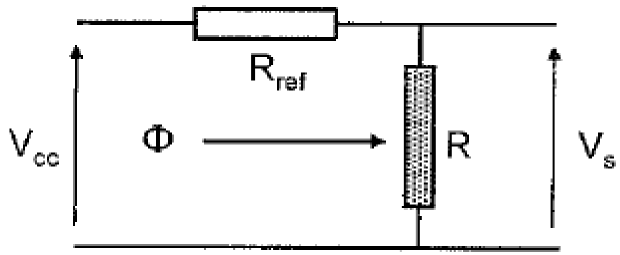
$$\boxed{\beta = \frac{\alpha_m}{1 + \alpha_m T_d}}$$

Semi-conductor materials

$$R = Ke^{\frac{\alpha_{sc}}{T_d}}$$

$$\boxed{\beta = -\frac{\alpha_{sc}}{T_d^2}}$$

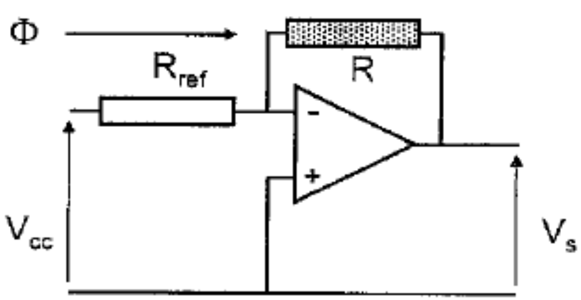
Infrared Sensors



$$V_s = \frac{R}{R + R_{ref}} V_{cc}$$

pour $R_{ref} >> R$:

$$\boxed{\mathcal{S} = \frac{dV_s}{dT} \approx \mathcal{B} \frac{R}{R_{ref}} V_{cc}}$$



$$V_s = -\frac{R}{R_{ref}} V_{cc}$$

$$\boxed{\mathcal{S} = -\mathcal{B} \frac{R}{R_{ref}} V_{cc}}$$

Wheastone bridge could be used too.

Families of IR cameras

The near infrared spectral range covers 0.7 microns to 1.7 microns

The short wave spectral range has many uses in research with a spectral range that covers 1 microns to 3 microns.

The mid wave spectral range covers 3 microns to 5 microns of the infrared spectral range.

For obvious reasons, the long wave spectral range is the most common among thermal cameras on the market. Long wave infrared covers 7 or 8 microns to 14 microns

Infrared Cameras

Application to thermography

- One of the main application of IR is the thermography :

the goal is to determine the temperature of an object using IR image of this object

What are Infrared Rays?

Infrared ray is similar to light, excepted that it cannot be perceived by the eye

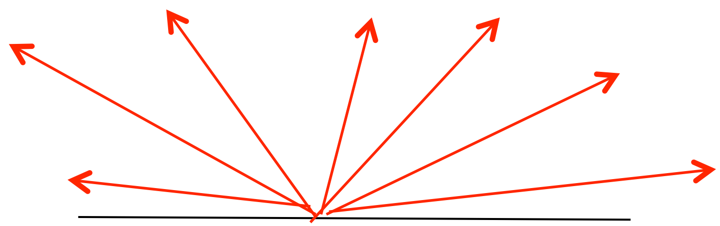
All objects above 0K emit IR
The higher the temperature is, the more energy is emitted.
Only hot objects (few hundred degrees °C) emit radiation which can be perceived by the eyes.

Example :

The visible rays stimulates our eyes
The infrared rays is absorbed by our skin

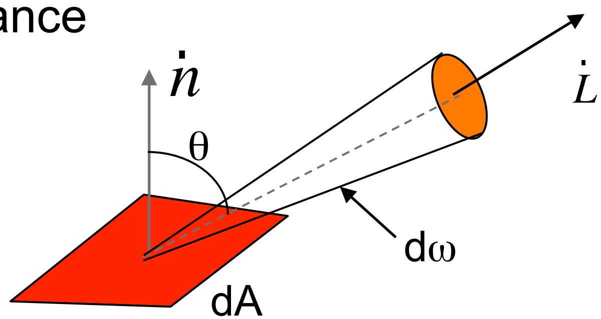
Infrared cameras is only sensible to IR

What are Infrared Rays?



the emission of IR rays is omnidirectional

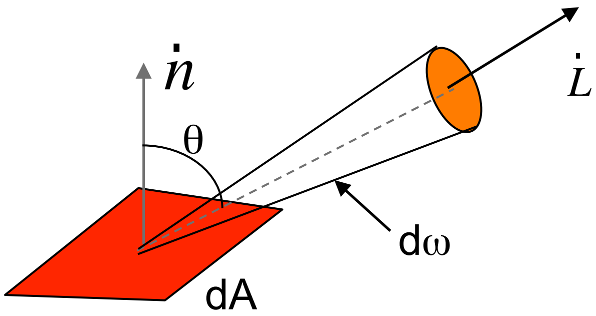
the intensity of ray in one direction is called : luminance



$$L = \frac{d^2\Phi}{dA\cos\theta d\omega}$$

(candela / m2)

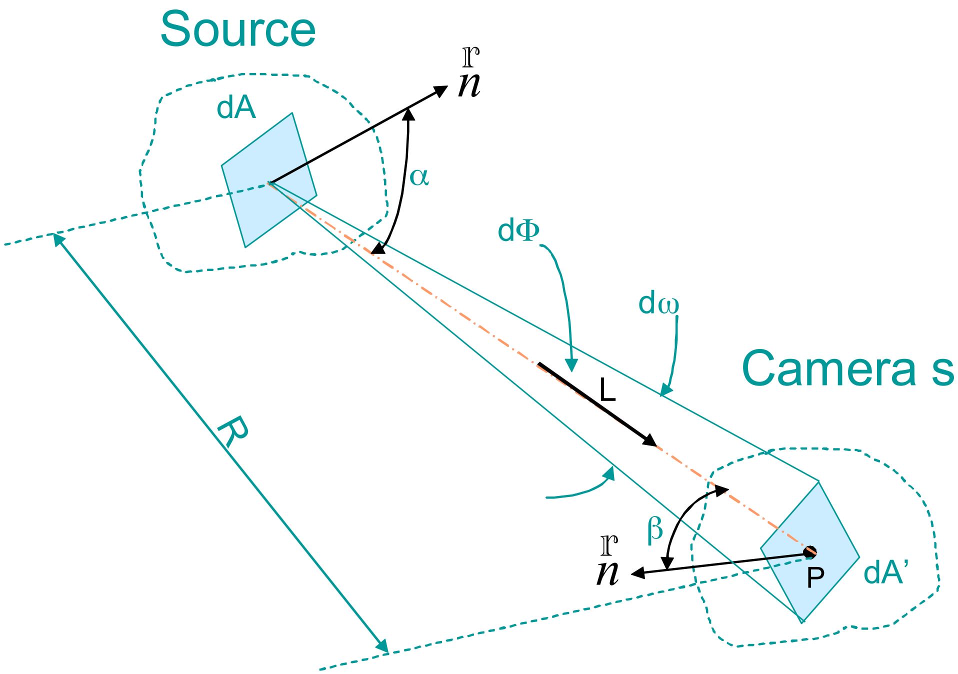
What are Infrared Rays?



$$L = \frac{d^2\Phi}{dA\cos\theta d\omega}$$ (candela / m2)

$$E = \frac{d\Phi}{dA}$$ Irradiance (Wm^{-2})

What a Infrared Camera can measure ?



