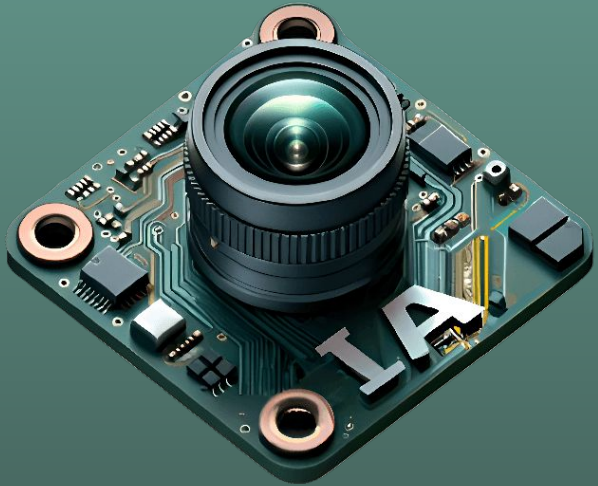
Universidad
Industrial de
Santander

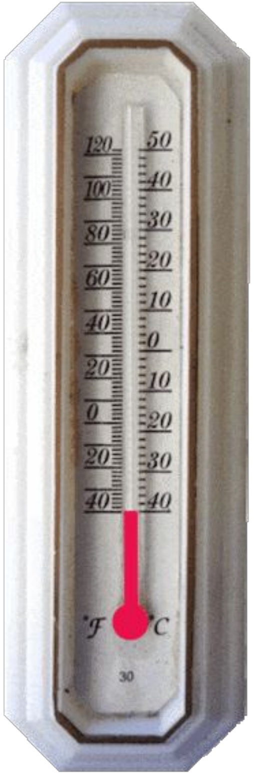


Semillero de Investigación
“Hands - on”
Computer Vision

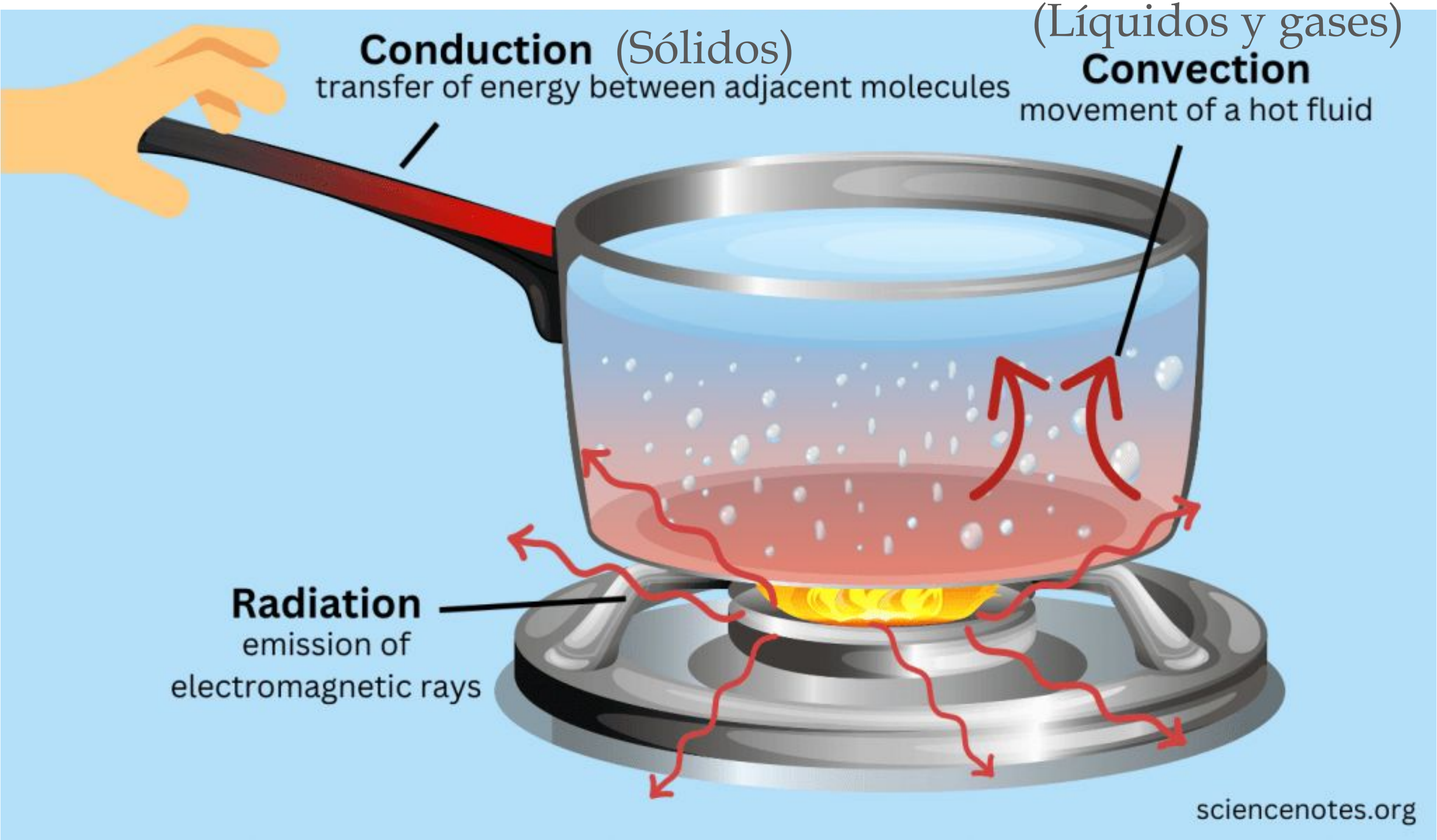
SESIÓN 8: IMÁGENES TÉRMICAS

Contenidos

¿Cómo podemos medir la temperatura?



Transferencia de calor



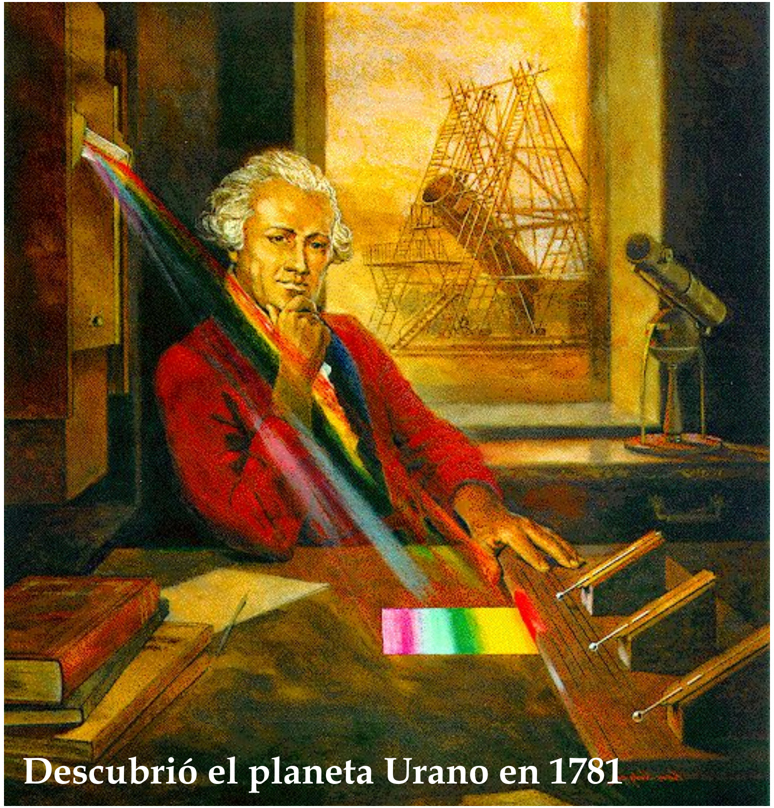
La conducción requiere contacto. La convección requiere flujo de fluido. La radiación no requiere ningún medio.

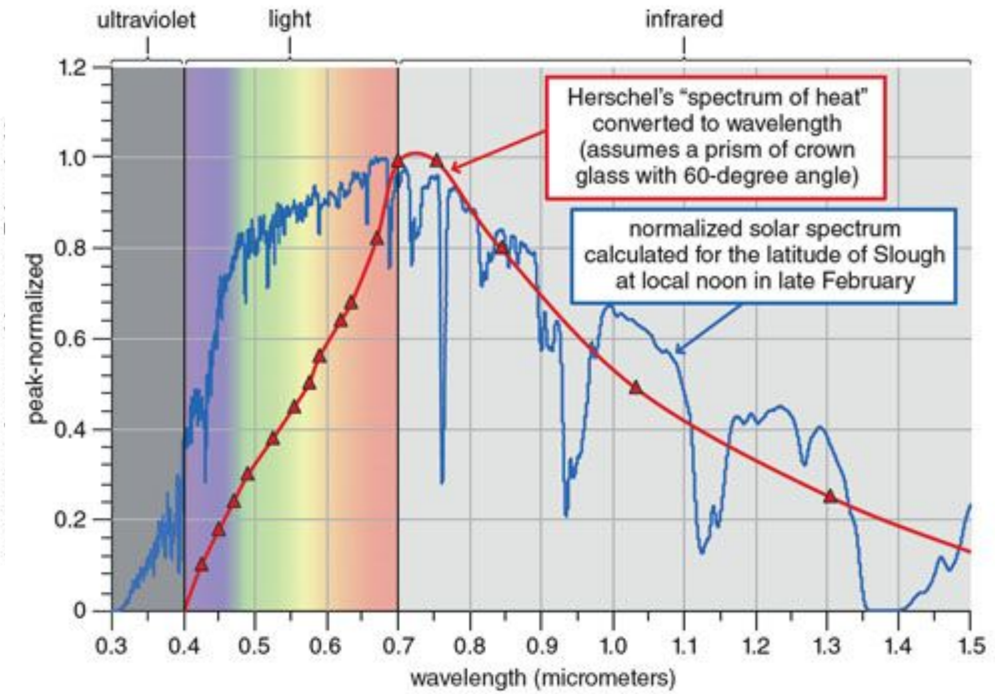
Sensores térmicos en la naturaleza

Víboras: pitones, boas y serpientes de cascabel

1. Imágenes Térmicas

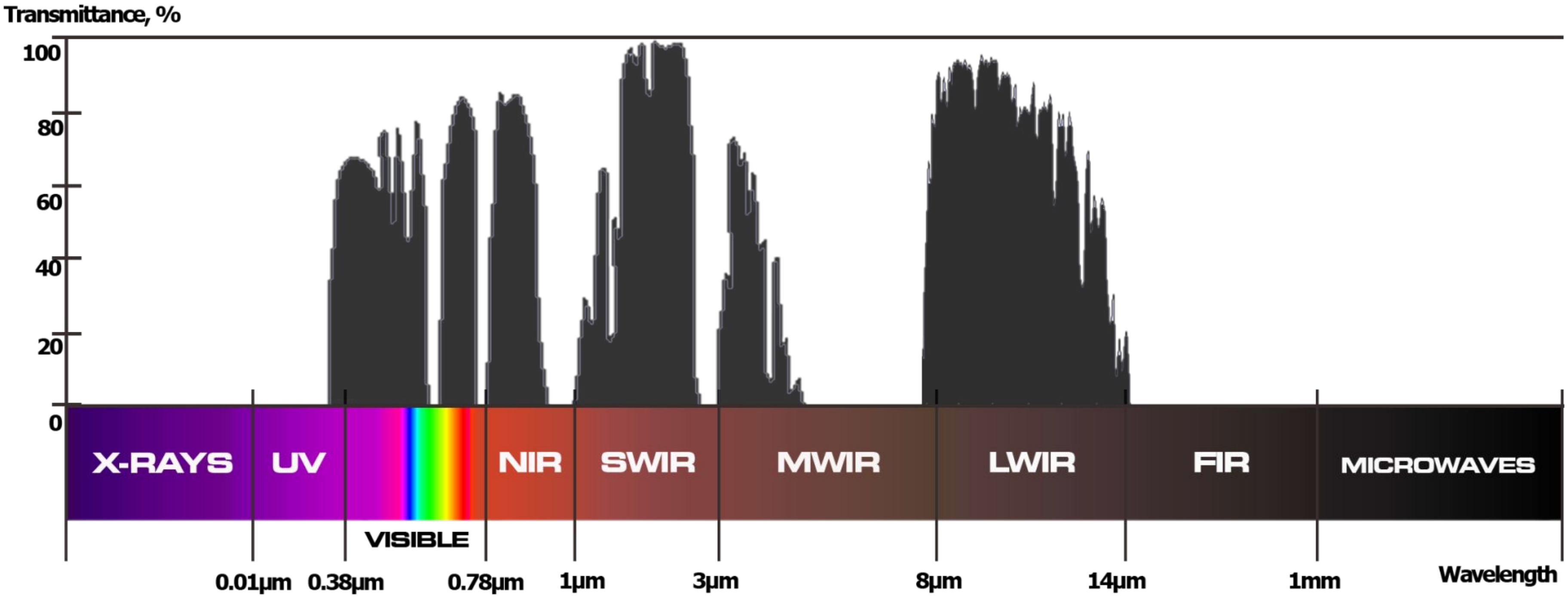
Infrared light discovery (Frederick W Herschel in 1800)





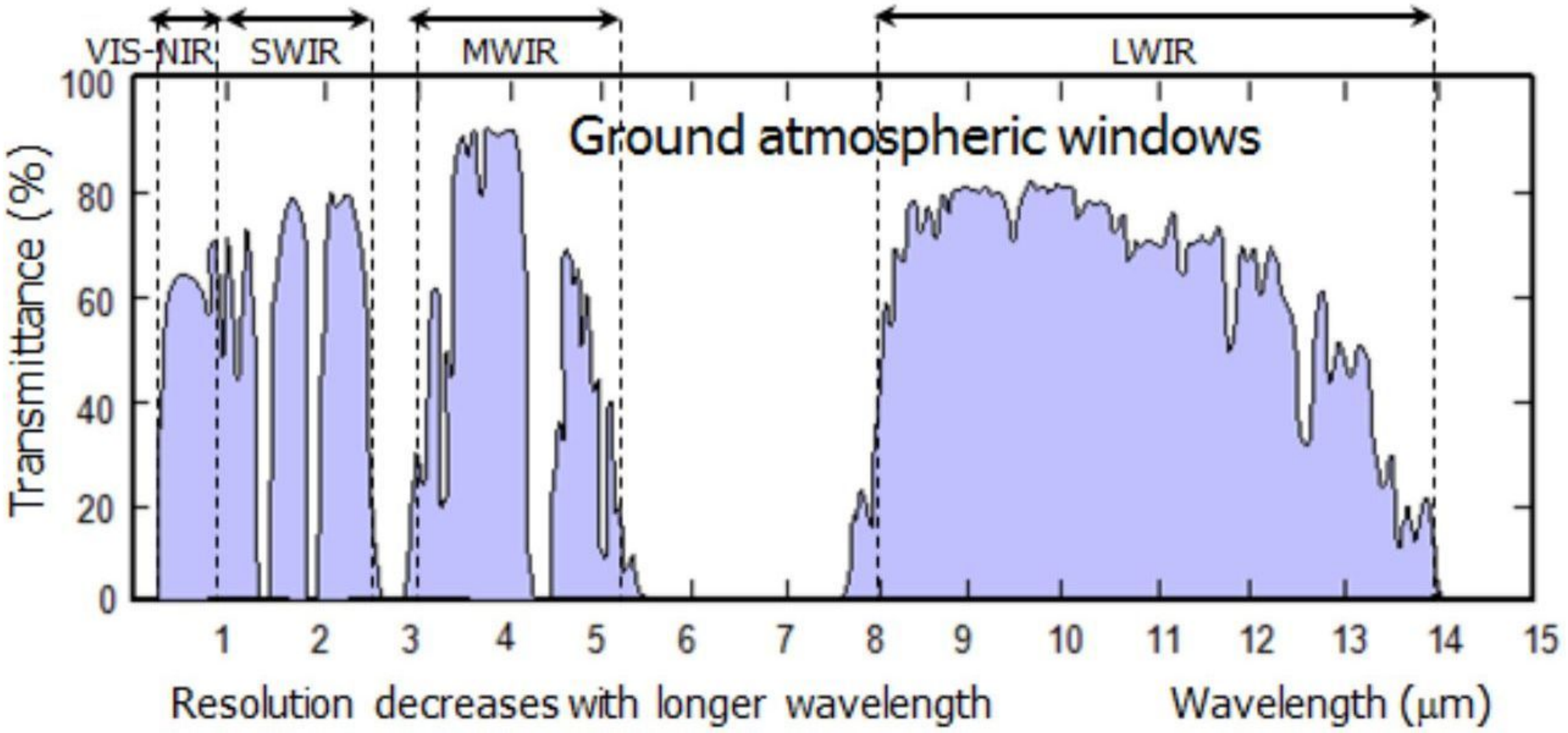
https://www.americanscientist.org/article/herschel-and-the-puzzle-of-infrared

