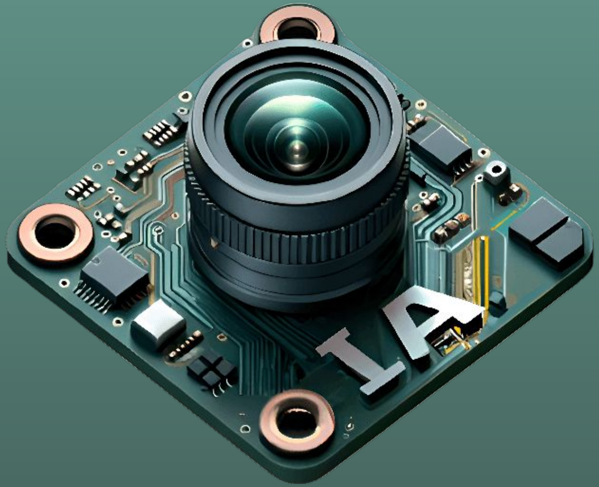
Universidad Industrial de Santander



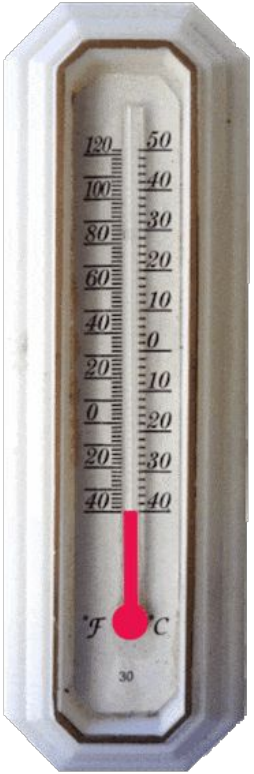
Semillero de Investigación
“Hands - on”
Computer Vision