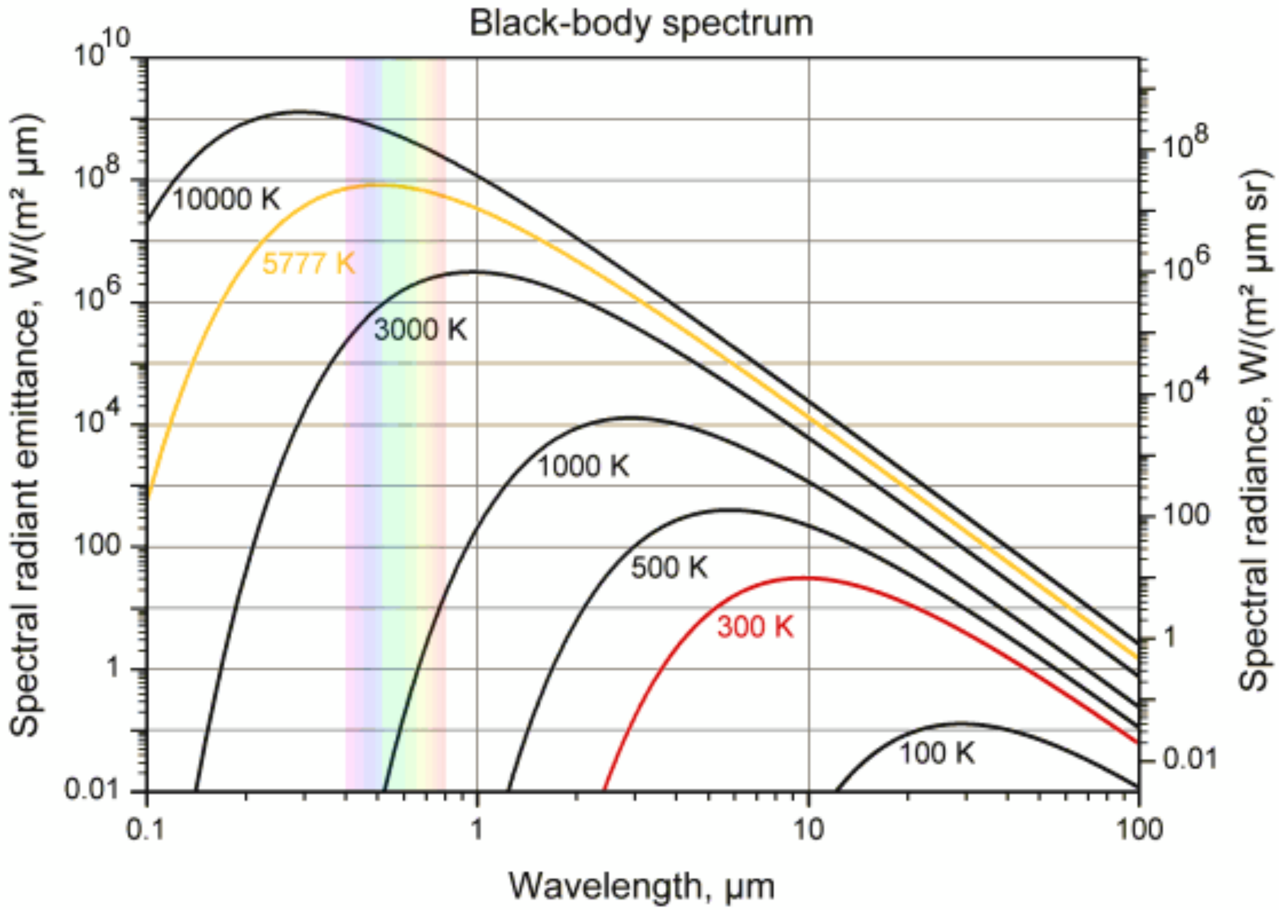
$$d\Phi = L.dA.\cos\alpha.d\omega$$

$$d\omega = \frac{dA'.\cos\beta}{R^2}$$

$$dE = \frac{L \cdot dA \cdot \cos\alpha \cdot \cos\beta}{R^2}$$

Planck's Law, Wien's law

The luminance depends to the temperature of the material.
The spectral domain of
the emmitted rays depends also to the temperature



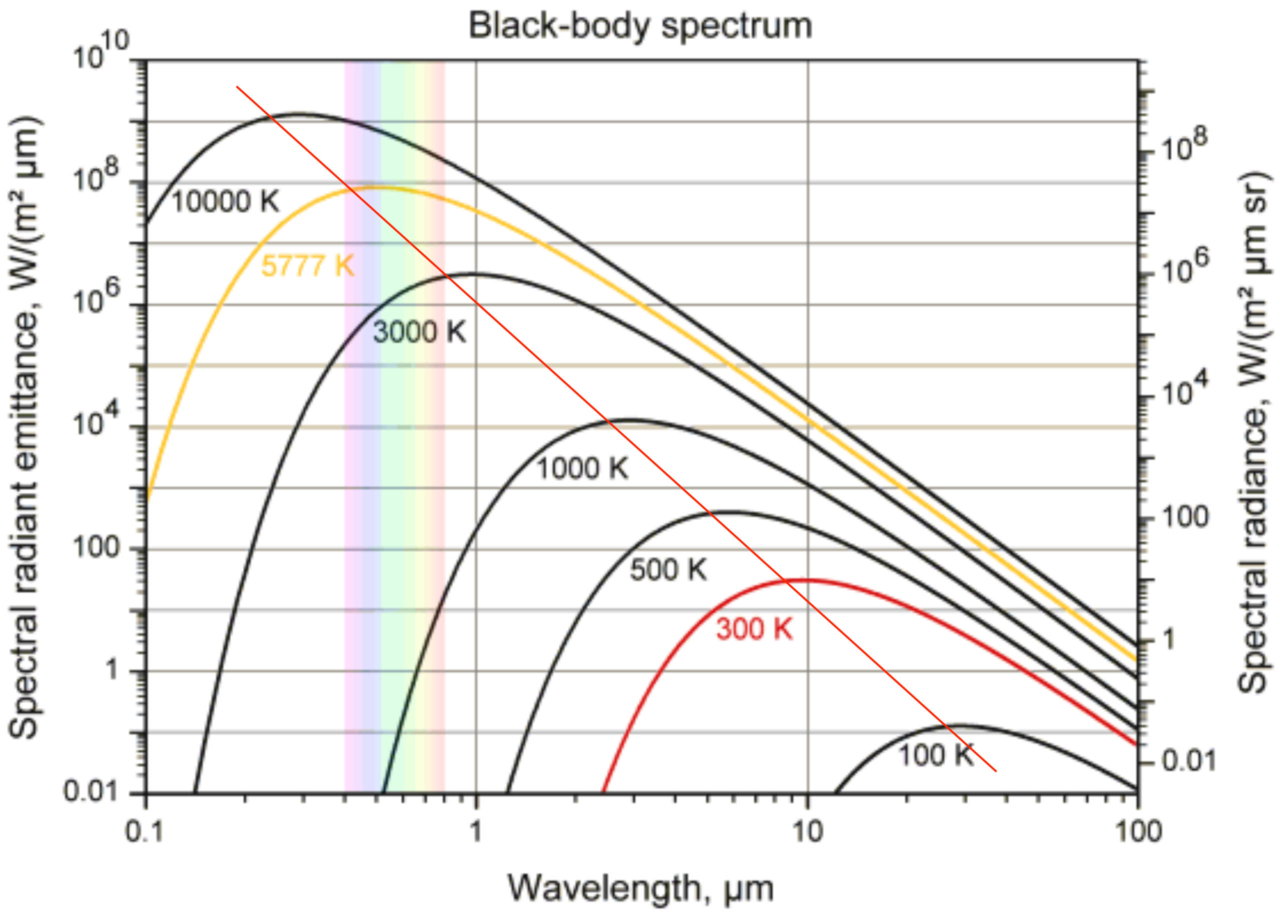
Planck's Law, Wien's law

Planck's Law

$$L^\circ(\lambda,T)=\frac{2hc^2}{\pi\lambda^5}\cdot\frac{1}{\exp(\frac{hc}{\lambda kT})-1}$$

c = 299 792 458 m/s (light celerity)
h = 6,626 17×10^{-34} J.s (Planck's constant)
k = 1,380 66×10^{-23} J/K (Boltzmann's constant)
T = temperature of the material (in K)