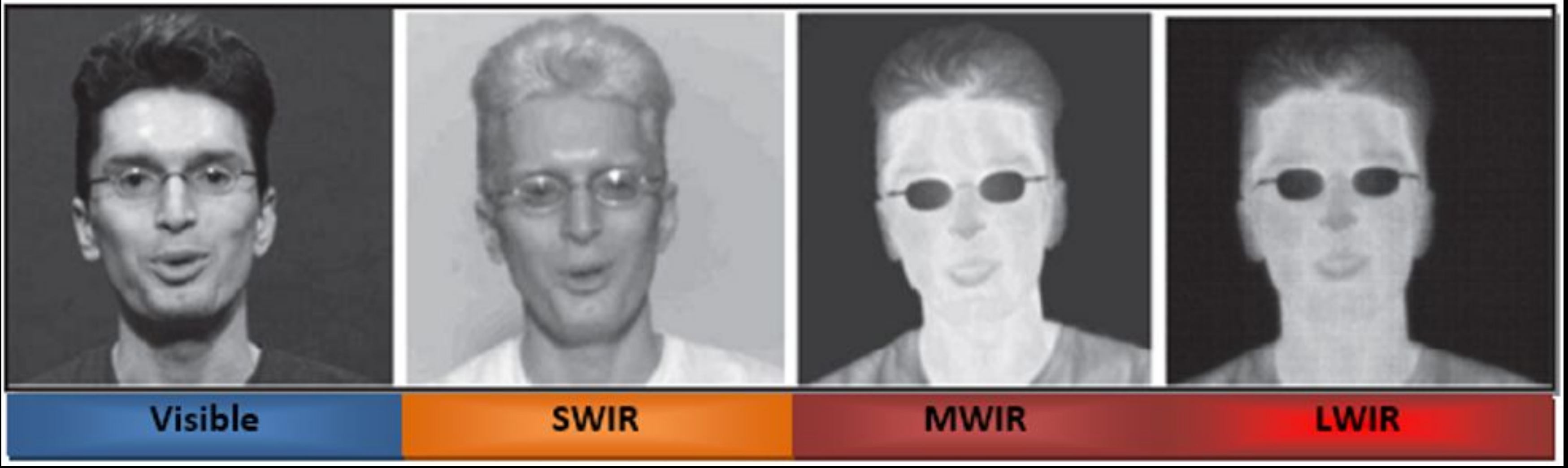
Espectro electromagnético



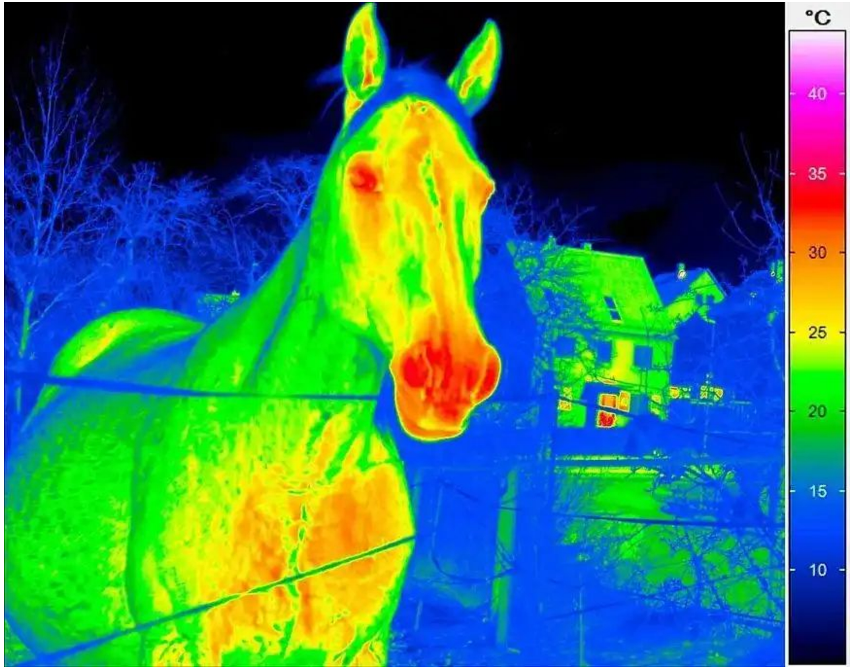
Térmico = LWIR

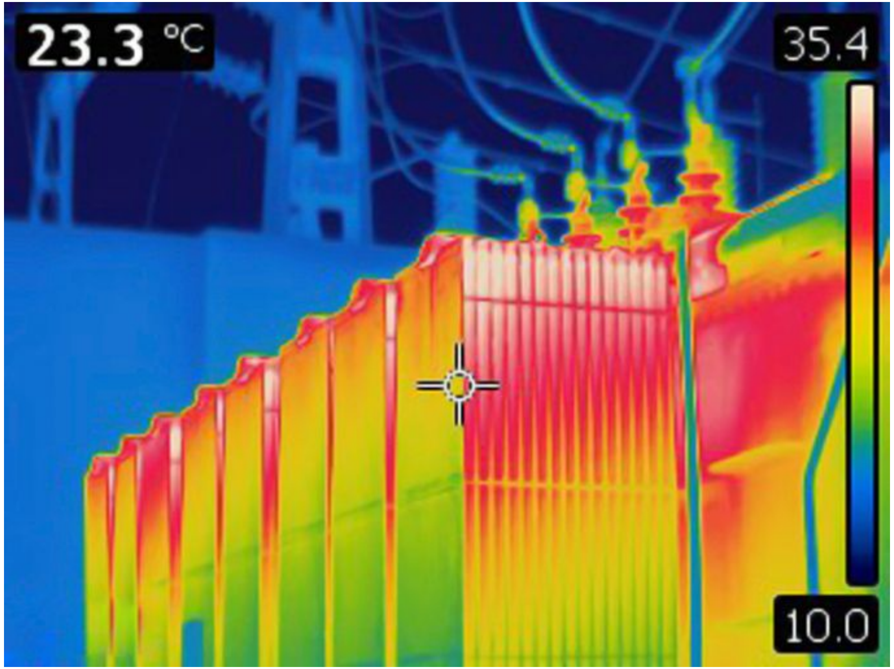
Importancia de la Atmósfera




Visible
SWIR
MWIR
LWIR

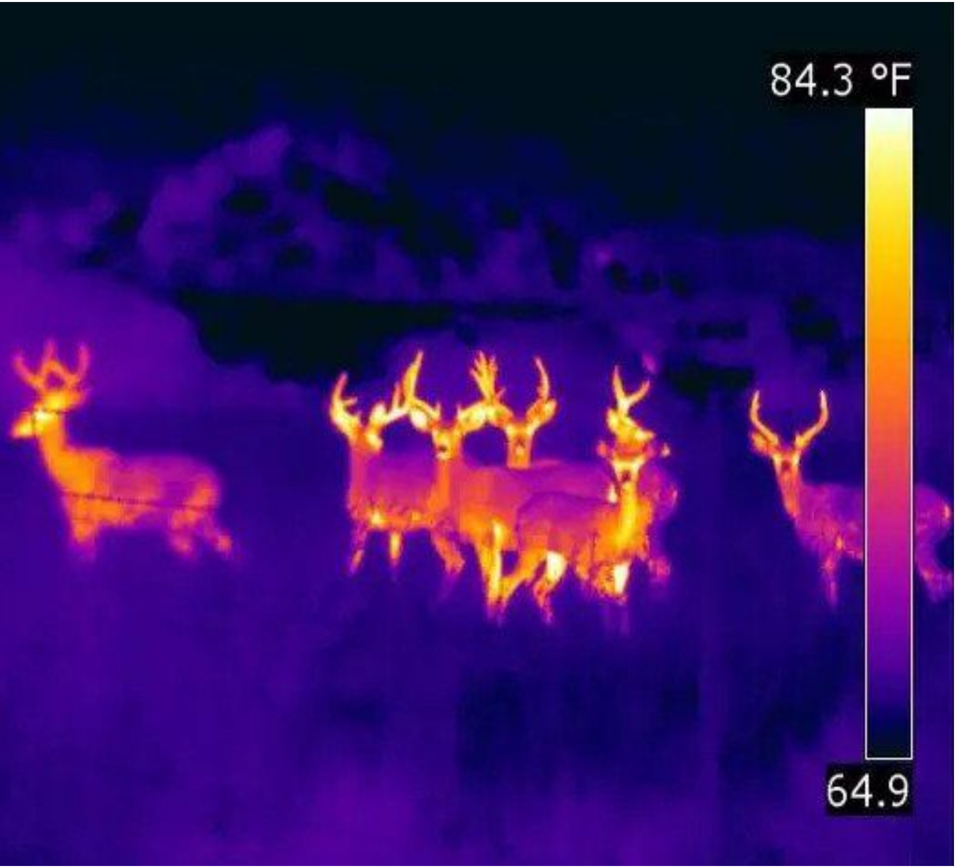
Imágenes térmicas





- Un termograma es una representación digital de la radiación térmica emitida por los objetos
- Las cámaras termográficas permiten detectar esta radiación en forma de luz infrarroja
- Una imagen térmica nos permite detectar de forma remota la temperatura de un objeto

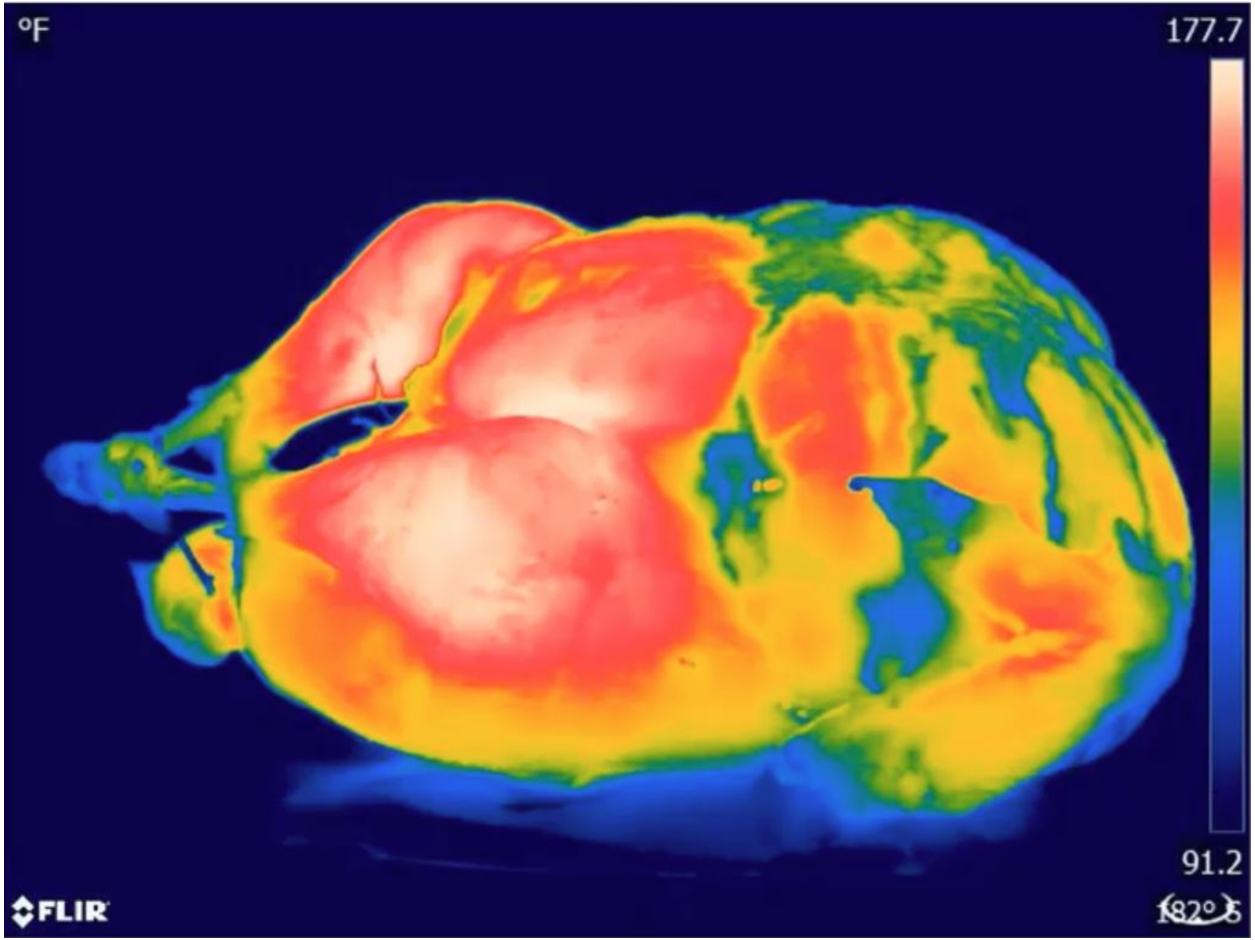
Imágenes térmicas




FLIR
Pioneer

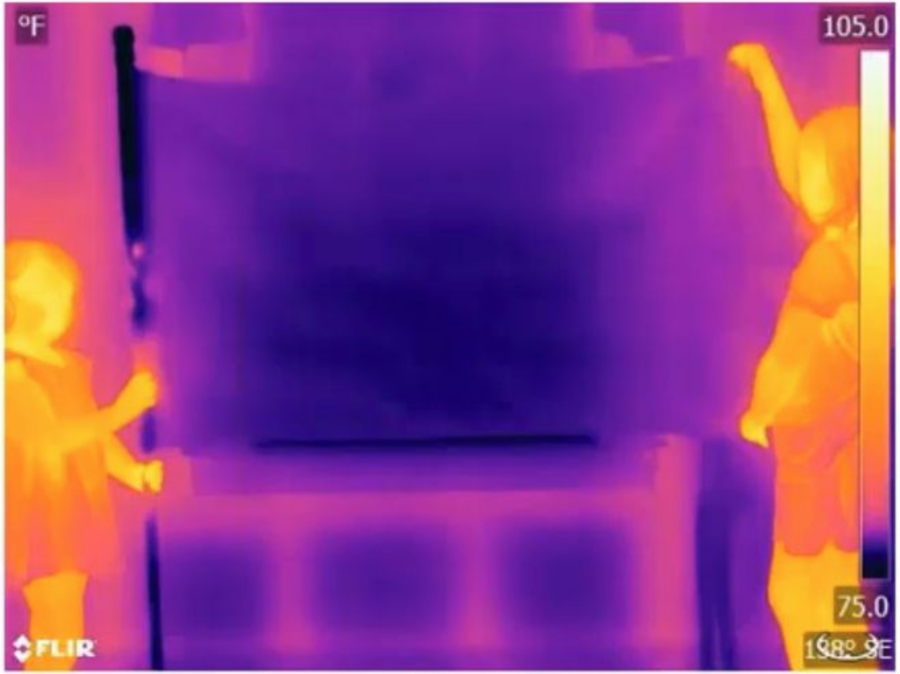
Cool stuff

Las alas se enfriaron más rápido (heat capacity, humedad)



Por qué la bandera se ve diferente?

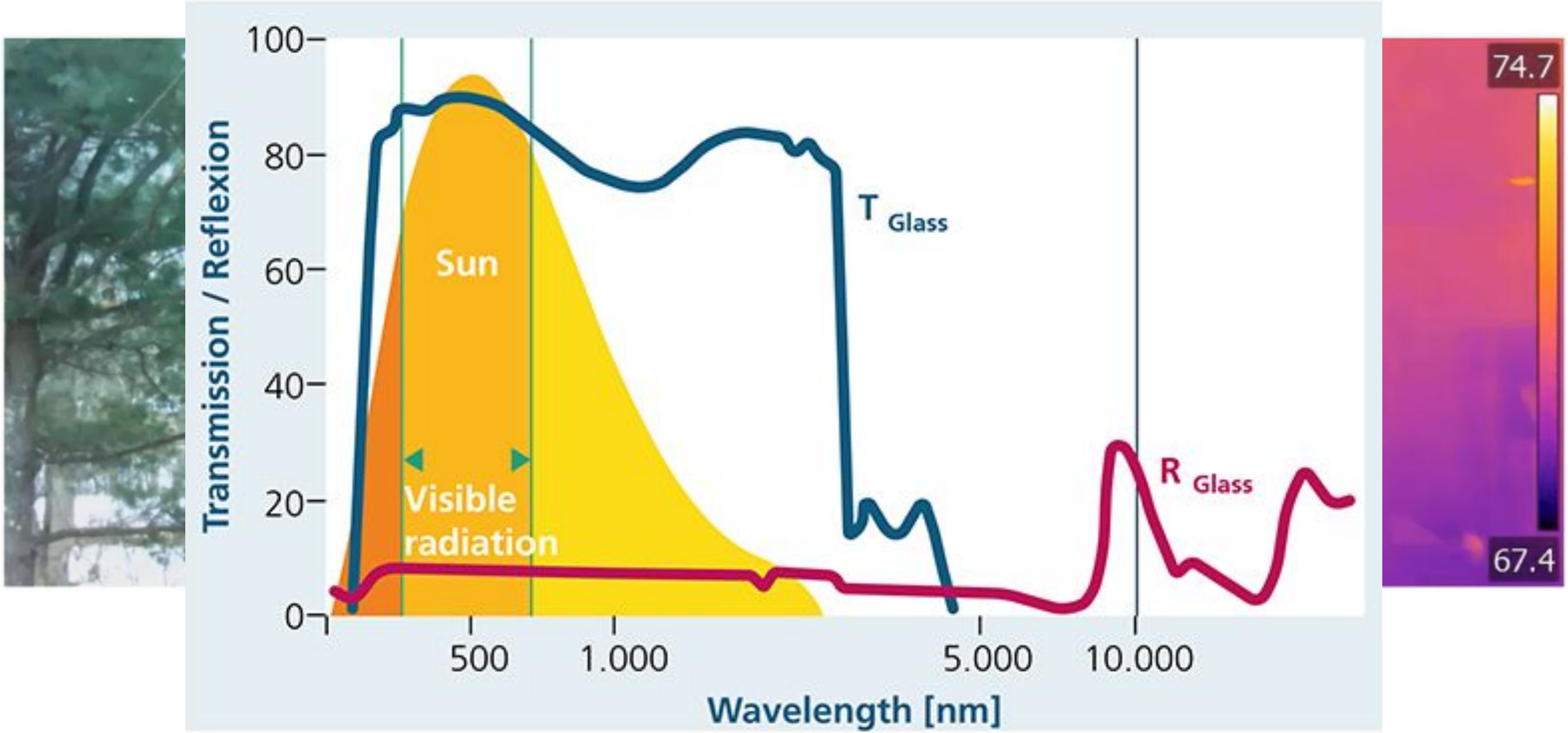
Afuera de casa



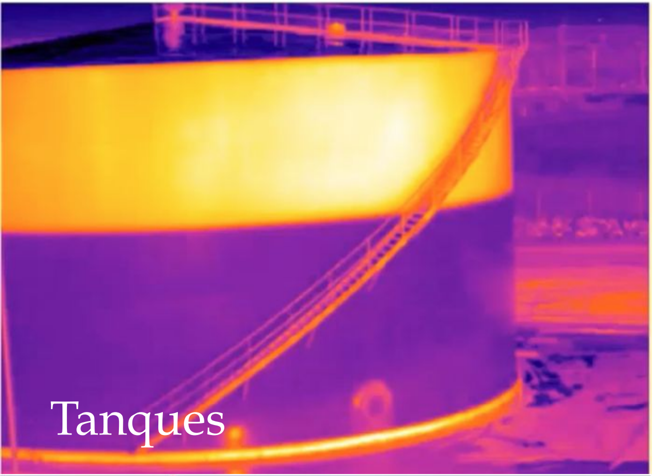
Dentro de casa

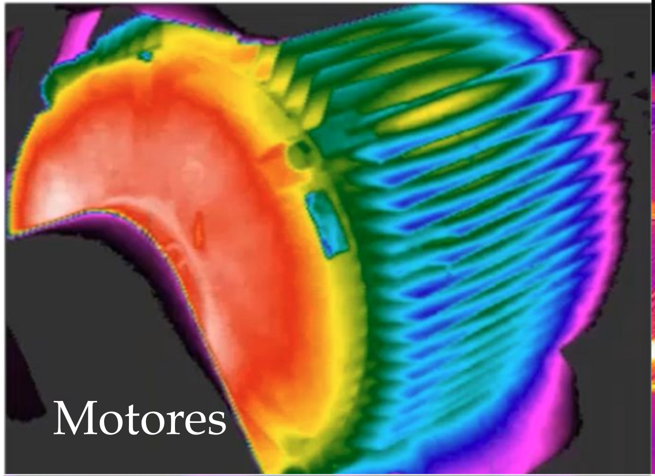
Metales reflejan luz y pueden ser difíciles de medir