Planck's Law, Wien's law

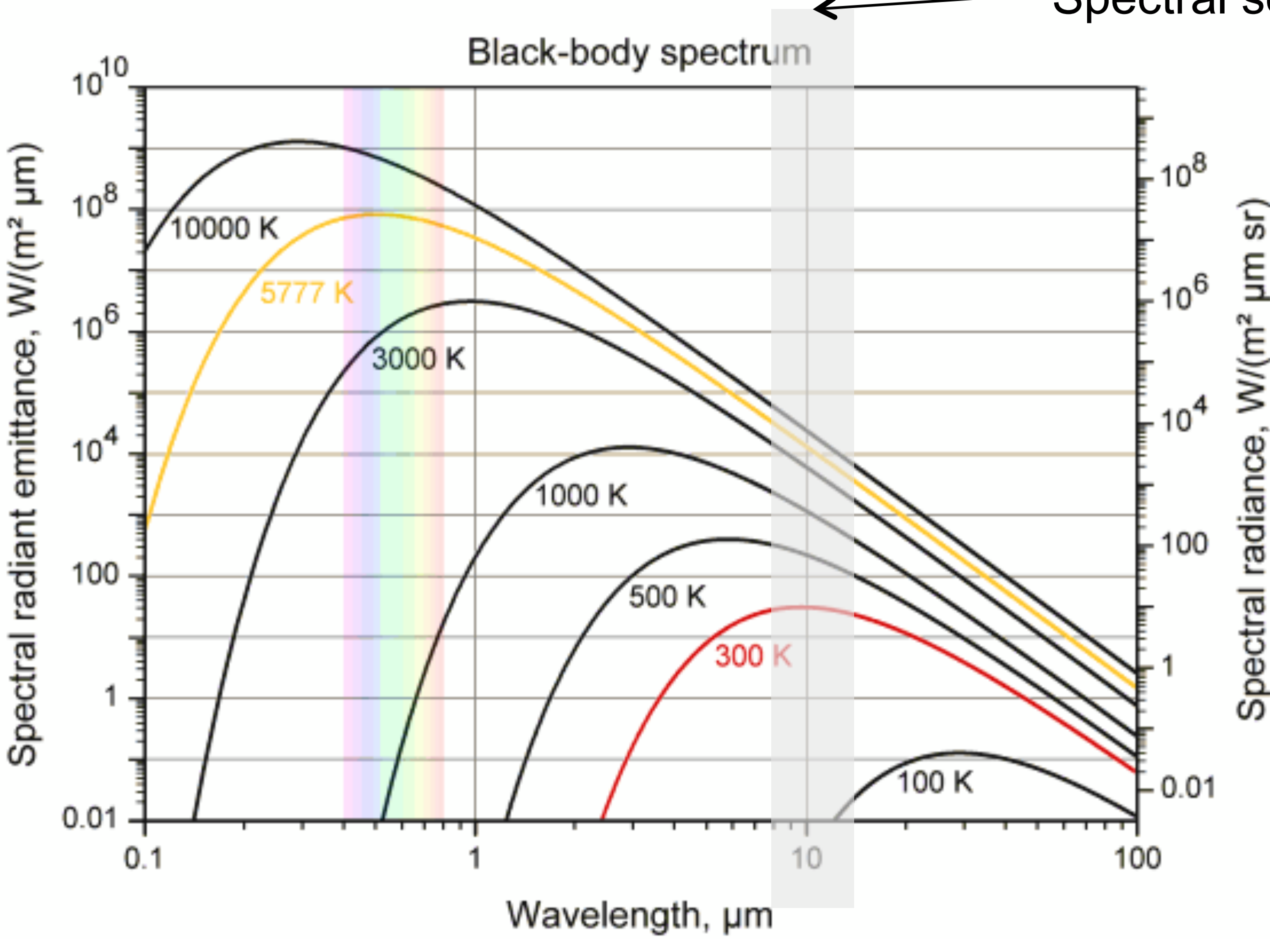


$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

Wien's displacement law

Application to thermography

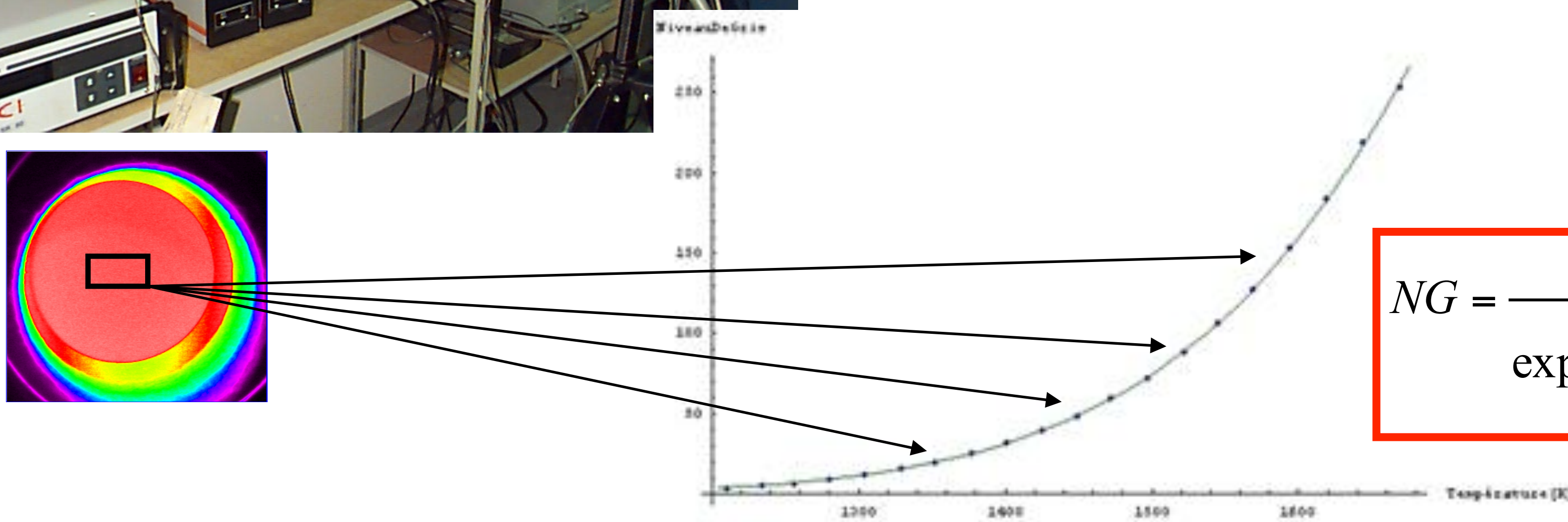
Spectral sensitivity of a IR camera



The « gray level » of the IR image depends to the temperature

Application to thermography

The « gray level » of the IR image depends to the temperature

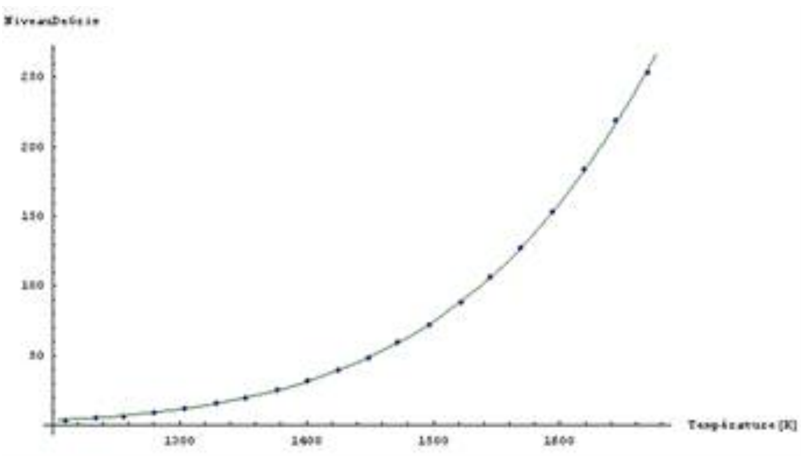


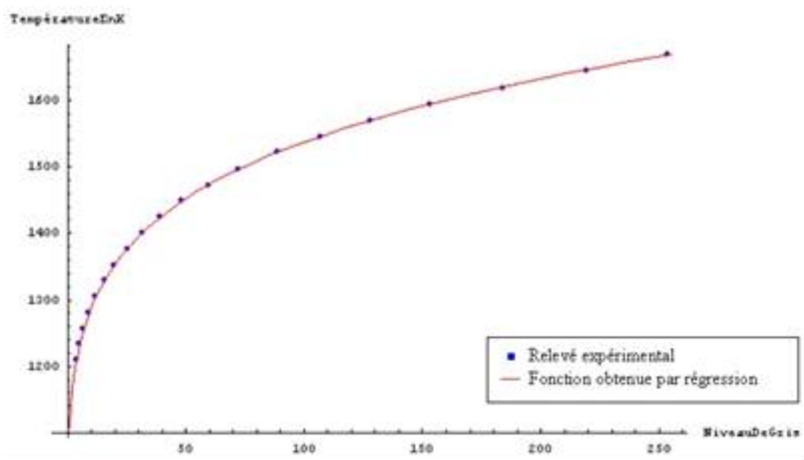
$$NG = \frac{A}{\exp\left[\frac{B}{T}\right] - 1}$$

Application to thermography

$$\boxed{NG = \frac{A}{\exp\left[\frac{B}{T}\right] - 1}}$$

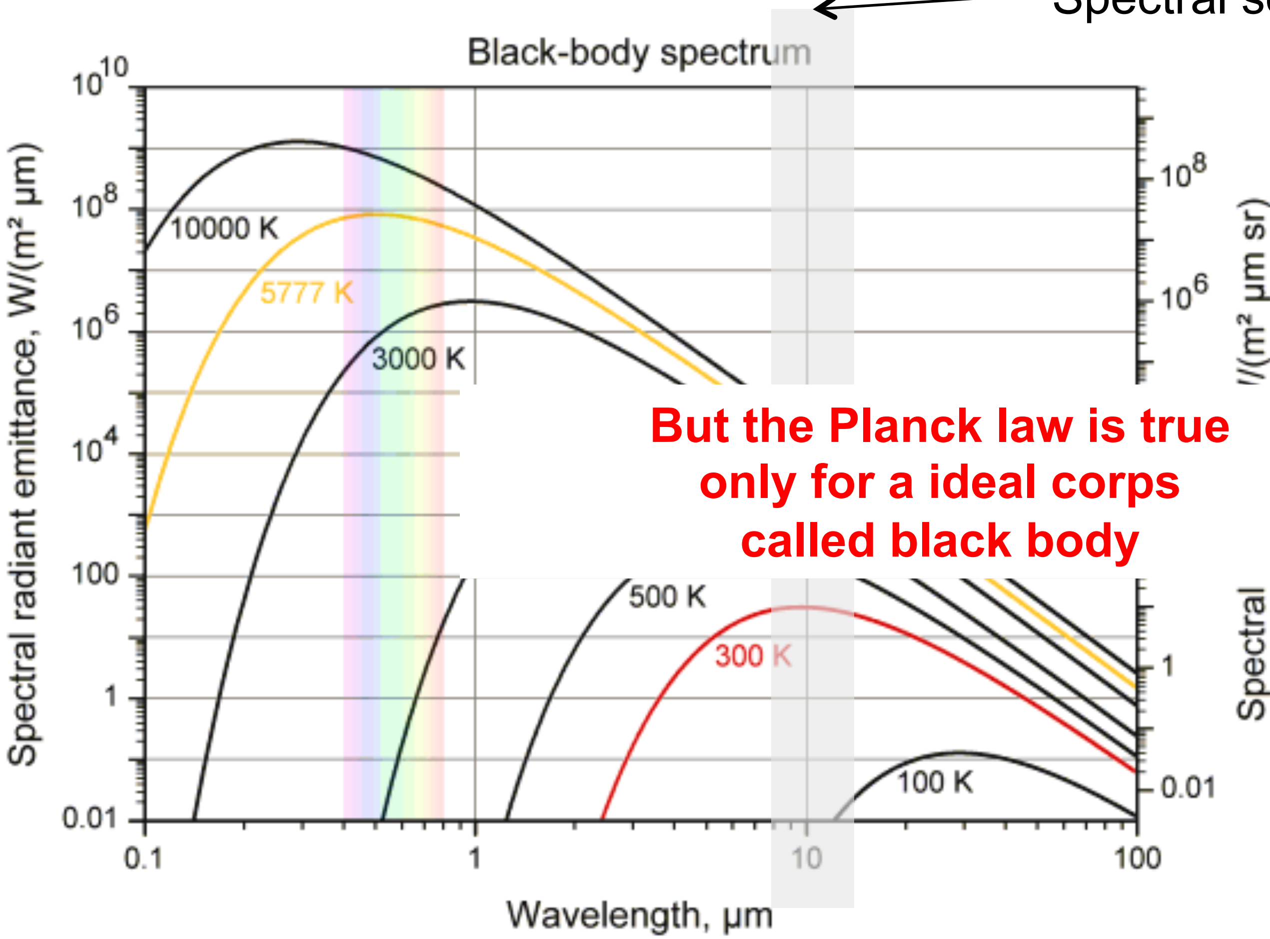
$$\boxed{T = \frac{B}{Log\left[1 + \frac{A}{NG}\right]}}$$





Application to thermography

Spectral sensitivity of a IR camera



The « gray level » of the IR image depends to the temperature

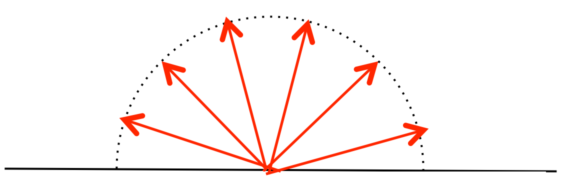
But the Planck law is true only for a ideal corps called black body

Black Body

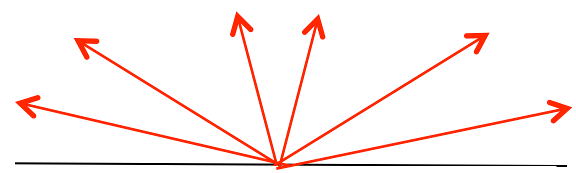
A black body in thermal equilibrium has two notable properties:

- It is an ideal emitter: it emits as much or more energy at every frequency than any other body at the same temperature.

- It is a diffuse emitter: the energy is radiated isotropically, independent of direction.



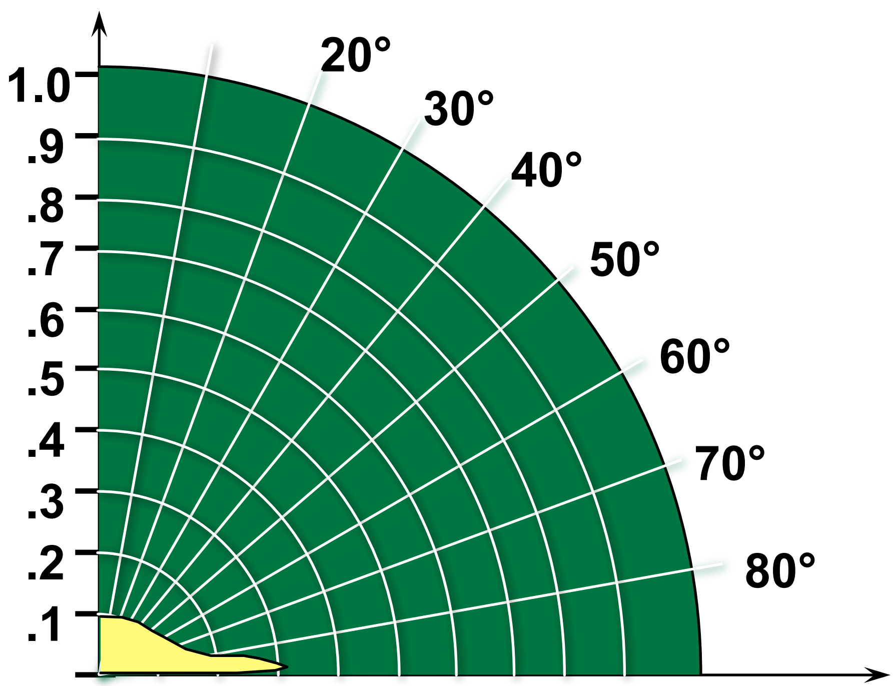
Luminance of a black body at temperature T



Luminance of a real object at temperature T

Emissivity

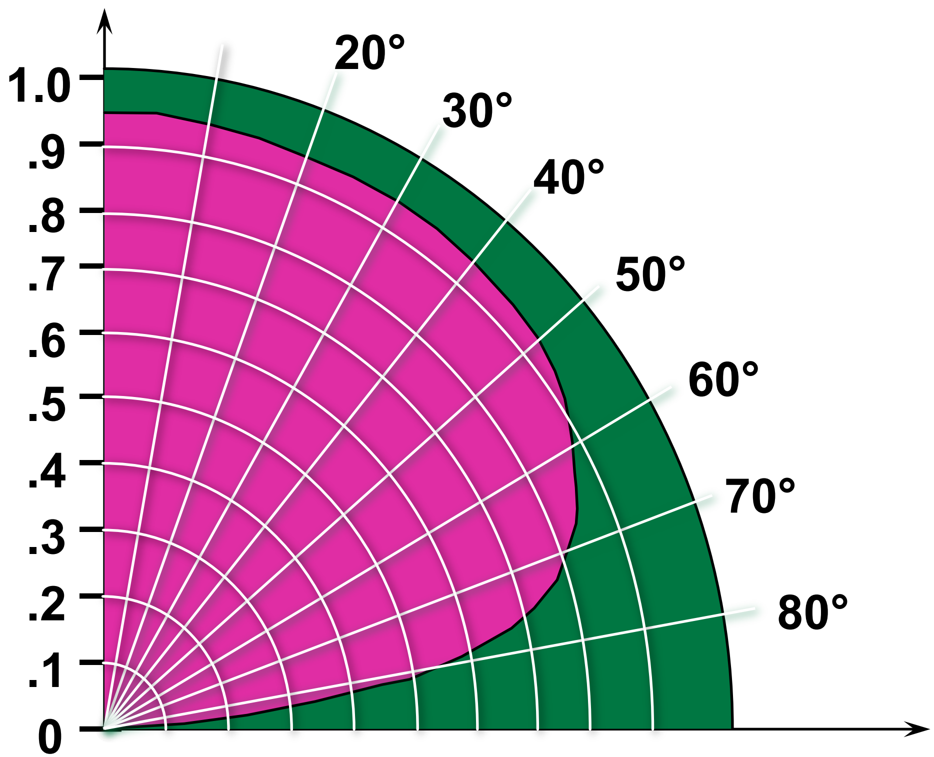
The ratio between the luminance of a real material and a balck body is called emissivity



Example for polished metal

Emissivity

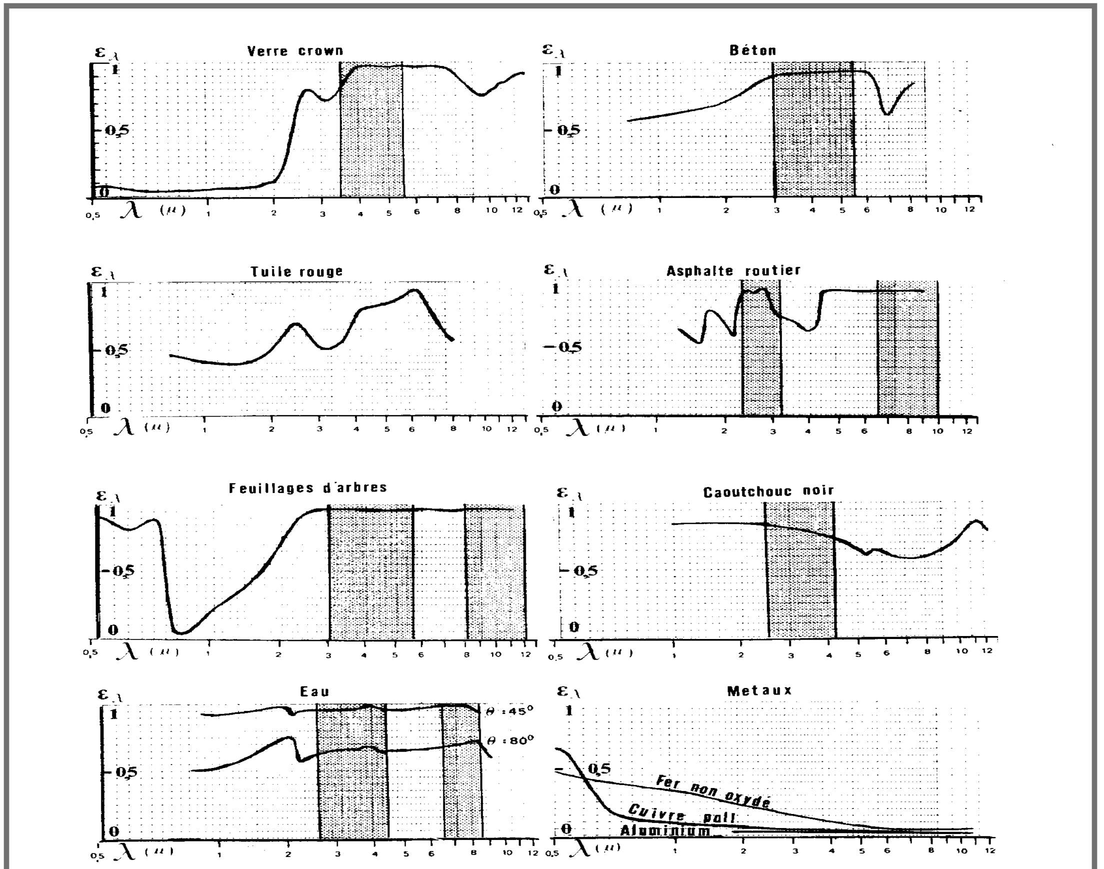
The ratio between the luminance of a real material and a balck body is called emissivity