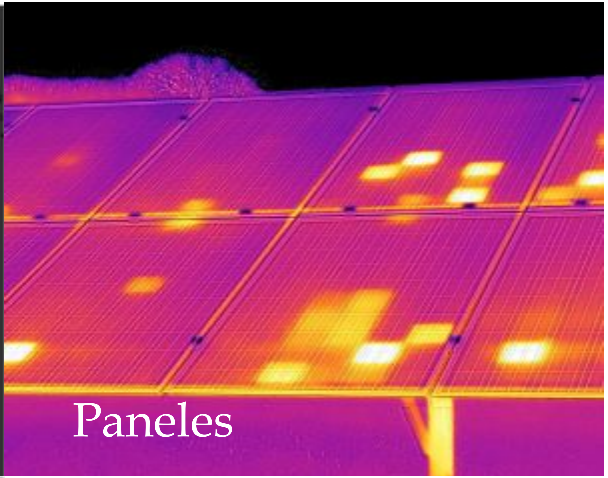
Los vidrios son opacos en el rango térmico

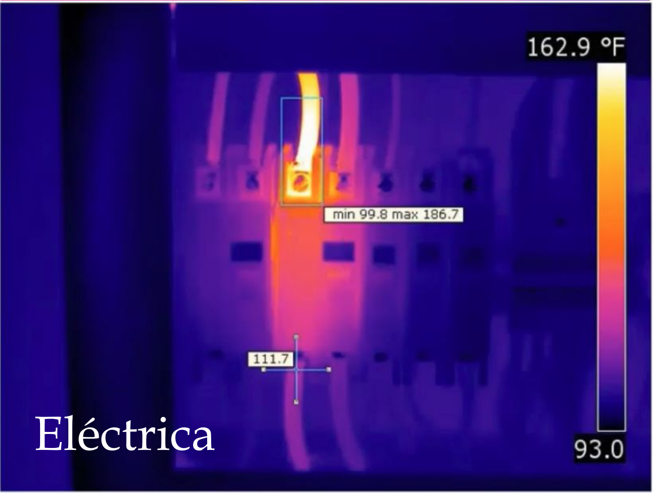


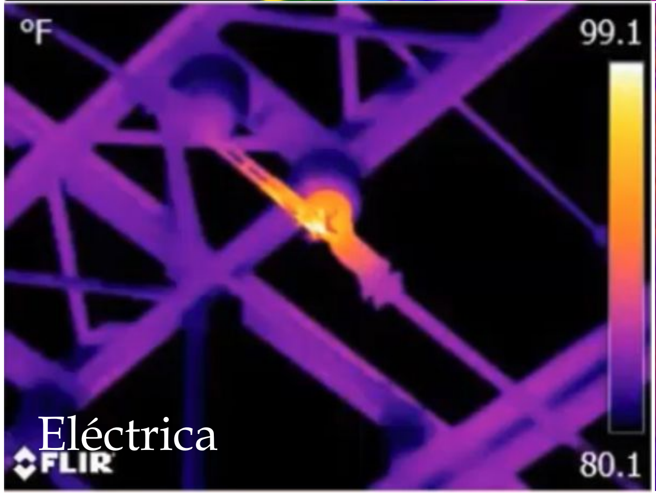
Aplicaciones



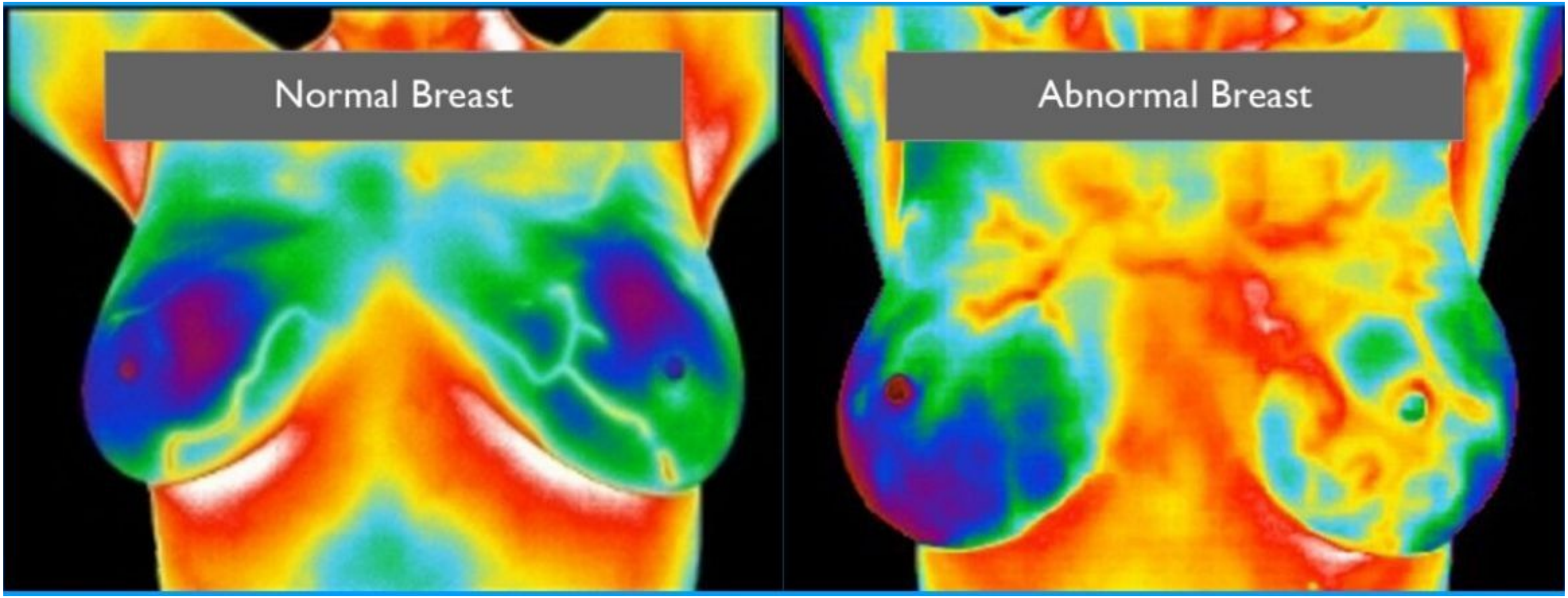






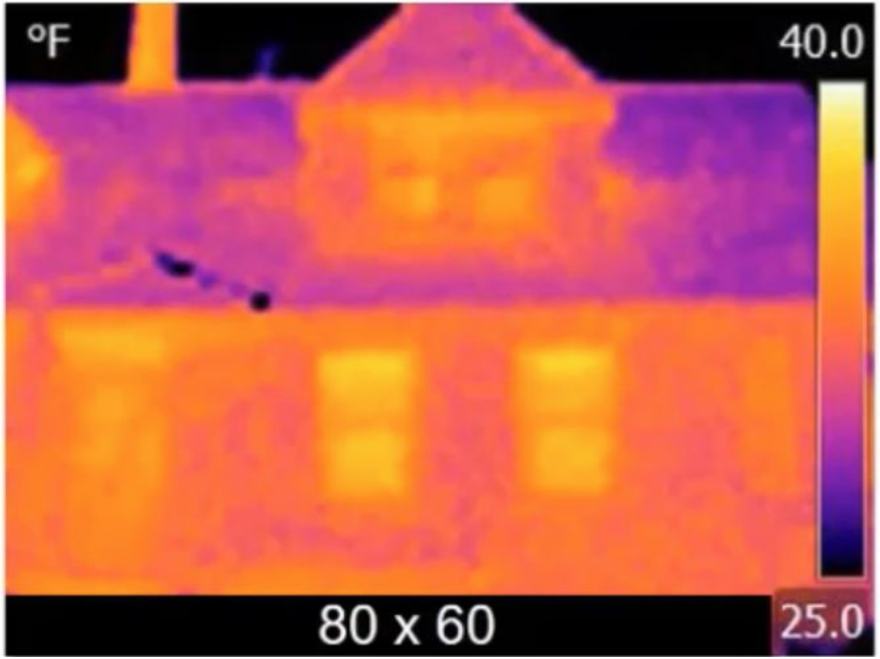


Aplicaciones en Salud



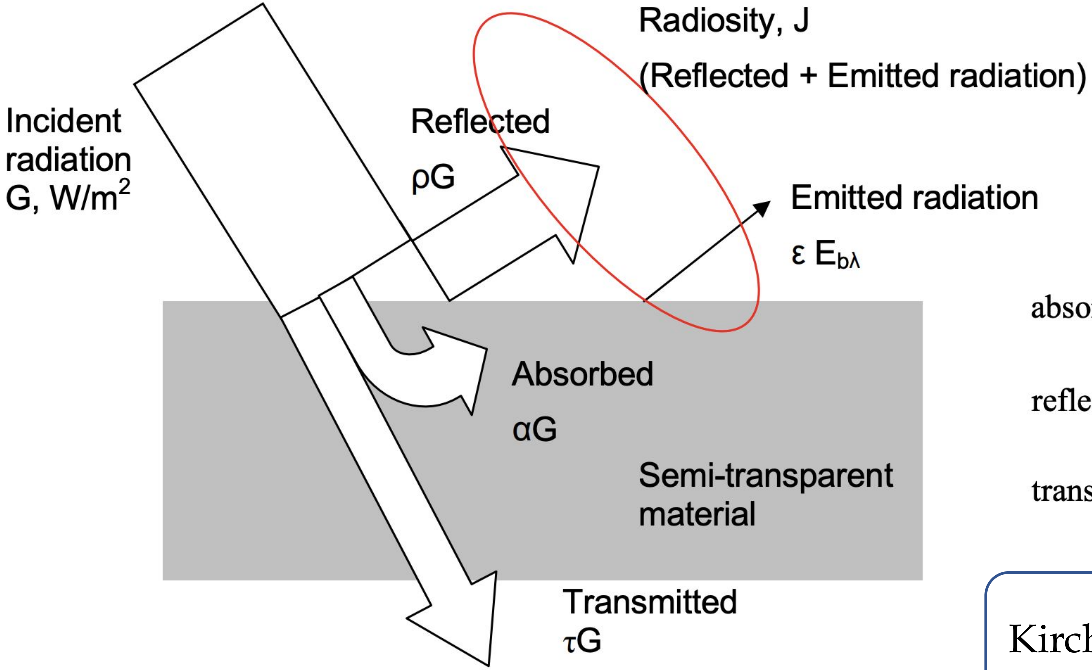

36.8ºC
36.7ºC
36.6ºC
38.3ºC
35.9ºC

Efecto de resolución



2. Luz y radiación

Radiation



By first law of thermodynamics (conservation of energy):

$$G_{abs} + G_{ref} + G_{tr} = G$$

$$\alpha + \rho + \tau = 1$$

absorptivity : $\alpha = \dfrac{\text{absorbed radiation}}{\text{incident radiation}} = \dfrac{G_{abs}}{G} \qquad 0 \le \alpha \le 1$

reflectivity : $\rho = \dfrac{\text{reflected radiation}}{\text{incident radiation}} = \dfrac{G_{ref}}{G} \qquad 0 \le \rho \le 1$

transmissivity : $\tau = \dfrac{\text{transmitted radiation}}{\text{incident radiation}} = \dfrac{G_{tr}}{G} \qquad 0 \le \tau \le 1$

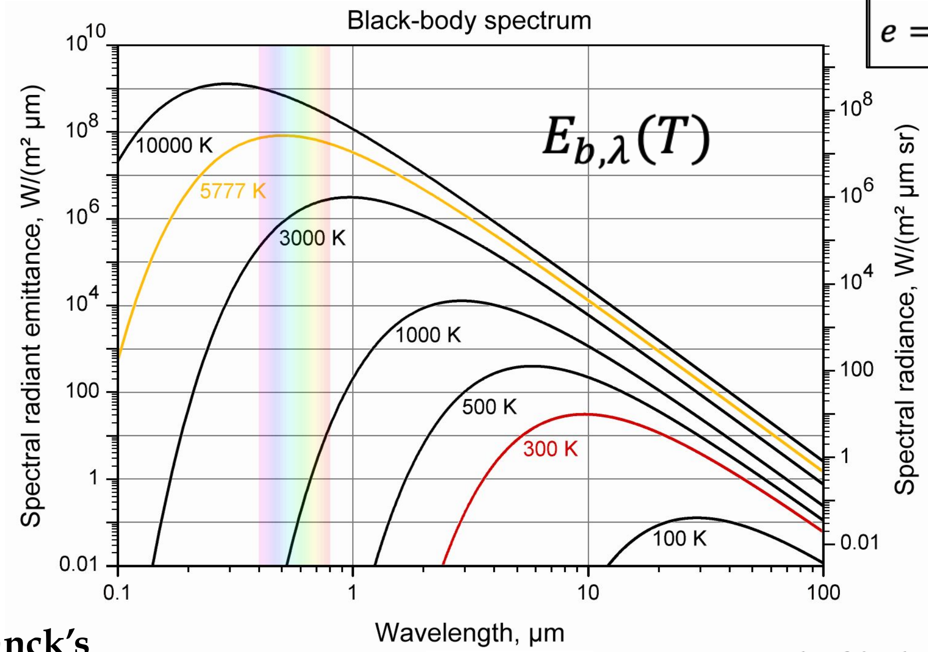
Kirchhoff's law: $\alpha = 1 - \tau$, Transparent ($\rho = 0$)
$\alpha = 1 - \rho$, Opaque ($\tau = 0$)

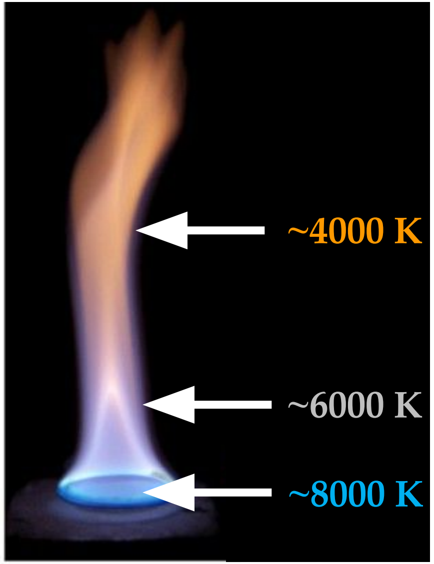
The radiation energy incident on a surface per unit area per unit time is called irradiation, G.