Example for dielectric

Emissivity

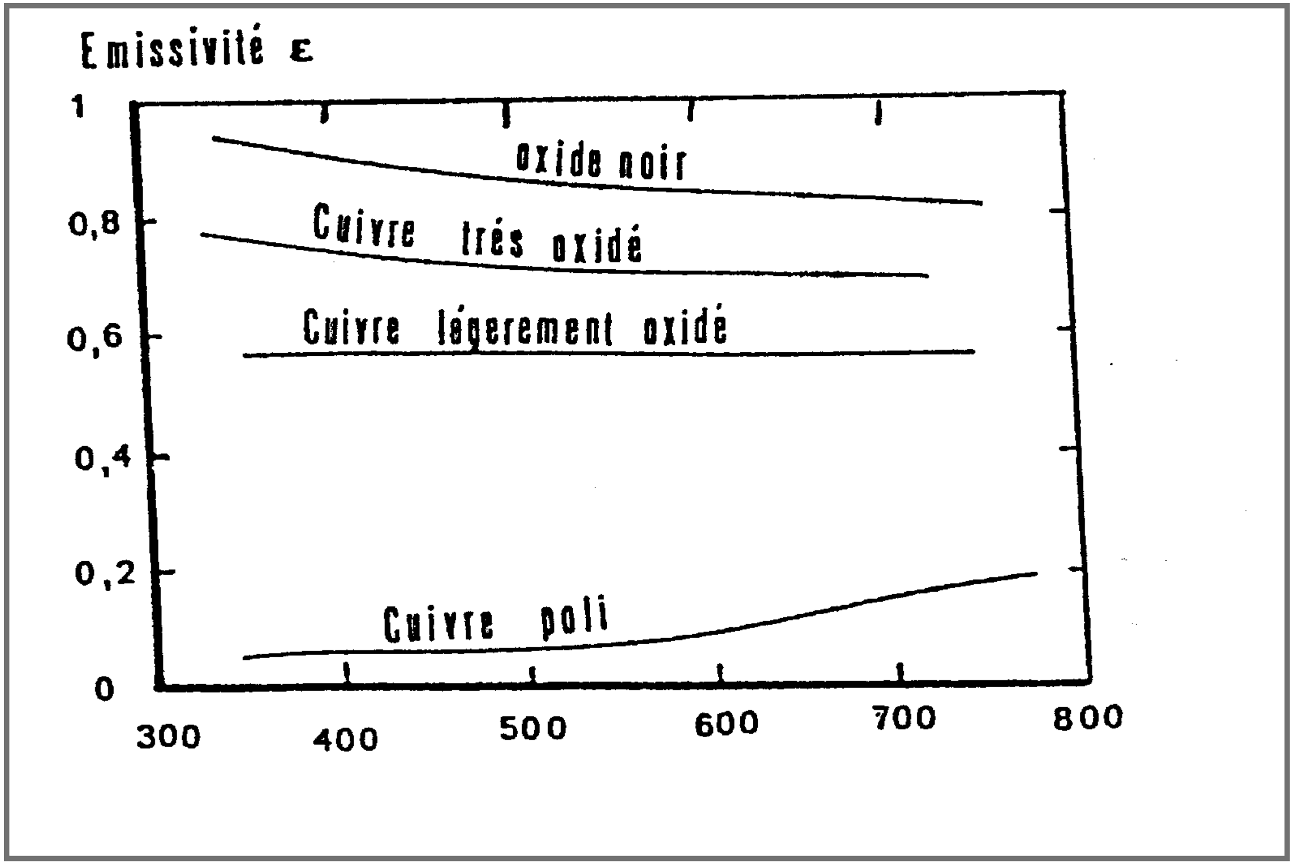
Emissivity depends to the material and to the wavelengh



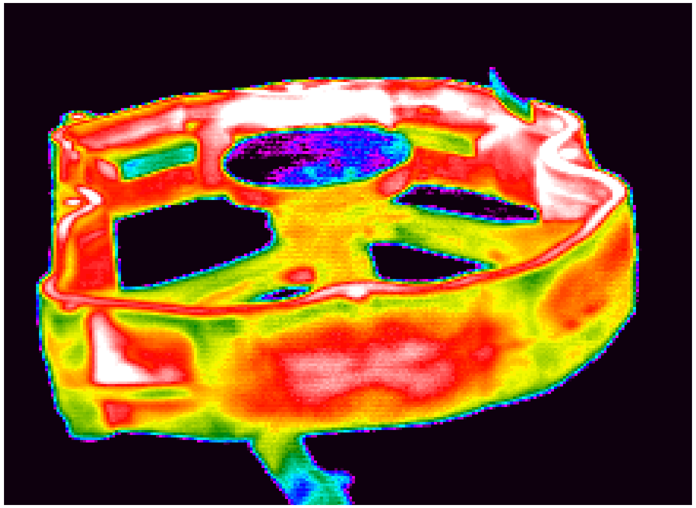
Emissivité Spectrale de quelques Matériaux

Emissivity

Emissivity depends to roughness of the surface



Emissivity

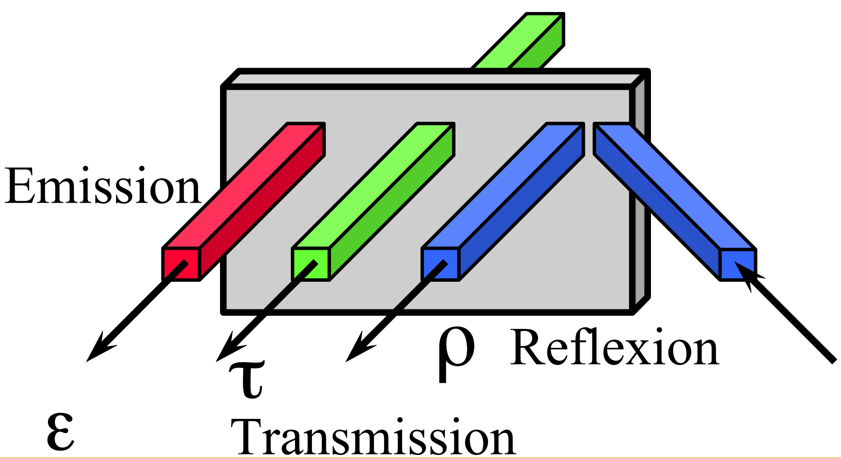


Reflexion and Transmission

As in visible domain, rays can be reflected on a surface or can be transmitted through a material.