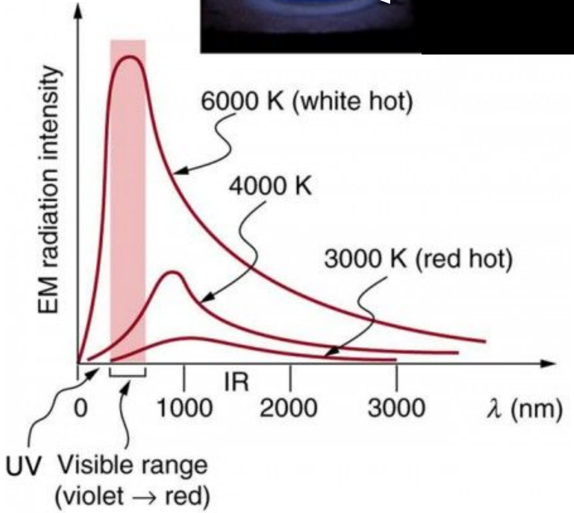
Blackbody radiation

- At a fix T and λ, no surface can emit more energy than a blackbody
- Einstein: “Energy of a photon is inversely proportional to its wavelength”

$$\boxed{e = h\nu = h\frac{c}{\lambda}}$$







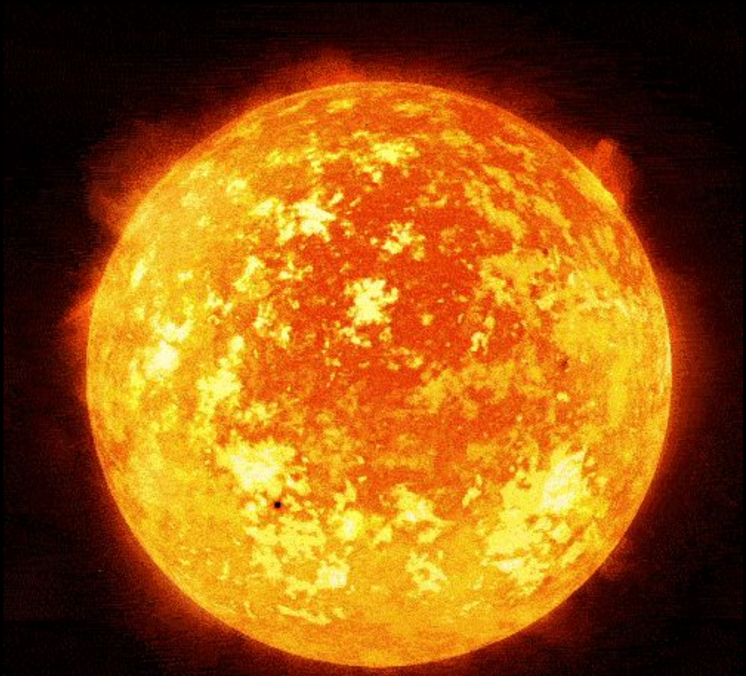
Planck's law:

$$E_{b,\lambda}(T) = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)} \quad \left(\frac{W}{m^2.\mu m}\right)$$

- c: Speed of light
- h: Planck's constant
- k: Boltzmann's constant

Incandescencia

Lava 700 - 1,200 °C

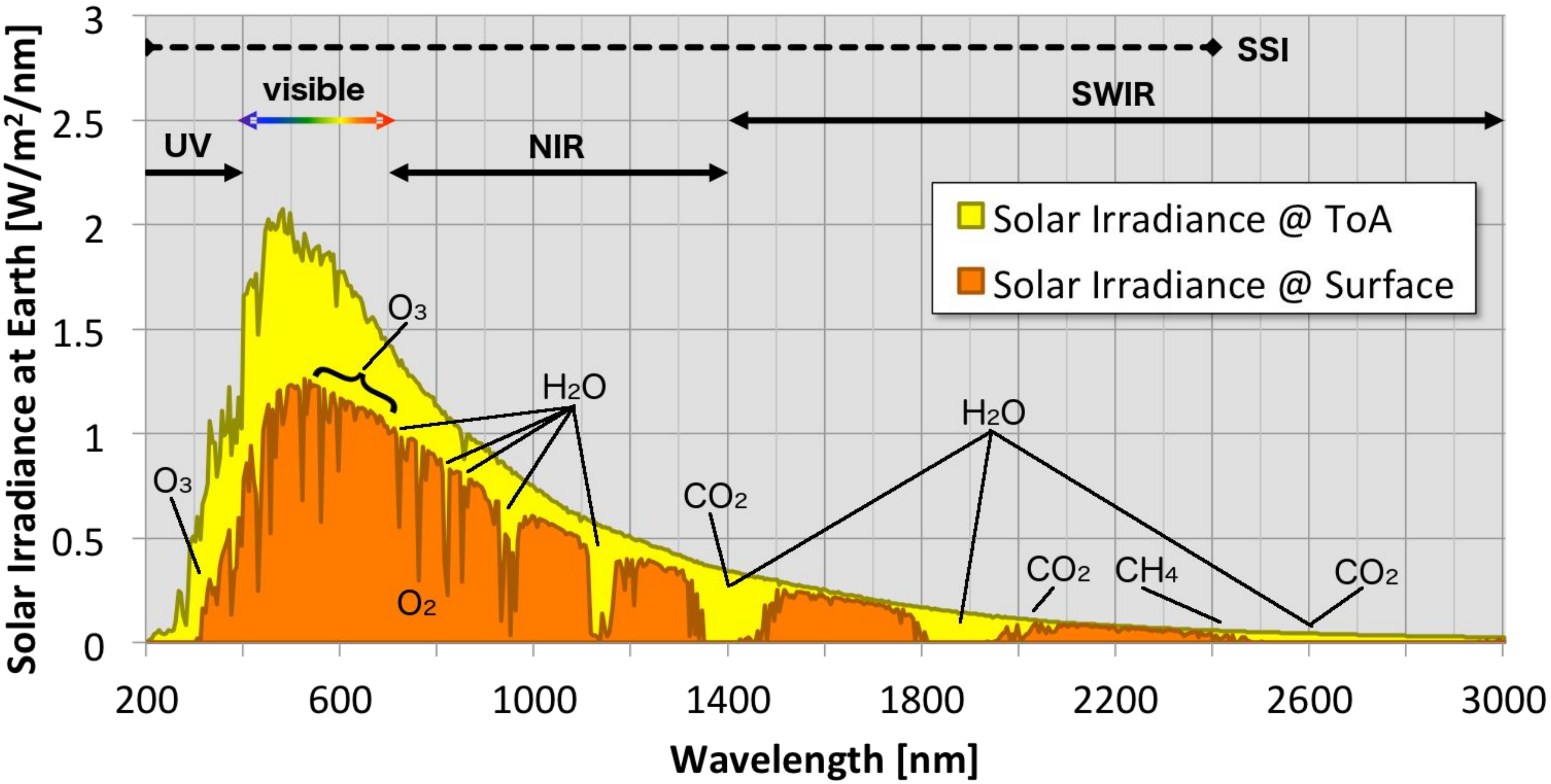


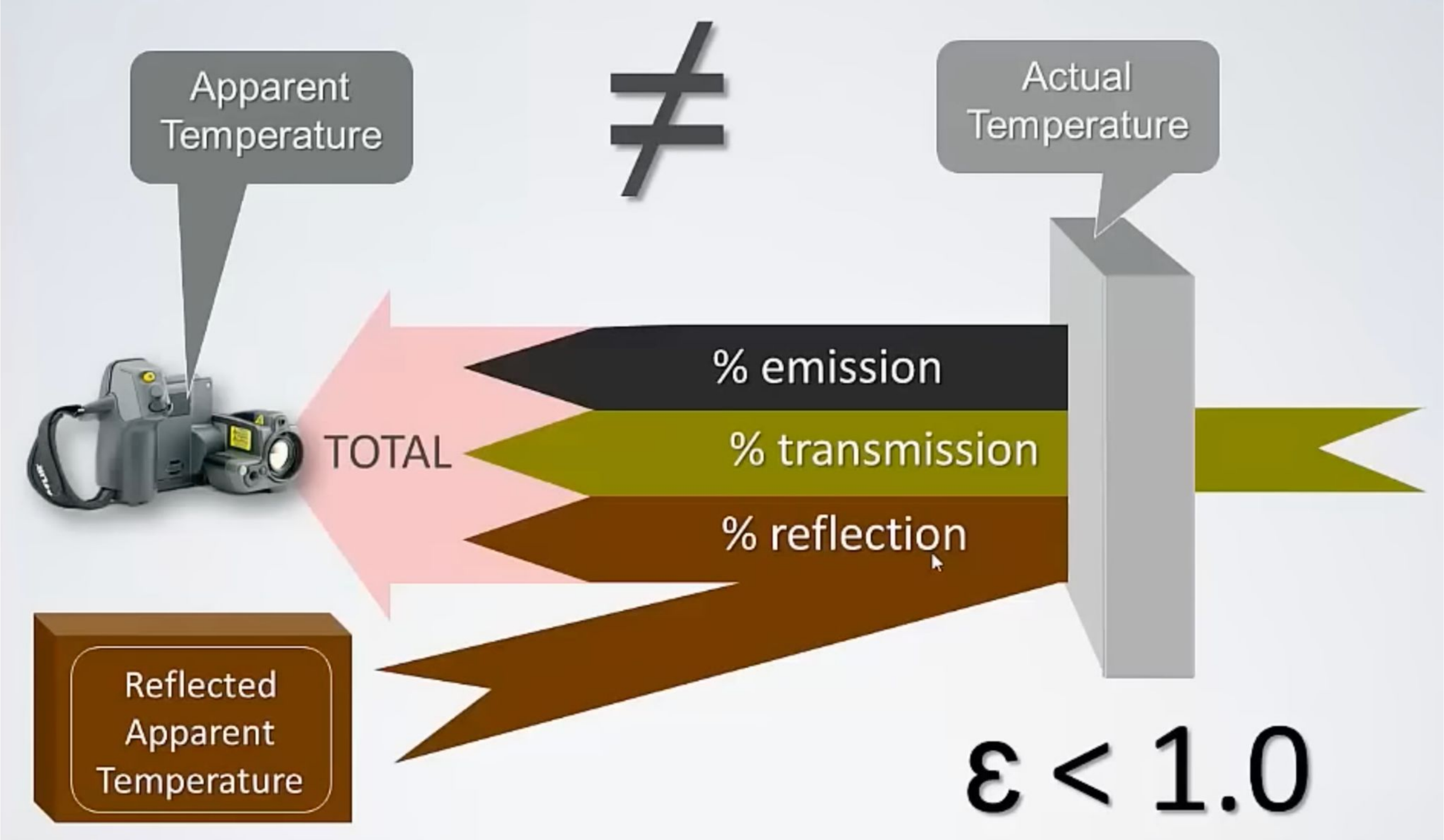
Superficie: 5600 °C; Centro: 15.000.000 °C

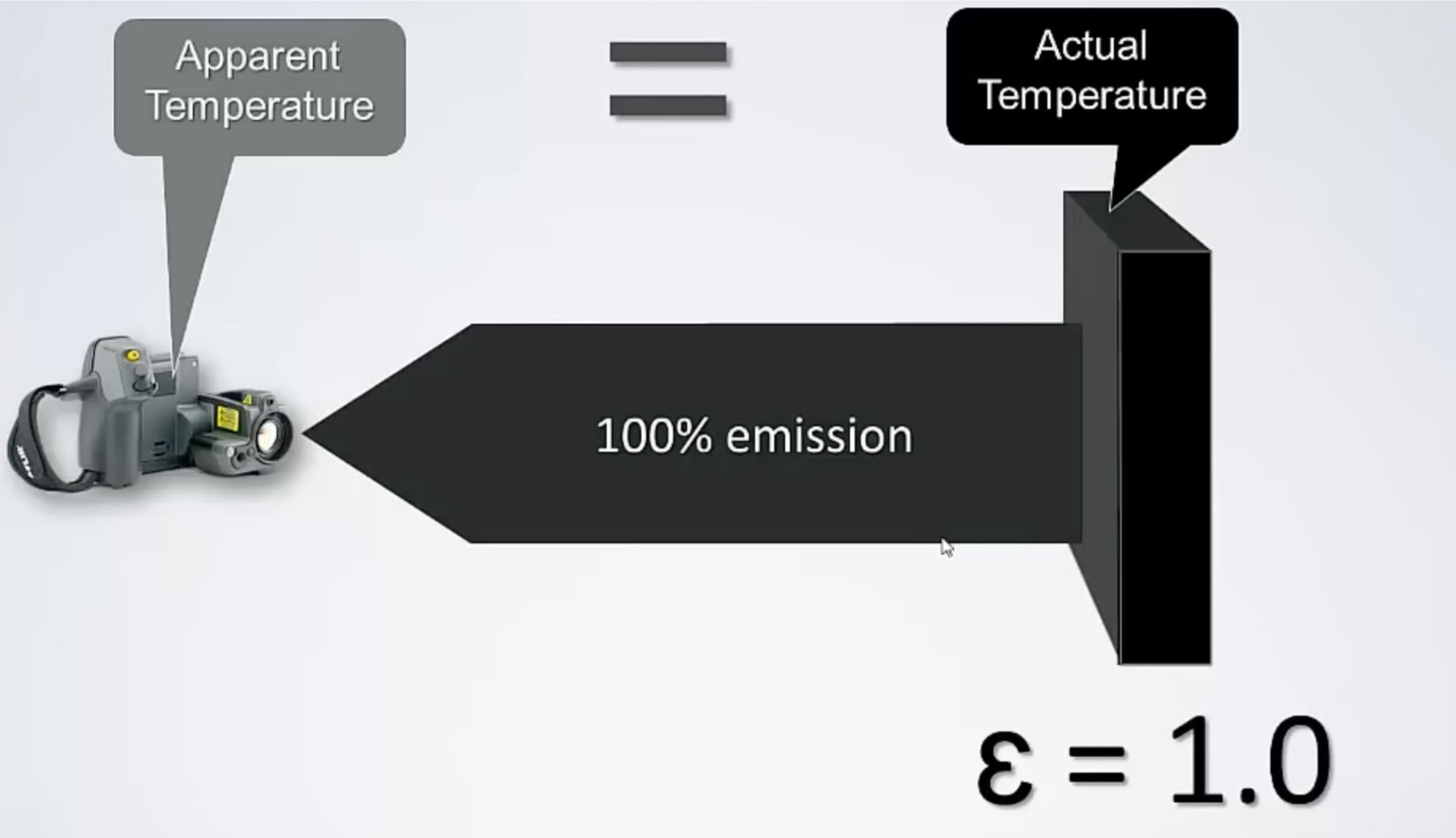
1500 to 20.000 °C

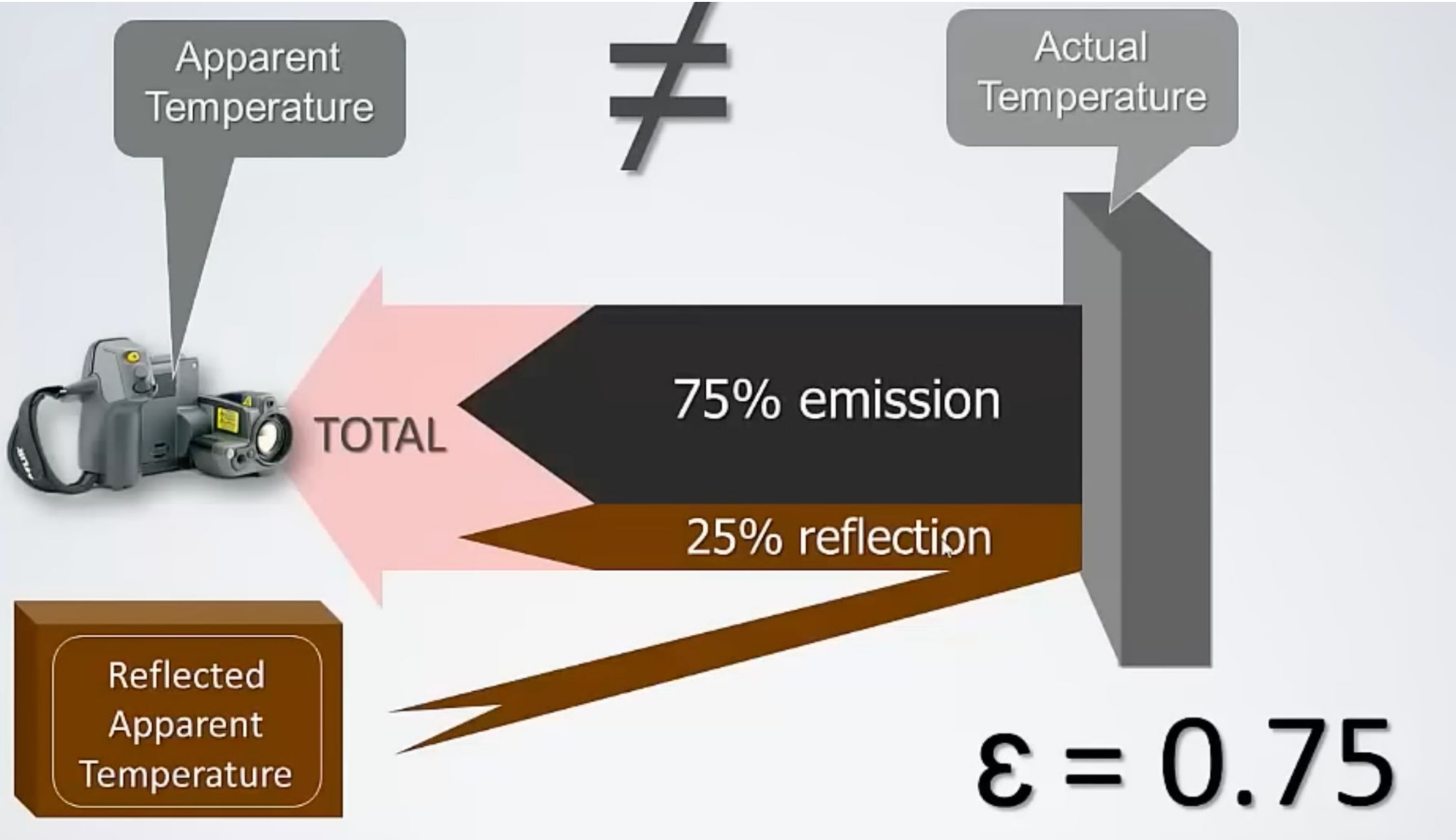
300 to 800 °C

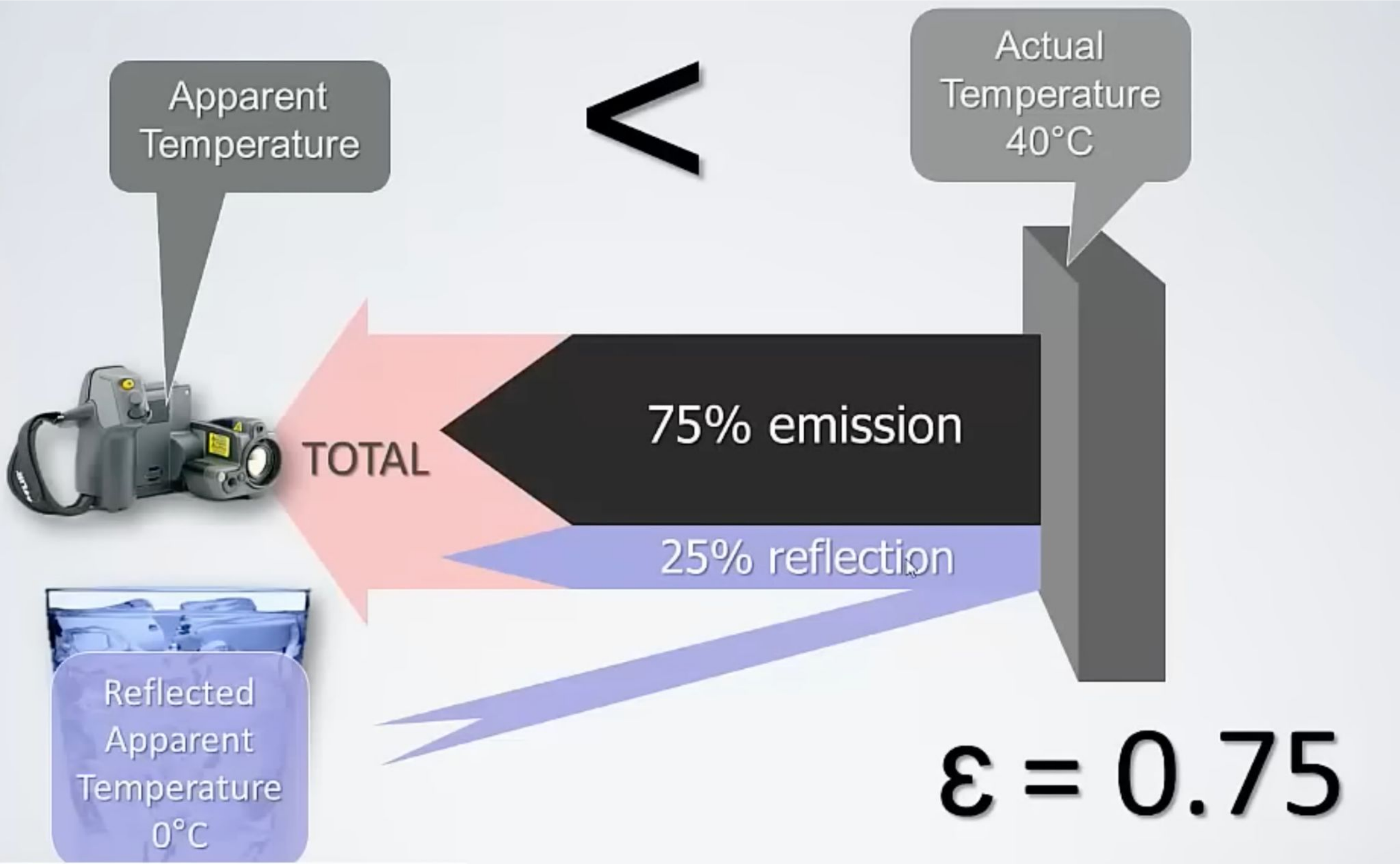
Irradiancia Solar

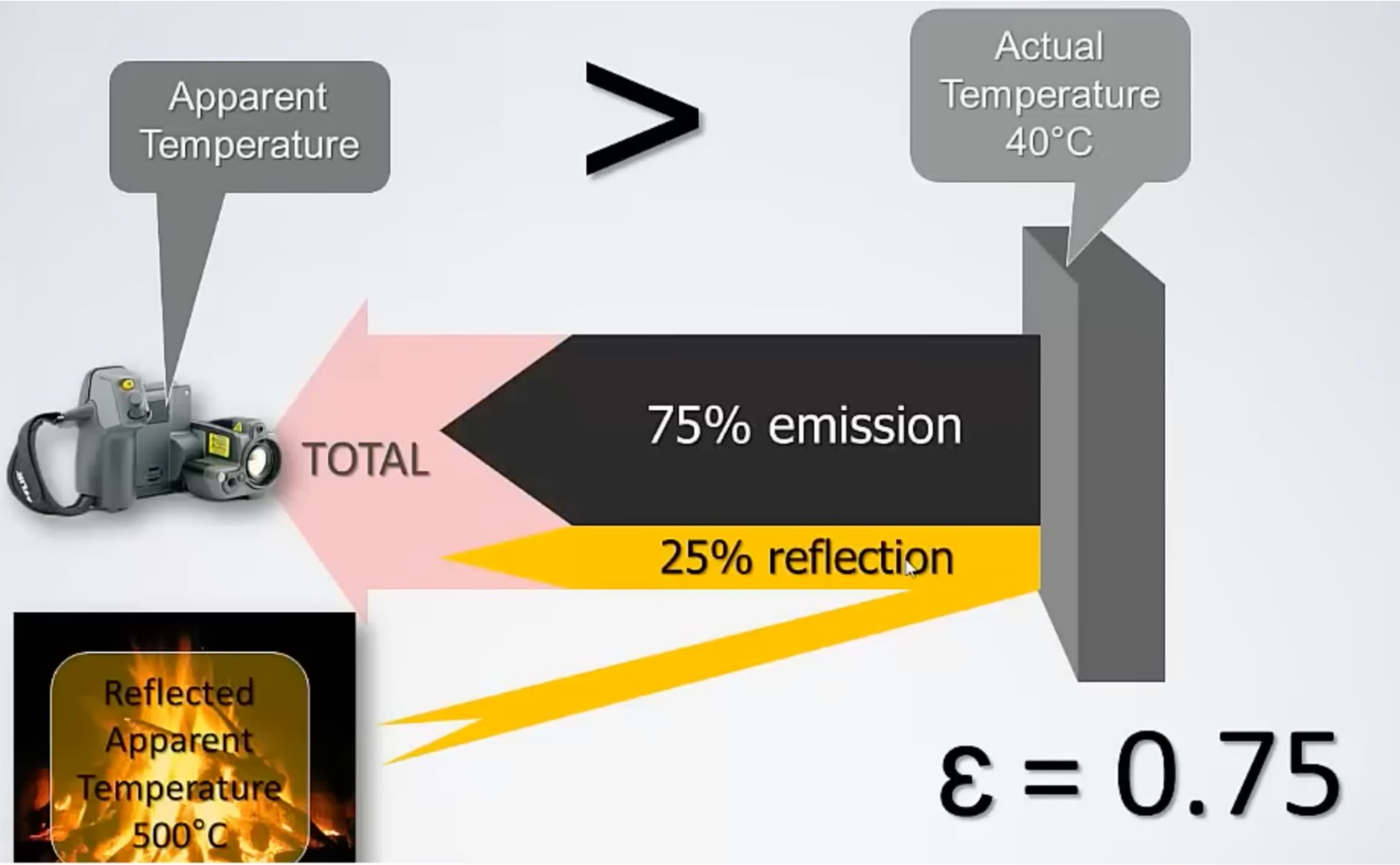



Apparent Temperature
≠
Actual Temperature
% emission
TOTAL
% transmission
% reflection
Reflected Apparent Temperature
ε < 1.0


Apparent Temperature
=
Actual Temperature
100% emission
ε = 1.0


Apparent Temperature
≠
Actual Temperature
TOTAL
75% emission
25% reflection
Reflected Apparent Temperature
ε = 0.75


Apparent Temperature
<
Actual Temperature 40°C
TOTAL
75% emission
25% reflection
Reflected Apparent Temperature 0°C
ε = 0.75


Apparent Temperature
>
Actual Temperature 40°C
TOTAL
75% emission
25% reflection
Reflected Apparent Temperature 500°C
ε = 0.75

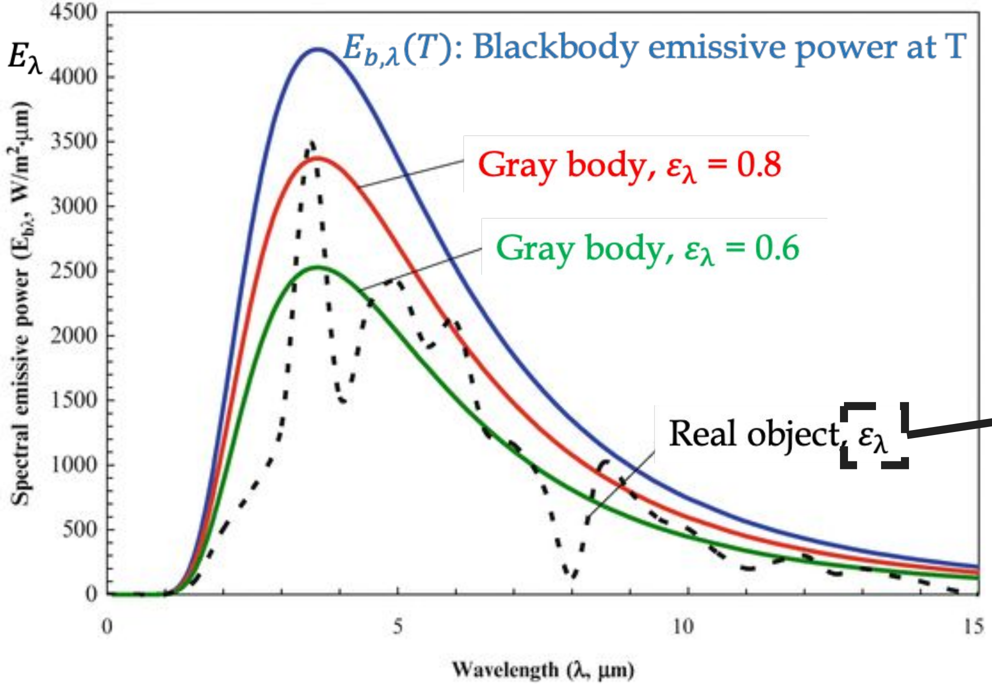
Emissivity de materiales comunes

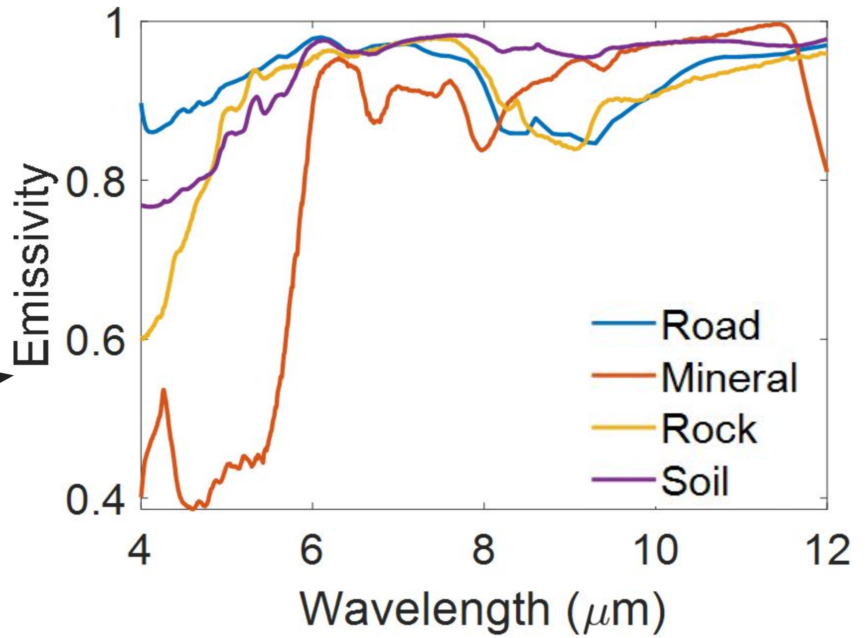
Metal	Emissivity	Non-metal	Emissivity
Bare aluminum	0.02–0.4	Concrete (rough)	0.93–0.96
Gold	0.02–0.37	Glass	0.76–0.94
Copper	0.02–0.74	Wood	0.8–0.95
Lead	0.06–0.63	Carbon	0.96
Brass	0.03–0.61	Human skin	0.98
Nickel	0.05–0.46	Paper	0.7–0.95
Steel	0.07–0.85	Plastic	0.8–0.95
Tin	0.04–0.08	Rubber	0.86–0.94
Silver	0.01–0.07	Water	0.67–0.96
Zinc	0.02–0.28	Sand	0.76–0.9

3. Imágenes Espectrales Térmicas

Emissivity depends on λ

$$E_\lambda(T) = \varepsilon_\lambda E_{b,\lambda}(T)$$

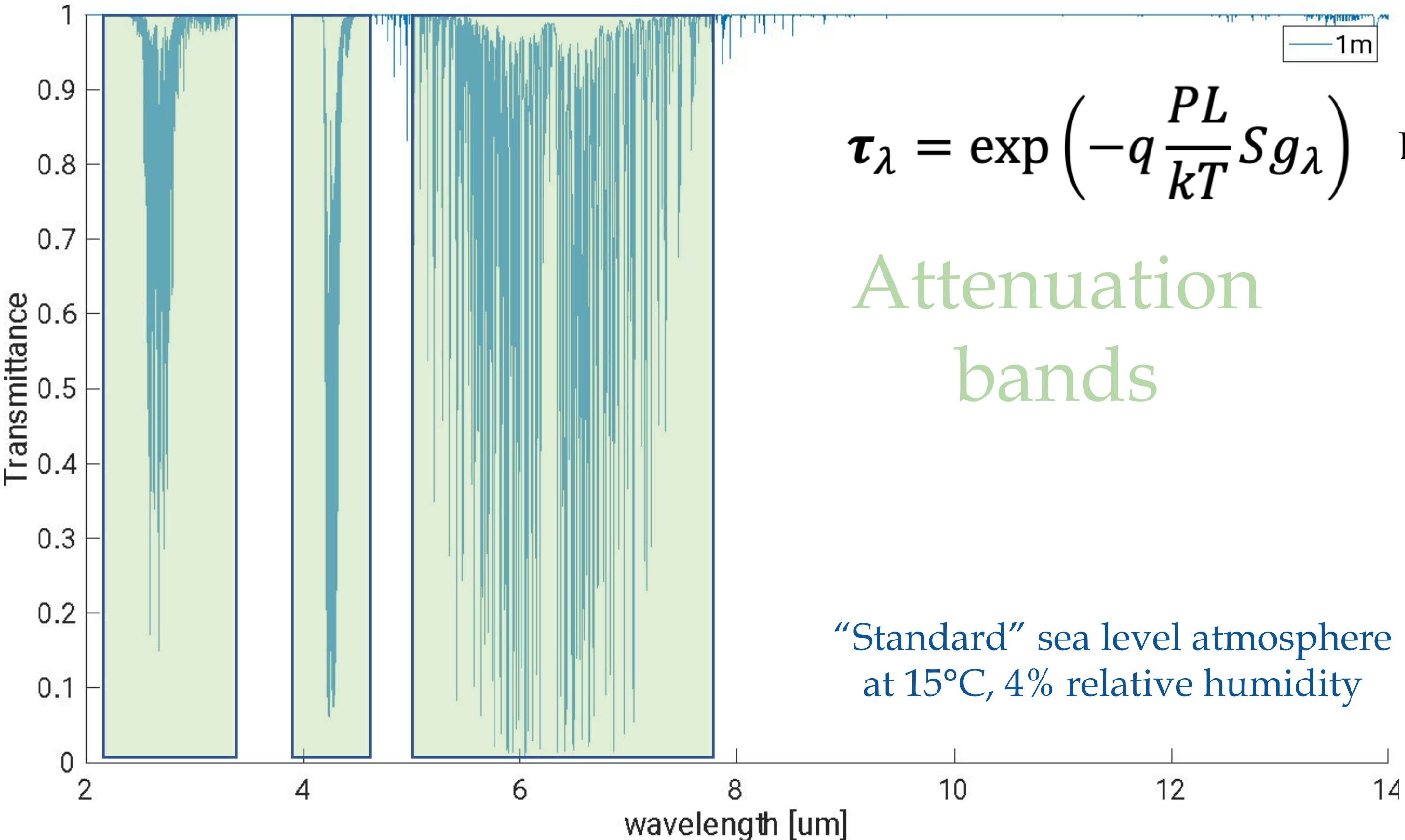




HITRANonline

Atmospheric transmittance

τ_λ



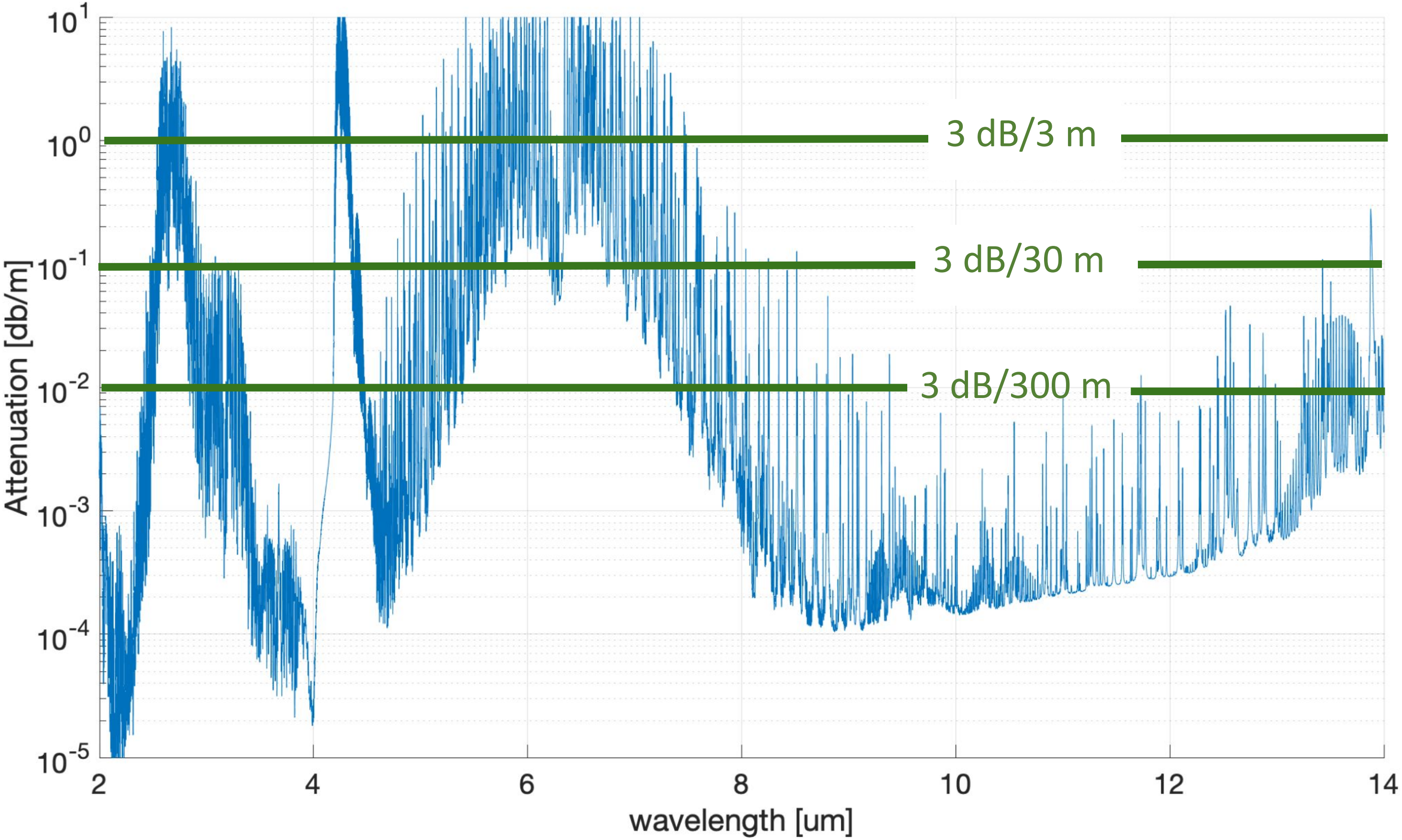
$$\tau_\lambda = \exp\left(-q\frac{PL}{kT}Sg_\lambda\right)$$