Finally we can consider that the luminance in one direction is the sum of :

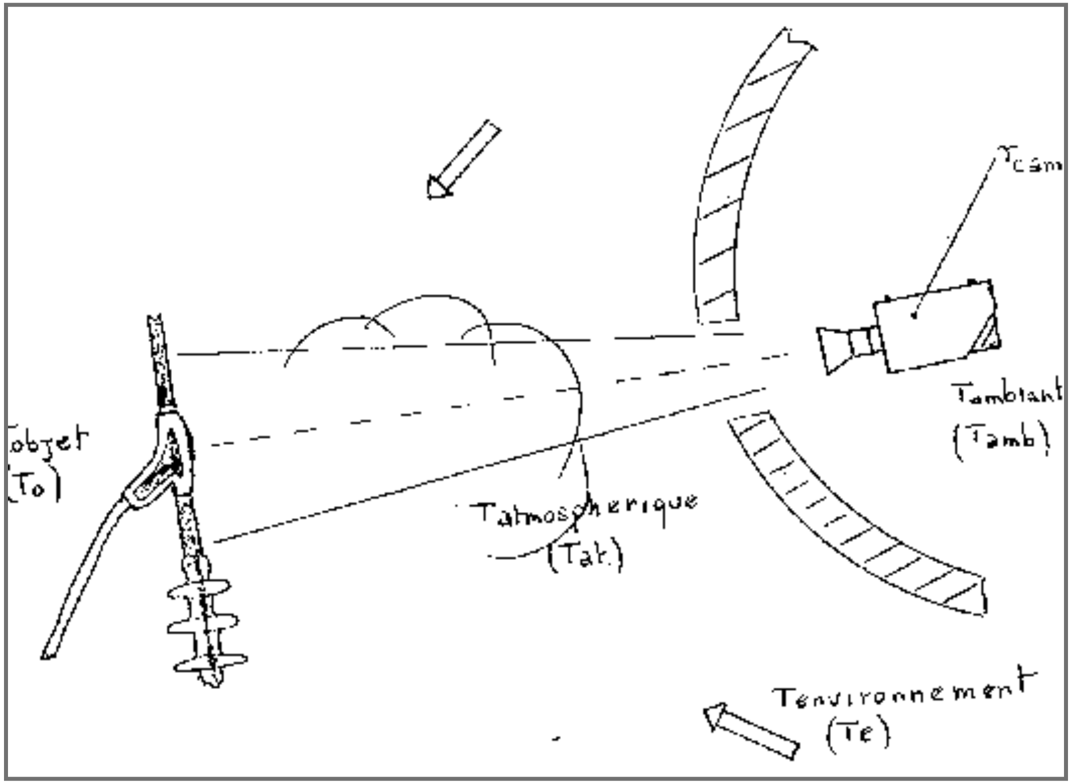
- what is emitted by the material
- what is transmit through the material
- what is reflected on the surface of the material



Kirchoff's law :

α+ε+τ =1

Luminance measured by the camera



Hypothesis

- Opaque object
- Gray body
- Surface Temperature is T_{obj}
- Environment similar to Black Body at T_{env}
- Atmosphere similar to Black Body at T_{atm}
- Atmosphere coefficient transmission t_{atm}

$$L' = \tau_{atm}\,\varepsilon_0 L_{obj} + \tau_{atm}\,(1 - \varepsilon_0)L_{env} + (1 - \tau_{atm})\,L_{atm}$$

Luminance measured by the camera

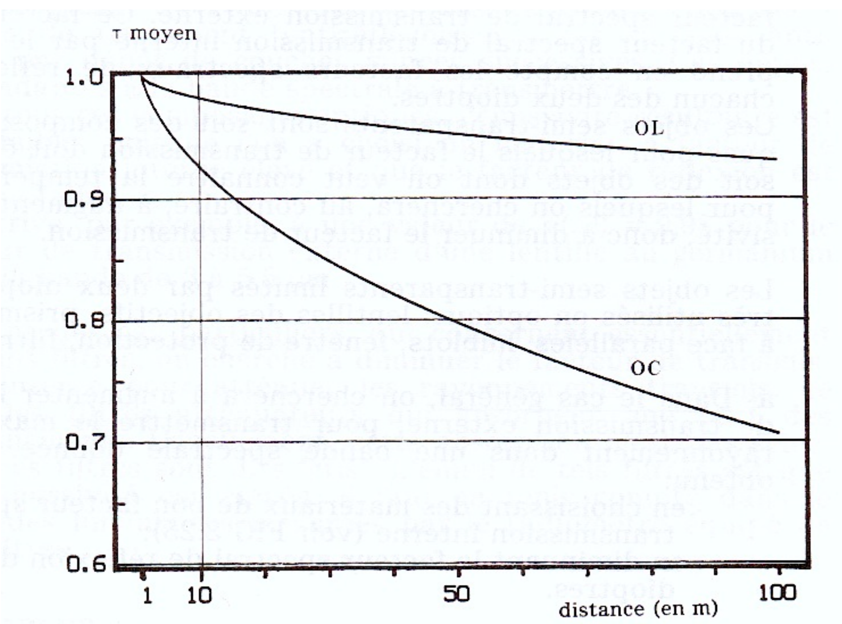
Simplified equation **if $T_{env} = T_{atm}$**

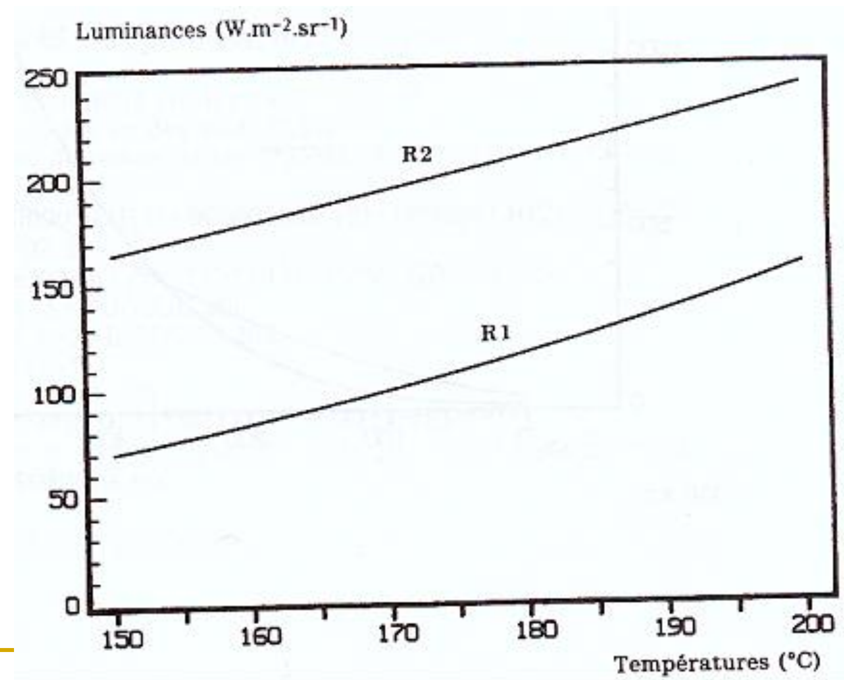
$$L' = \tau_{atm}\,\varepsilon_0 L_{obj} + (1 - \varepsilon_0\,\tau_{atm})L_{env}$$

To determine the real temperature of the object using L', we need to know ε_0 and τ_{atm} and Lenv

Effect of transmission coefficient on temperature measurement

Two IR sensors R1 et R2 respectively working in the SW range (3-5 μm) and Long Wave range (8 to 12 μm) observe a black body situated at 10 meters which temperature is set to 180°C. Using the calibration curves, what are the indicated luminance and what are the apparent temperature?(radiations emitted by the atmosphere will be neglected).





Effect of Reflexion on temperature measurement

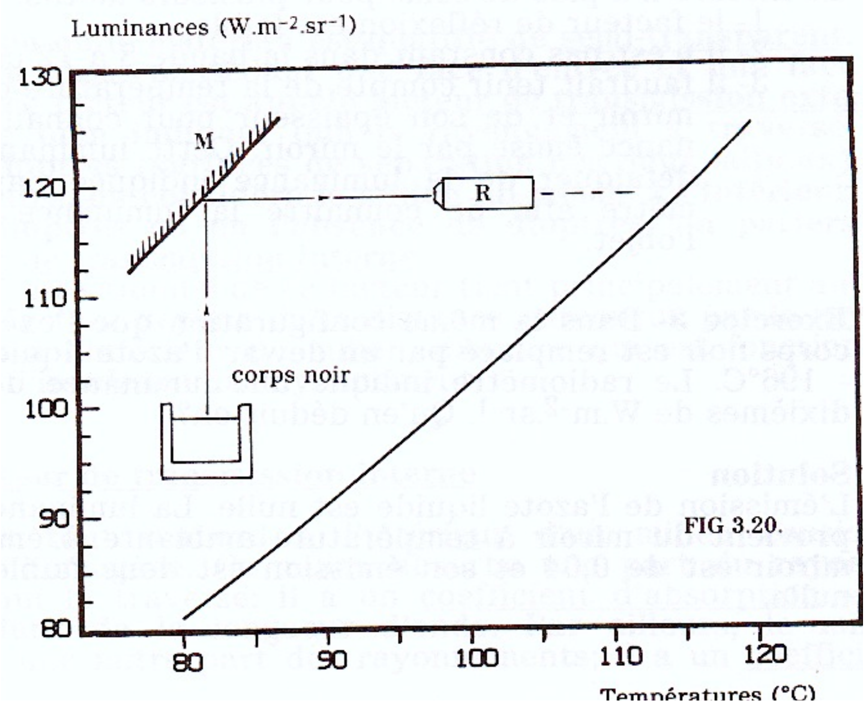


FIG 3.20.

A IR sensor R_2 observes a black body thanks to a mirror which reflexion coefficient is equal to. 0,96. The sensor indicates a luminance of 100 $Wm^{-2}\ sr^{-1}$.

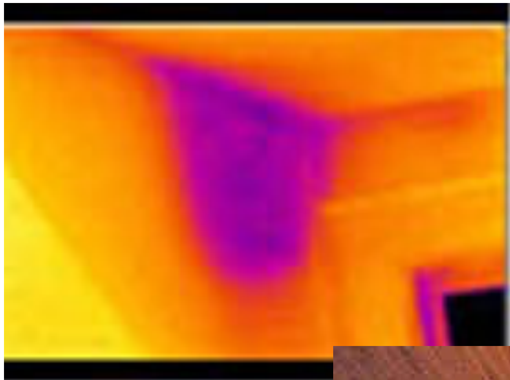
What is the appearing temperature?