Beer-Lambert

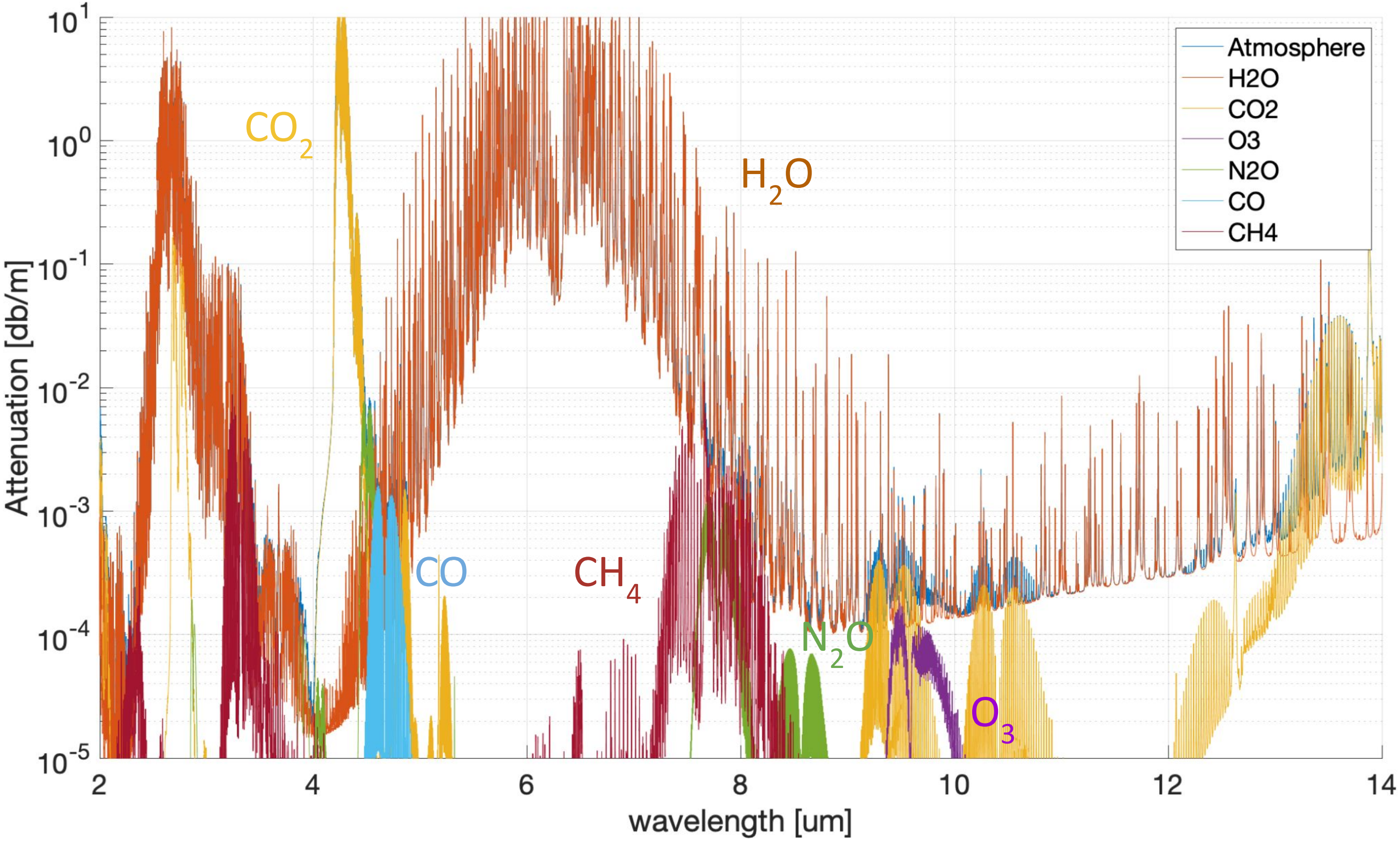
Attenuation bands

"Standard" sea level atmosphere at 15°C, 4% relative humidity

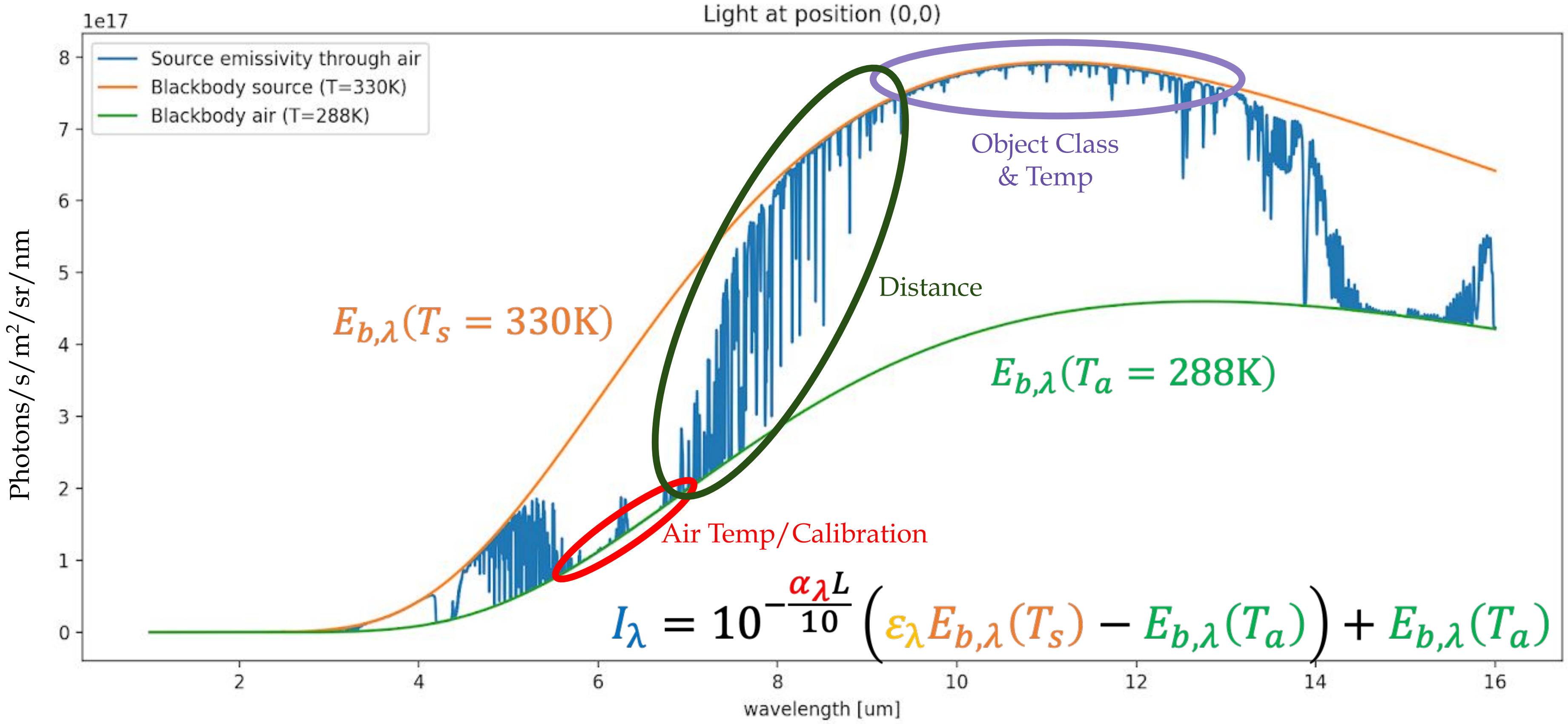
Atmospheric attenuation



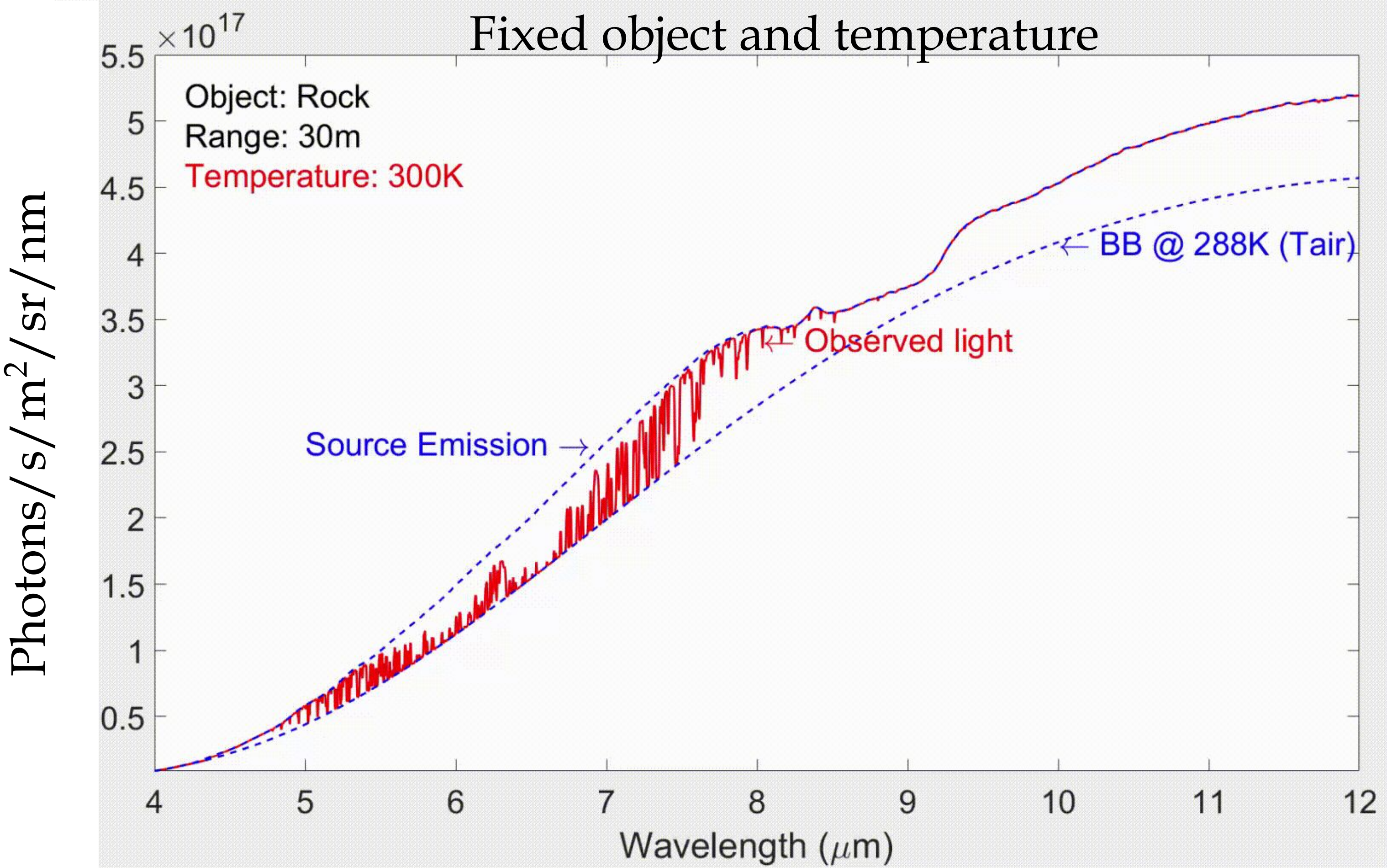
Atmospheric attenuation by gas composition



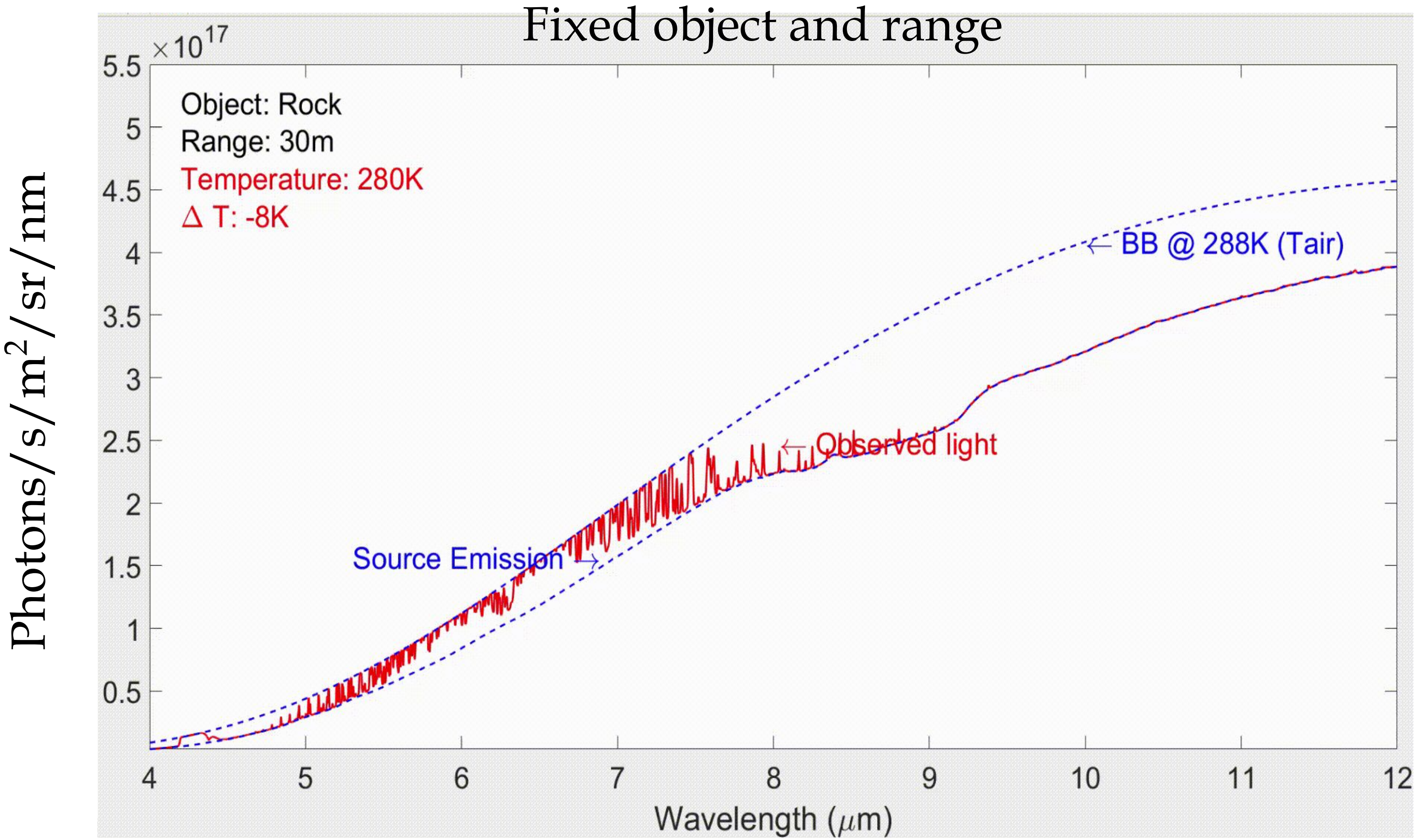
Emissivity through air



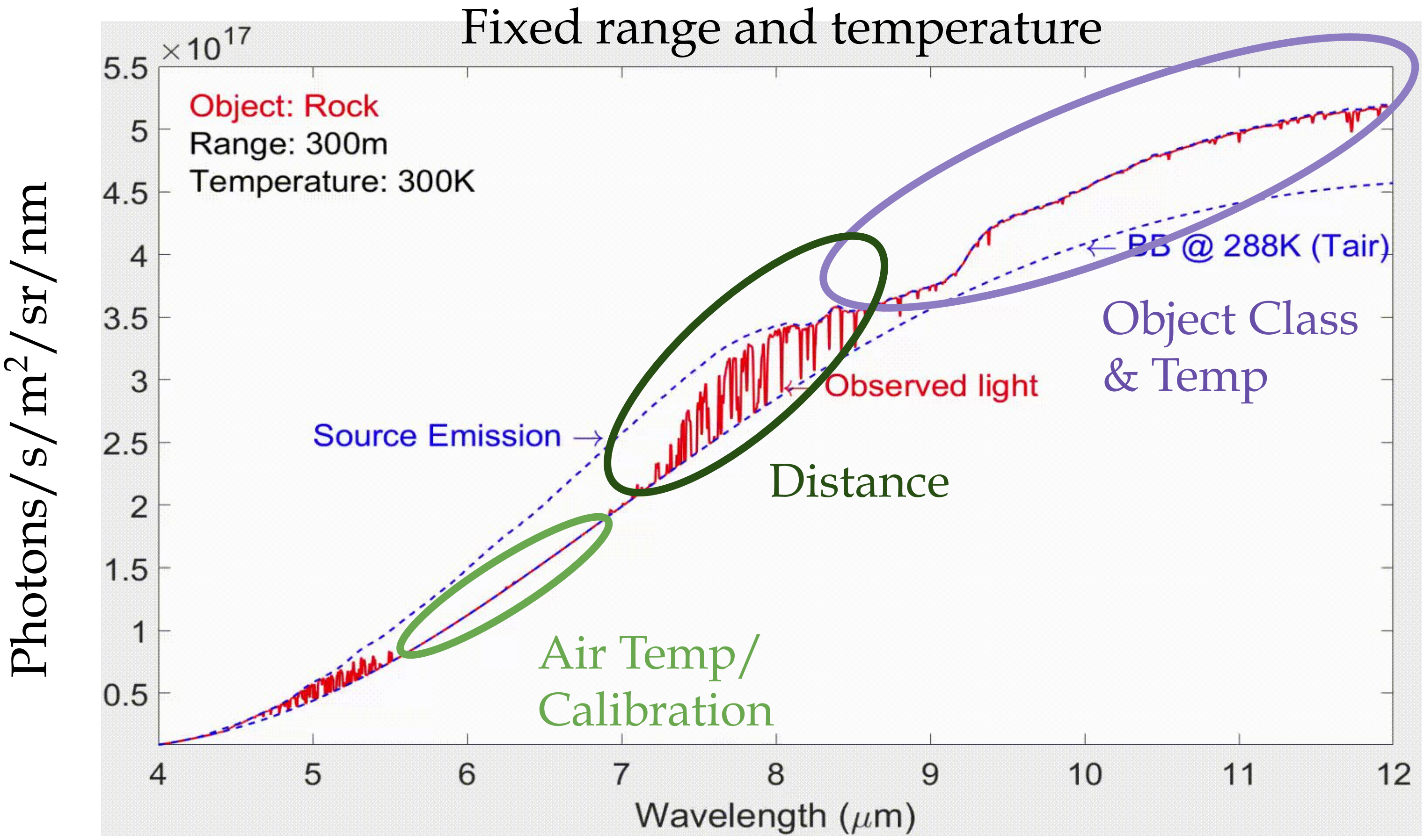
Range variation



Temperature variation



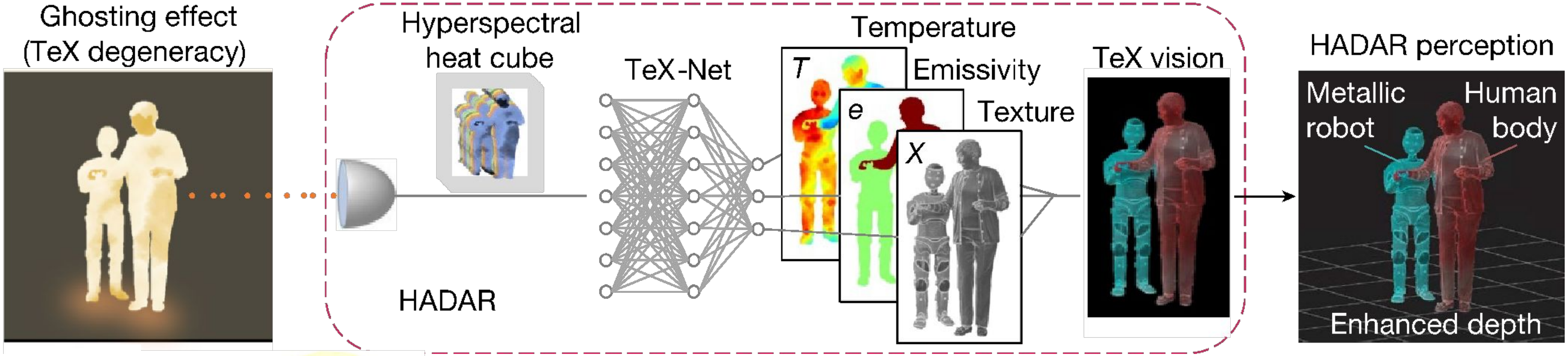
Emissivity variation



4. Thermal & CV

https://www.nature.com/articles/s41586-023-06174-6

TeX Vision: Temperature, emissivity, teXture




On (textureless)

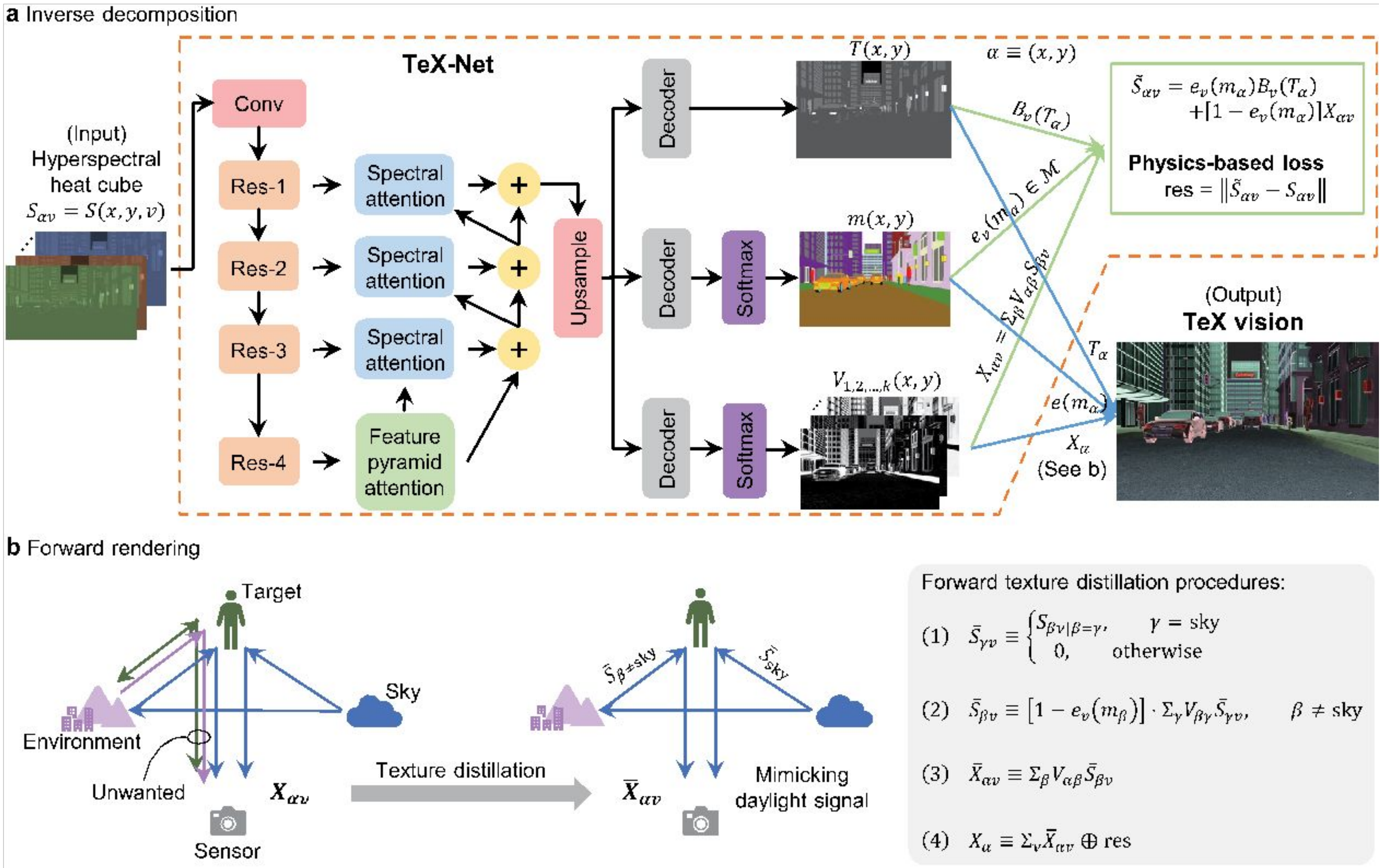

Off (textured)

$$I_\lambda = 10^{-\frac{\alpha_\lambda L}{10}}\left(\varepsilon_\lambda E_{b,\lambda}(T_s) - E_{b,\lambda}(T_a)\right) + E_{b,\lambda}(T_a)$$

$$I_\lambda = 10^{-\frac{\alpha_\lambda L}{10}}\left(\varepsilon_\lambda E_{b,\lambda}(T_s)\right) + \left(1 - 10^{-\frac{\alpha_\lambda L}{10}}\right) E_{b,\lambda}(T_a)$$

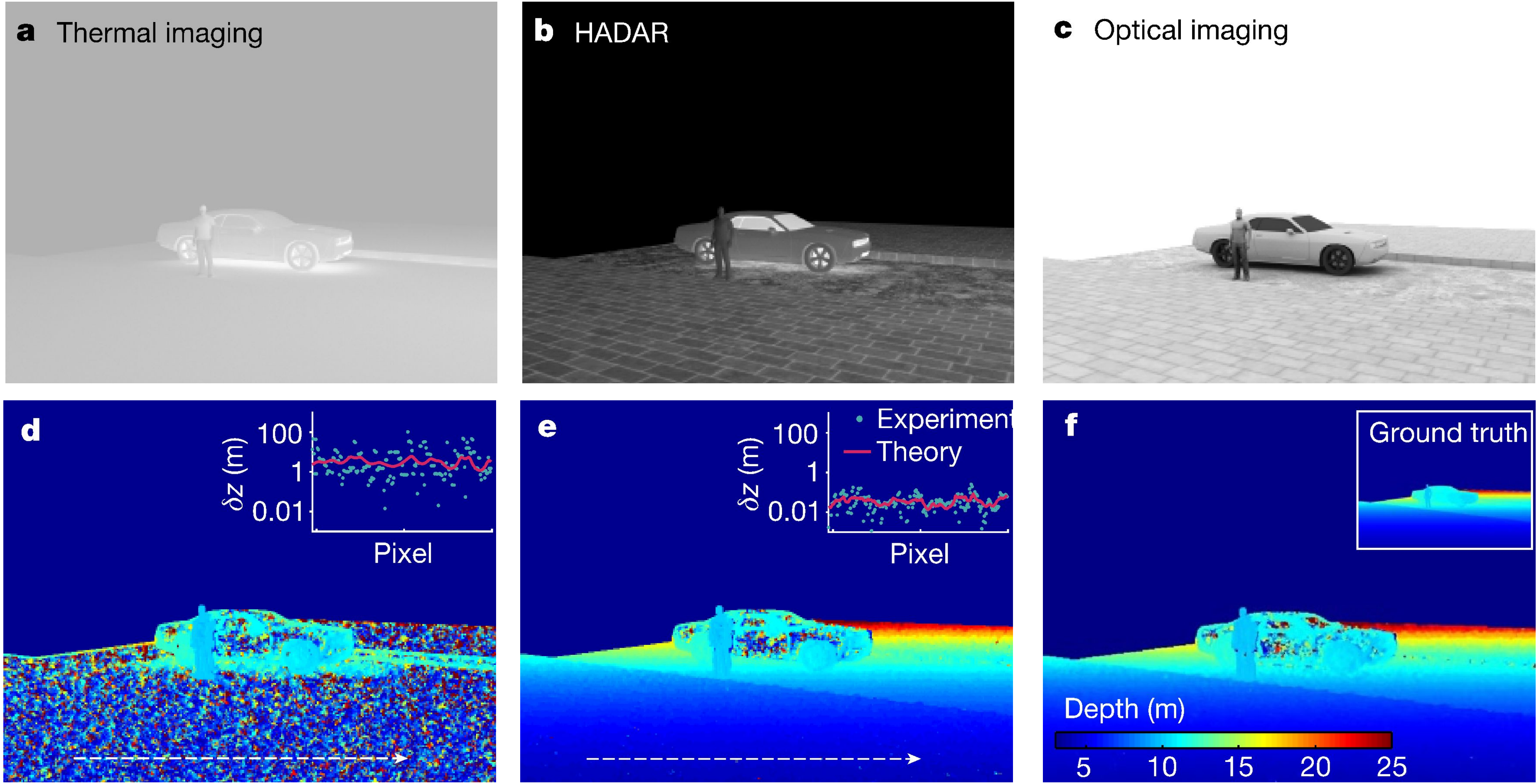
$$S_{\alpha\nu} = e_{\alpha\nu} B_\nu(T_\alpha) + [1 - e_{\alpha\nu}] X_{\alpha\nu}$$

TeX-Net

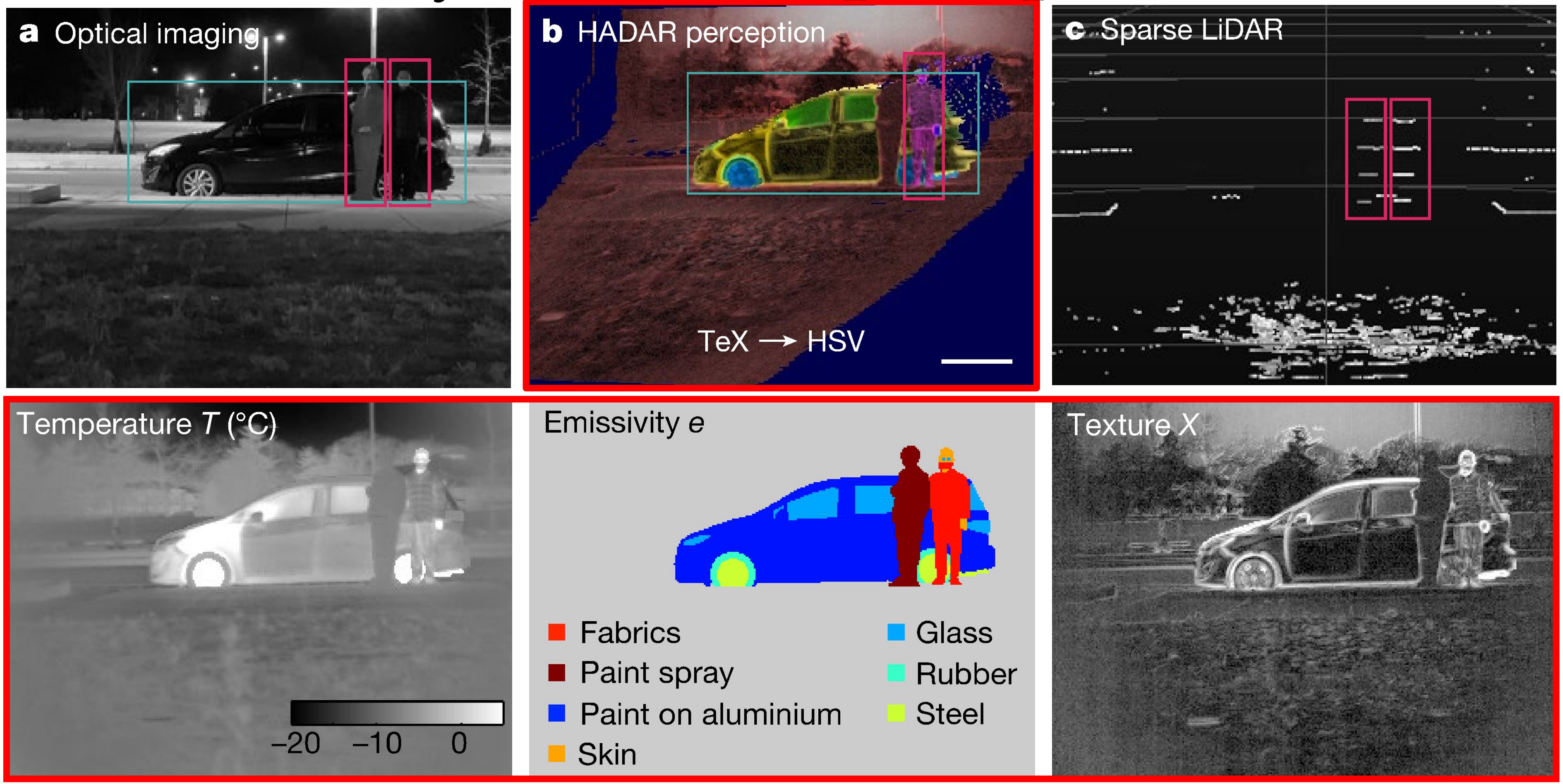


a Inverse decomposition
TeX-Net
(Input)
Hyperspectral
heat cube
$S_{\alpha v} = S(x, y, v)$
Conv
Res-1
Res-2
Res-3
Res-4
Spectral attention
Spectral attention
Spectral attention
Feature pyramid attention
Upsample
Decoder
Decoder
Decoder
Softmax
Softmax
$T(x,y)$
$m(x,y)$
$V_{1,2,\ldots,k}(x,y)$
$\alpha \equiv (x,y)$
$B_v(T_\alpha)$
$e_v(m_\alpha) \in \mathcal{M}$
$X_{\alpha v} = \Sigma_\beta V_{\alpha\beta} S_{\beta v}$
$\tilde{S}_{\alpha v} = e_v(m_\alpha) B_v(T_\alpha) + [1 - e_v(m_\alpha)] X_{\alpha v}$
Physics-based loss
$\text{res} = \|\tilde{S}_{\alpha v} - S_{\alpha v}\|$
T_α
$e(m_\alpha)$
X_α
(See b)
(Output)
TeX vision
b Forward rendering
Target
Sky
Environment
Unwanted
Sensor
$X_{\alpha v}$
Texture distillation
$\bar{S}_{\beta \neq \text{sky}}$
$\bar{S}_{\text{sky}}$
$\bar{X}_{\alpha v}$
Mimicking daylight signal
Forward texture distillation procedures:
(1) $\bar{S}_{\gamma v} \equiv \begin{cases} S_{\beta v|\beta=\gamma}, & \gamma = \text{sky} \\ 0, & \text{otherwise} \end{cases}$
(2) $\bar{S}_{\beta v} \equiv [1 - e_v(m_\beta)] \cdot \Sigma_\gamma V_{\beta\gamma} \bar{S}_{\gamma v}, \quad \beta \neq \text{sky}$
(3) $\bar{X}_{\alpha v} \equiv \Sigma_\beta V_{\alpha\beta} \bar{S}_{\beta v}$
(4) $X_\alpha \equiv \Sigma_v \bar{X}_{\alpha v} \oplus \text{res}$