What is the true temperature?

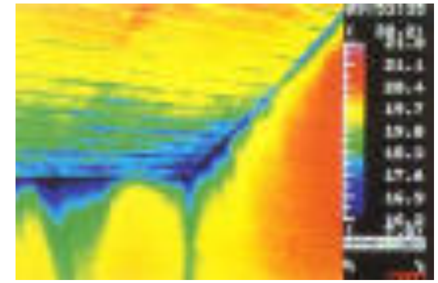
Effect of Emissivity on temperature measurement

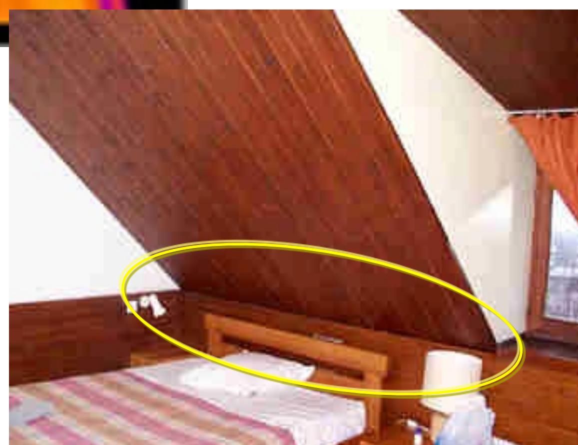
A metal plate is heated by induction to a temperature of 180°C. Its emissivity is 0.2 in the LW spectral band
This plate is then cover with a paint in order to increase its emissivity (avoid annoying reflexion). The IR sensors indicates 140 W m^{-2} sr^{-1}.
What is the emissivity of the material (paint + metal) assuming iosthermy between the plate and the coating?
What is the transmission coefficient of the paint?
What happens if one doubles the layer thickness? (hint: Beer Lamber’s law).

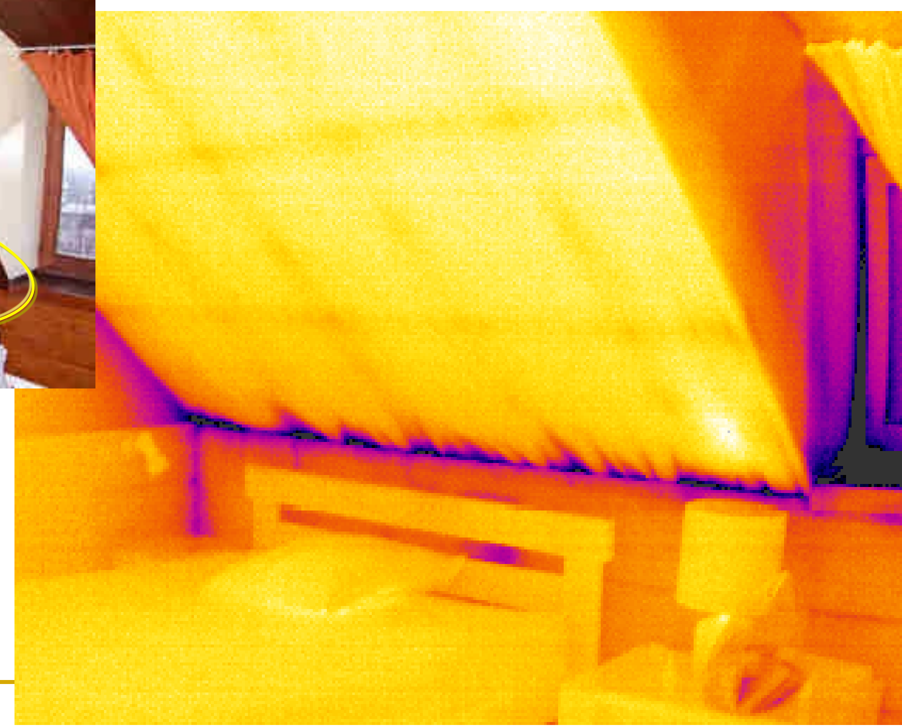
Applications

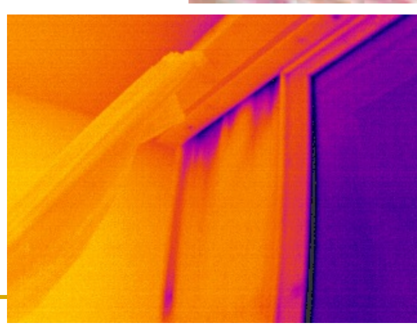


house→Insulation

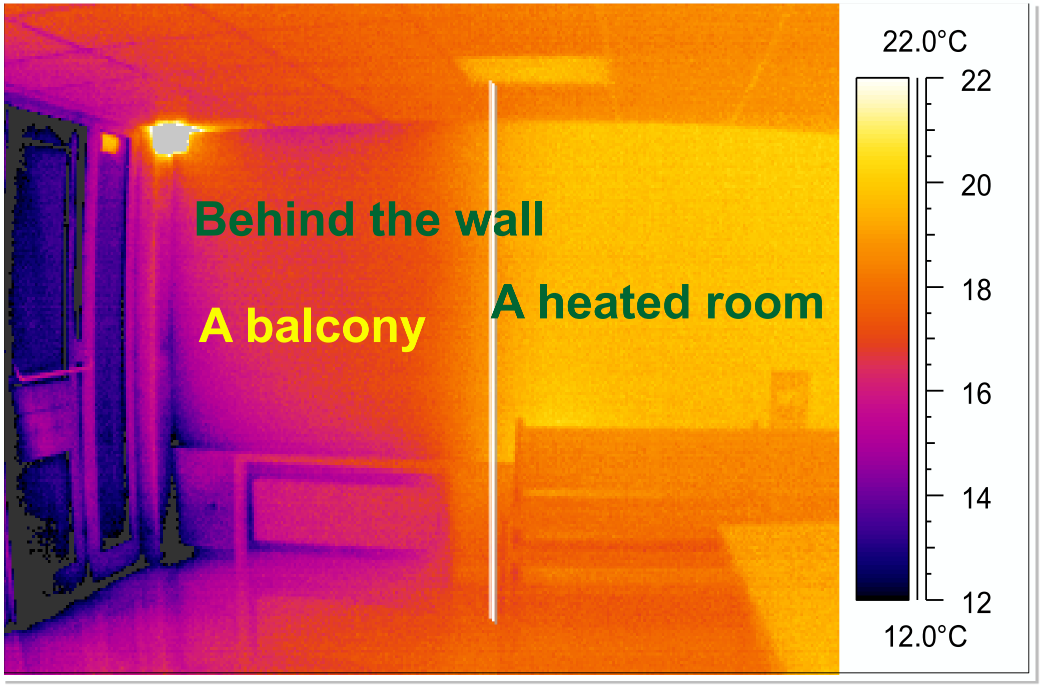








Applications



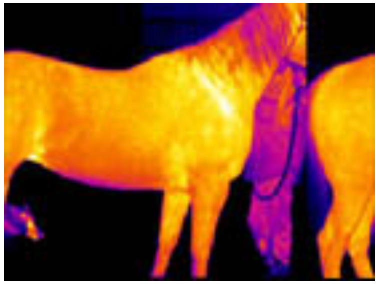
Applications

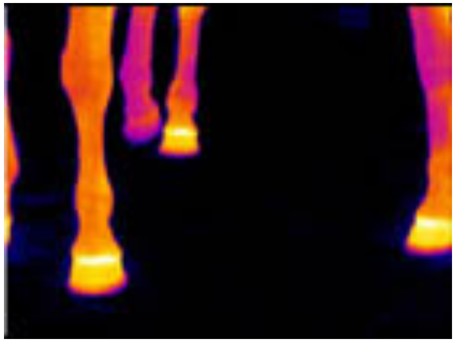
Medicine

-tumors, pneumothorax, muscular lesion …..

Veterinarian

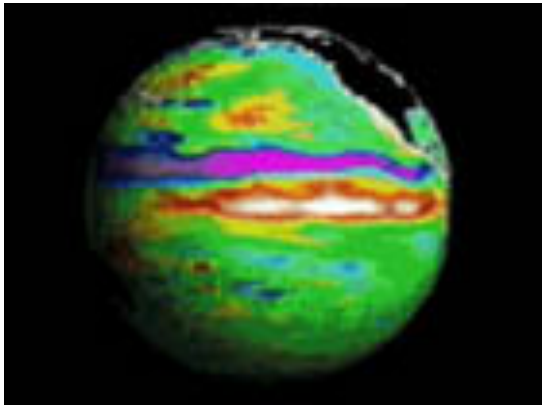
-muscular lesion



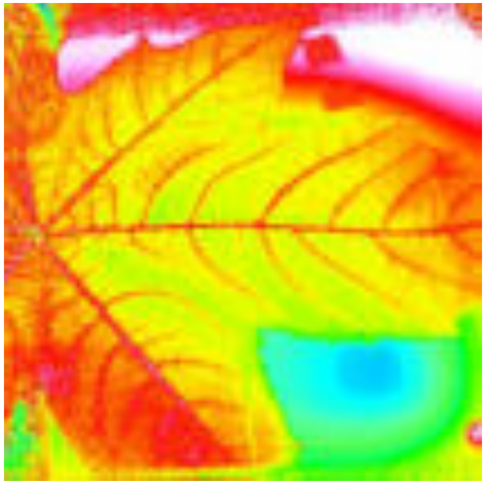


Application

- Environment

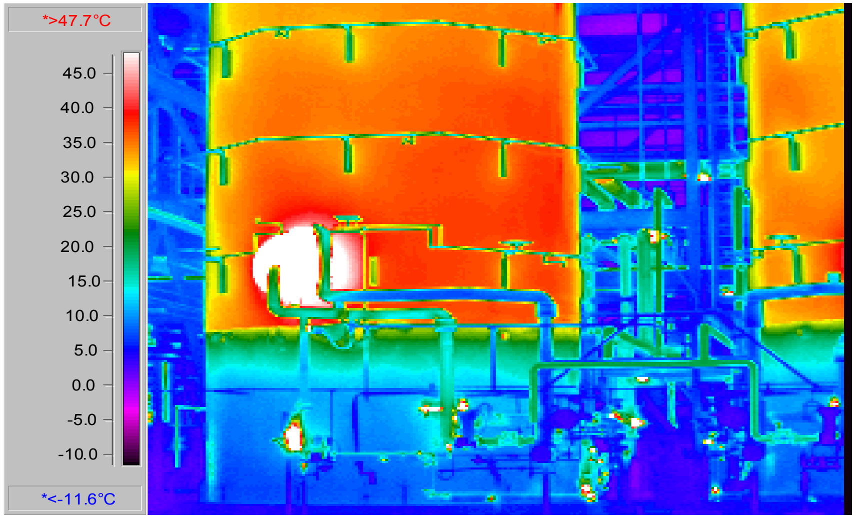


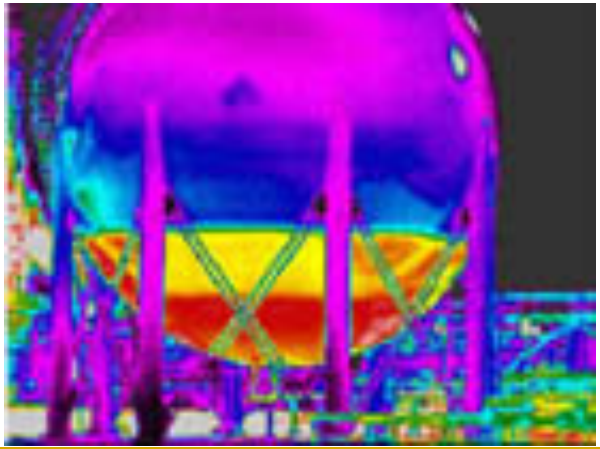
- Biology



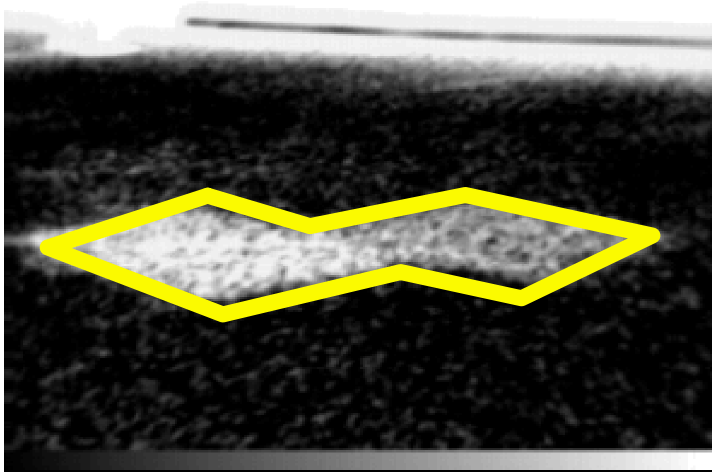
Application

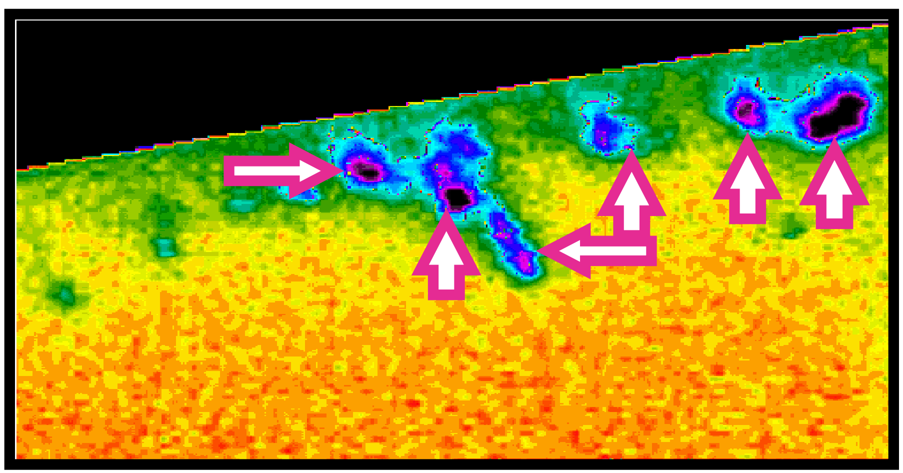
- Physics and chemistry indutries





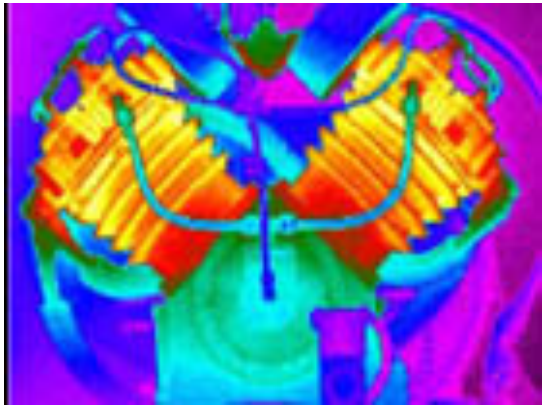
Application

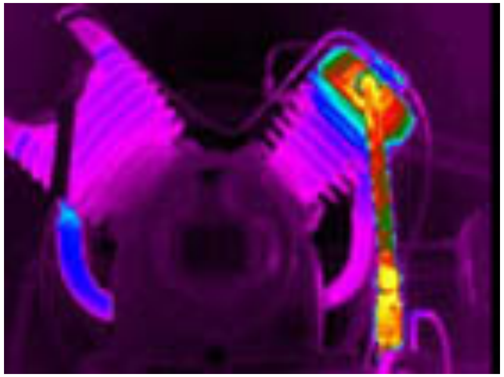


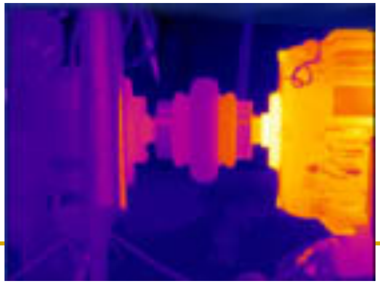


Application

- Mechanical industry

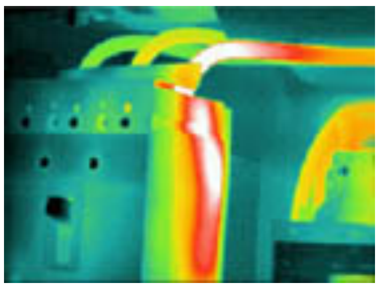


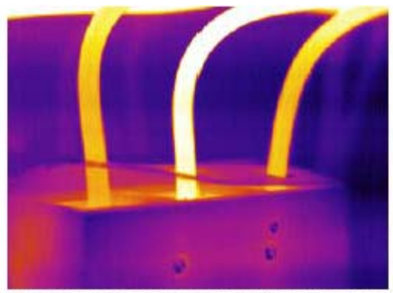




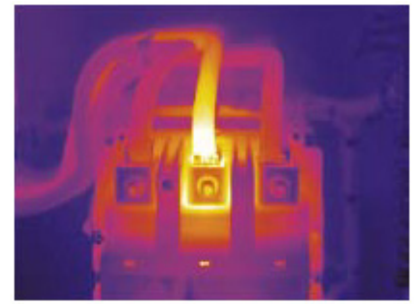
Application

Of course, electrical maintenance

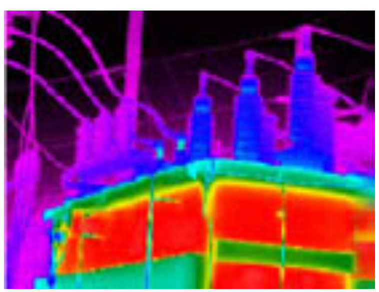




Harmonicas problems on circuit feeding a data processing room.



Increased resistance at the bolted connection. Note the trailing off of the thermal energy. If it were a load imbalance the temperature would be the same throughout the conductor.



Application

And others…