HADAR: Fundamental limits in **ranging**



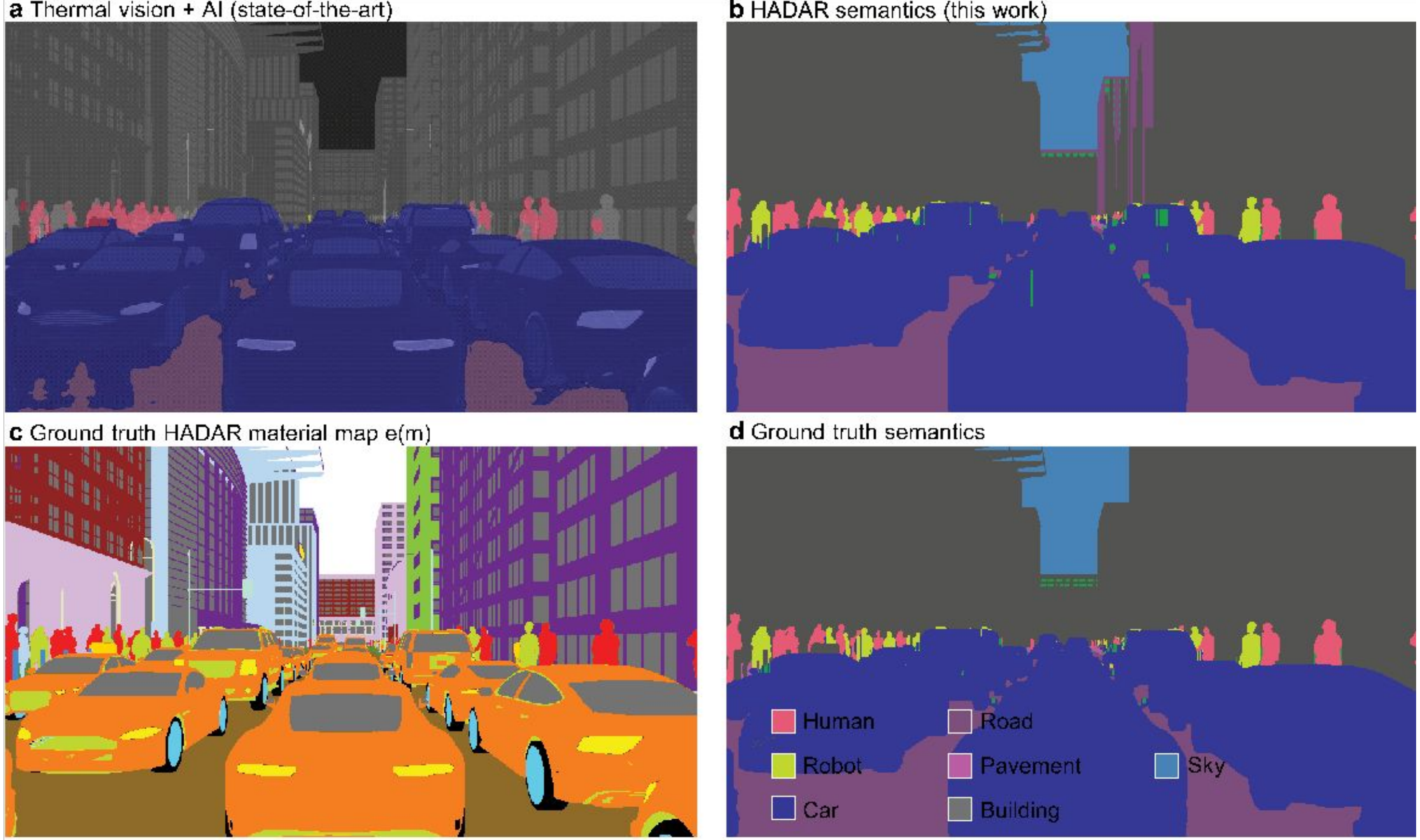
HADAR: Physics-driven **perception**



Thermal Semantic Segment.

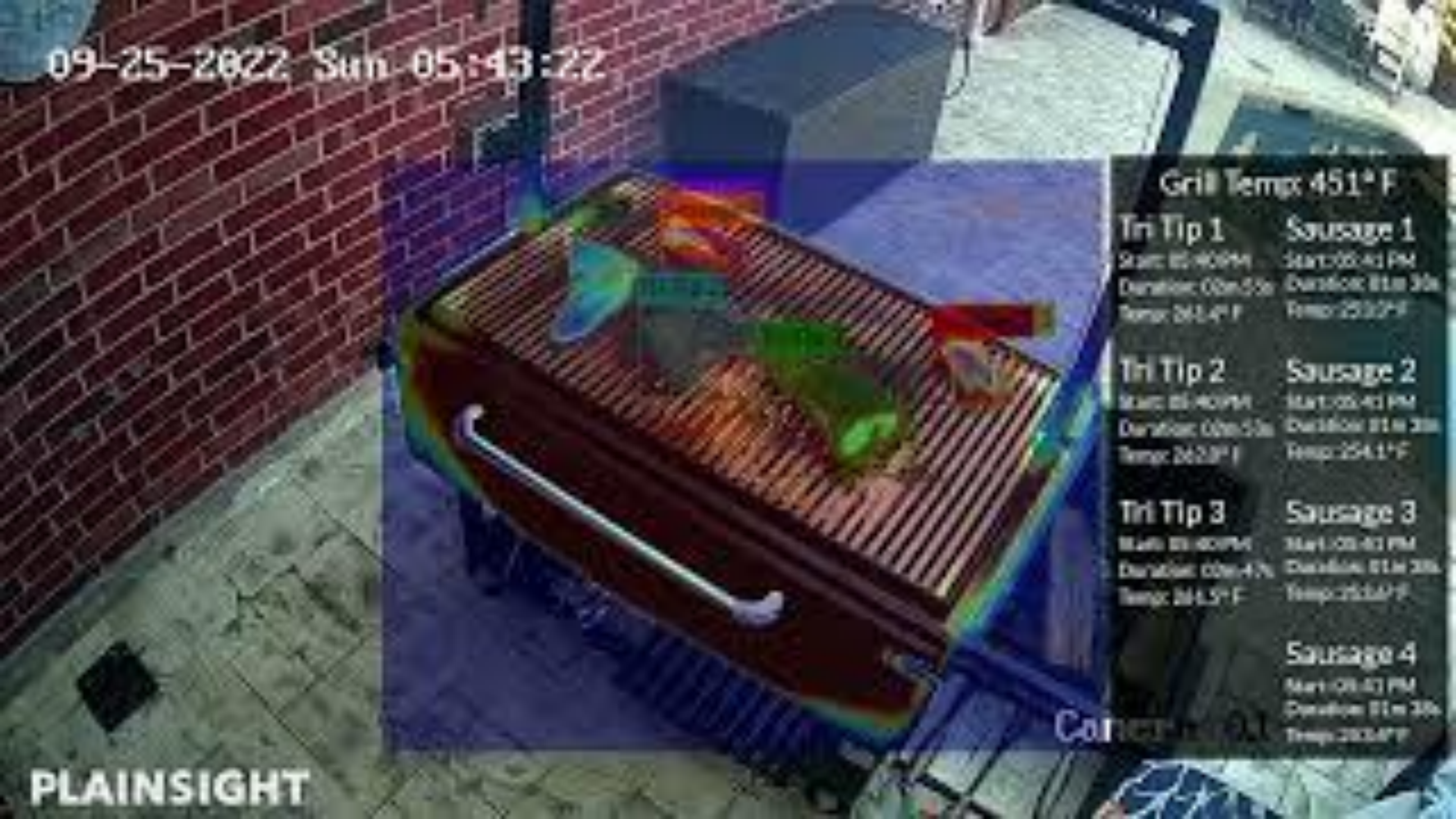
(DANet)

Fu, J. et al. in *CVPR* 3146–3154, 2019.



mIoU %	Human	Robot	Car	Road	Pavement	Building	Sky
Thermal vision + AI	33	0	90	67	25	69	16
TeX vision + non-AI	**94**	**84**	**98**	**92**	**87**	**84**	**90**

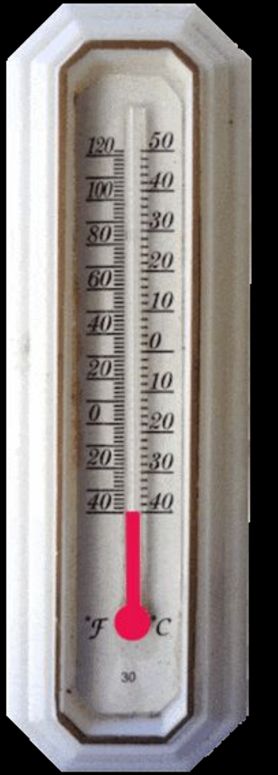
mIoU: pixelwise mean intersection over union.


09-25-2022 Sun 05:43:22
Grill Temp: 451° F
Tri Tip 1
Sausage 1
Tri Tip 2
Sausage 2
Tri Tip 3
Sausage 3
Sausage 4
PLAINSIGHT

Navigation

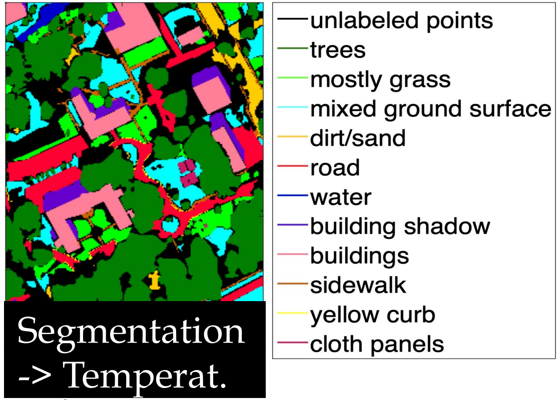

vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
person
alwaysAI

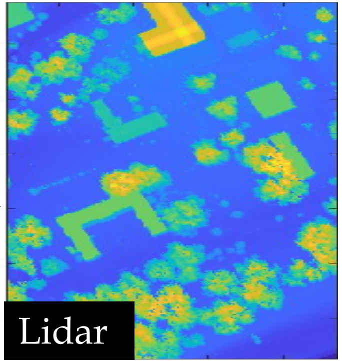
5. Hands-on: Thermal Imaging

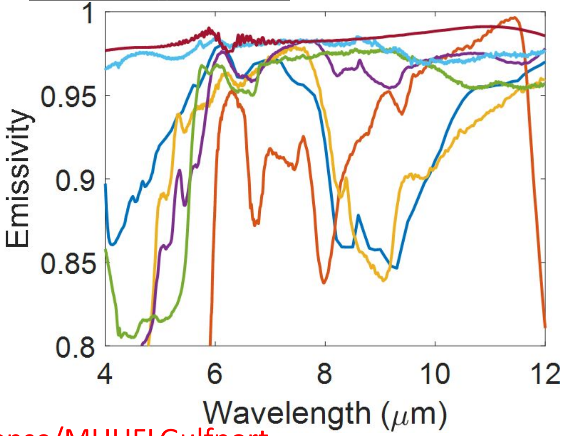


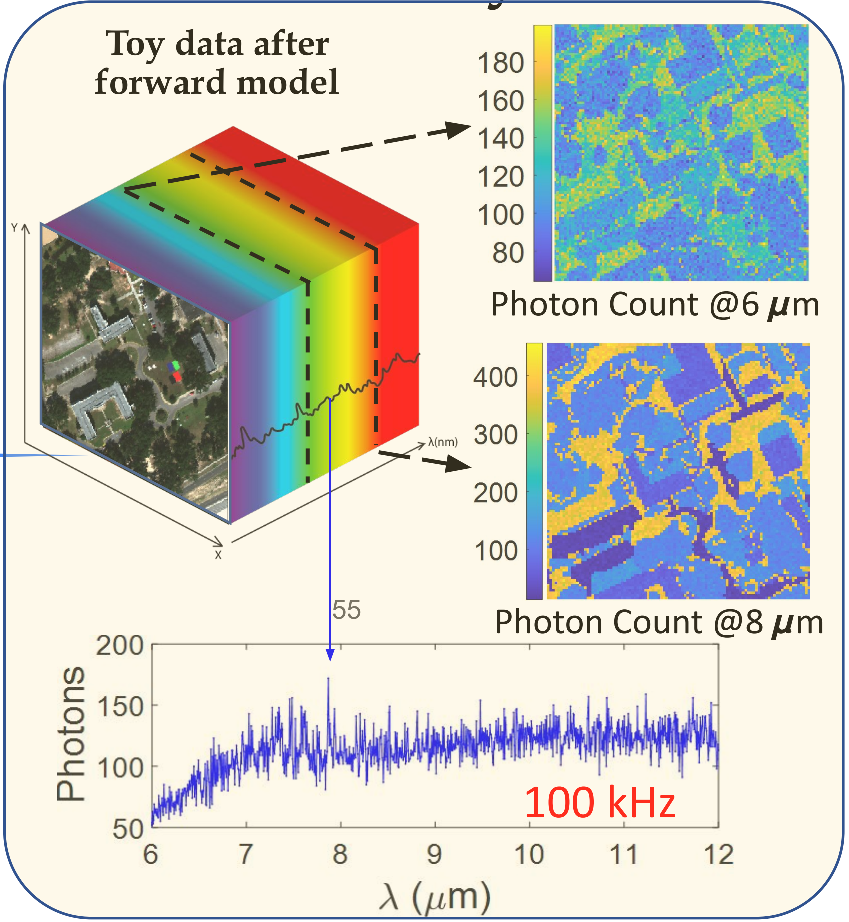
python + colab

Computational image formation and analysis



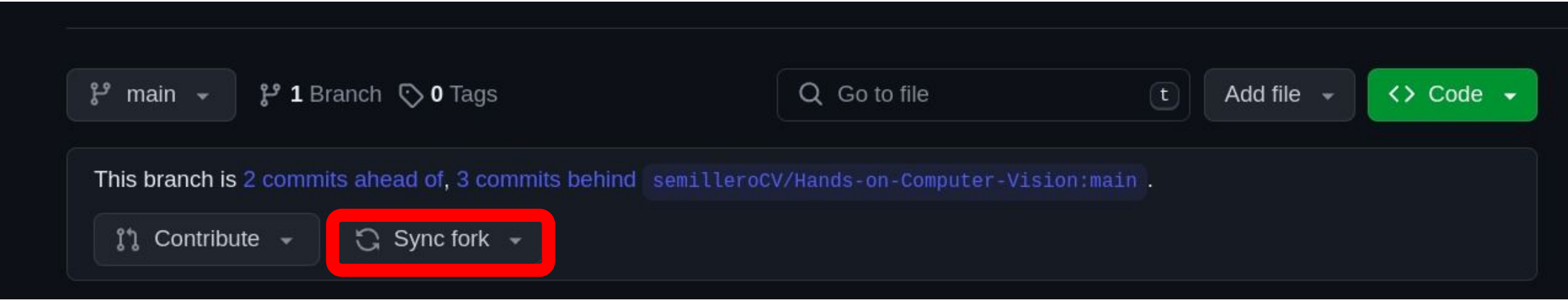




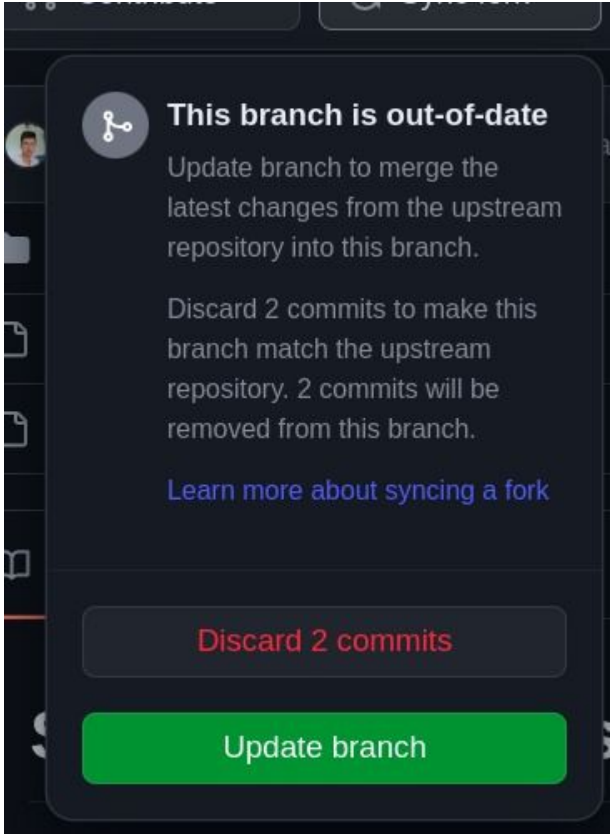


https://github.com/GatorSense/MUUFLGulfport

Actualicemos el repositorio!



Actualicemos el repositorio!



Actualicemos el repositorio!