SESIÓN 8: IMÁGENES TÉRMICAS

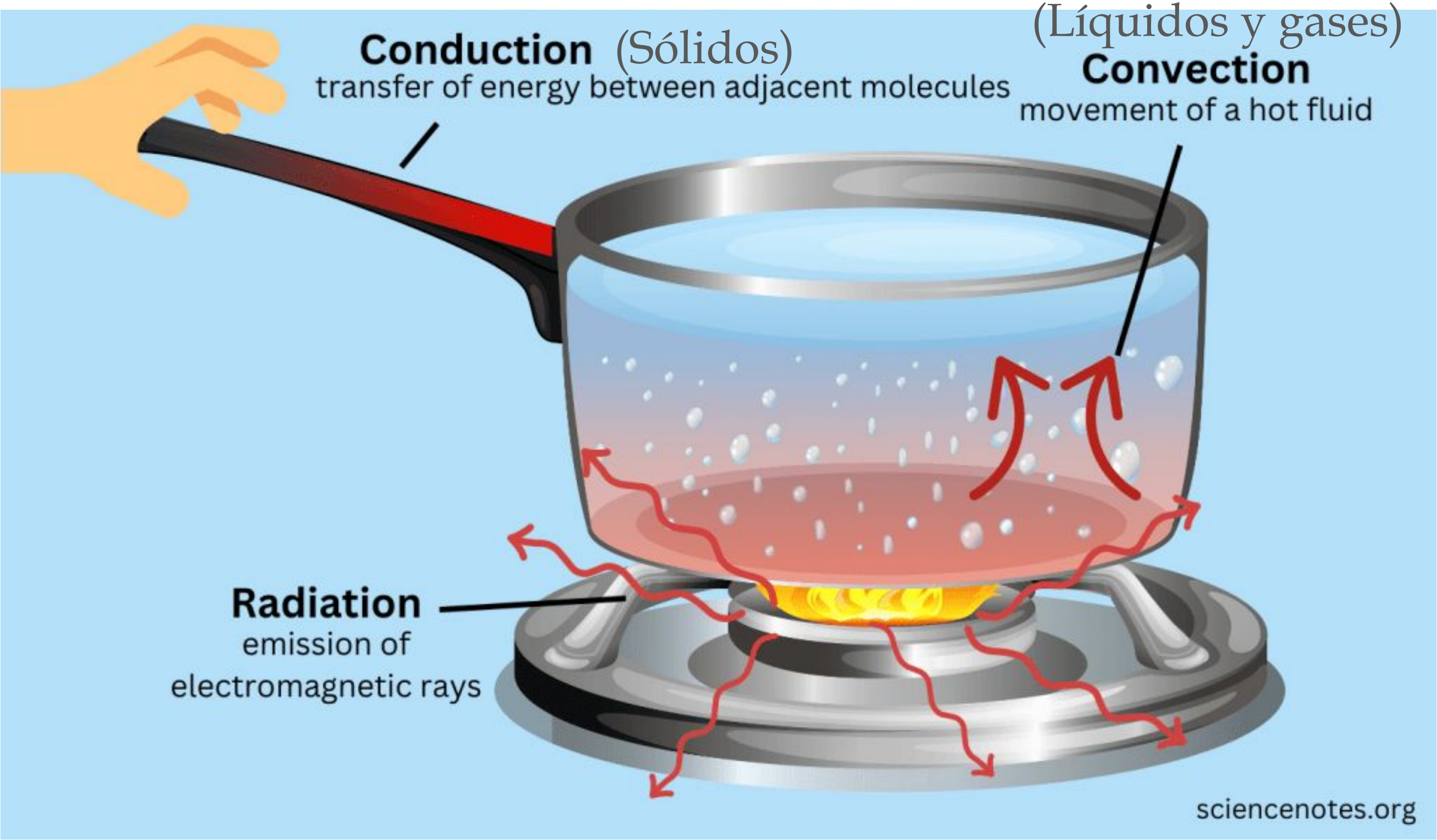
Contenidos

1. Imágenes térmicas y aplicaciones
2. Luz y radiación
    a. Ley de Kirchhoff
    b. Radiación de cuerpo negro (Planck)
    c. Emisividad y atenuación
3. Imágenes espectrales térmicas
4. Sensores infrarrojos
5. Thermal & CV
6. Hands-on Thermal Imaging

¿Cómo podemos medir la temperatura?



Transferencia de calor



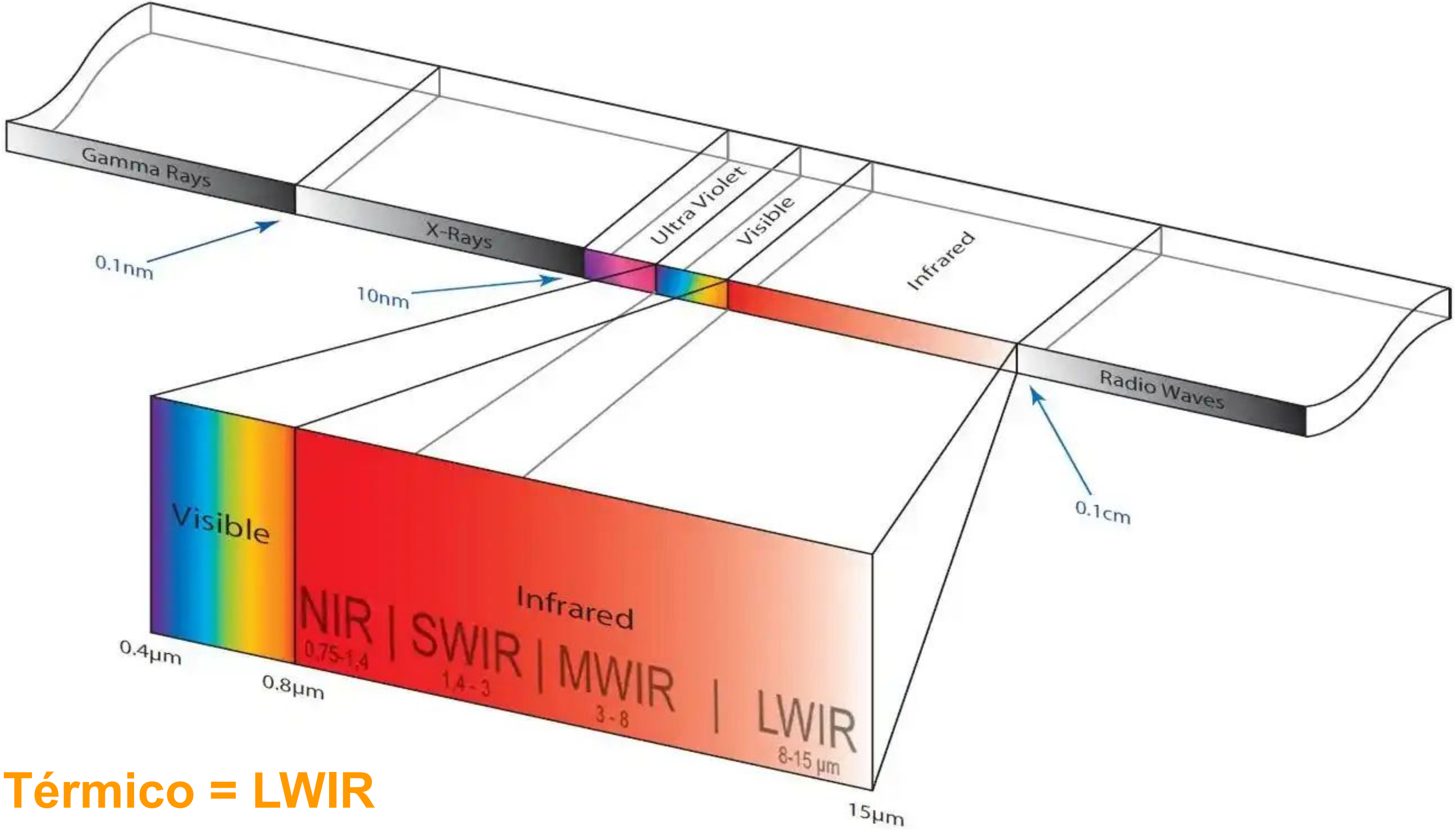
La conducción requiere contacto. La convección requiere flujo de fluido. La radiación no requiere ningún medio.

1. Imágenes Térmicas

Frederick William Herschel (1738, Germany)

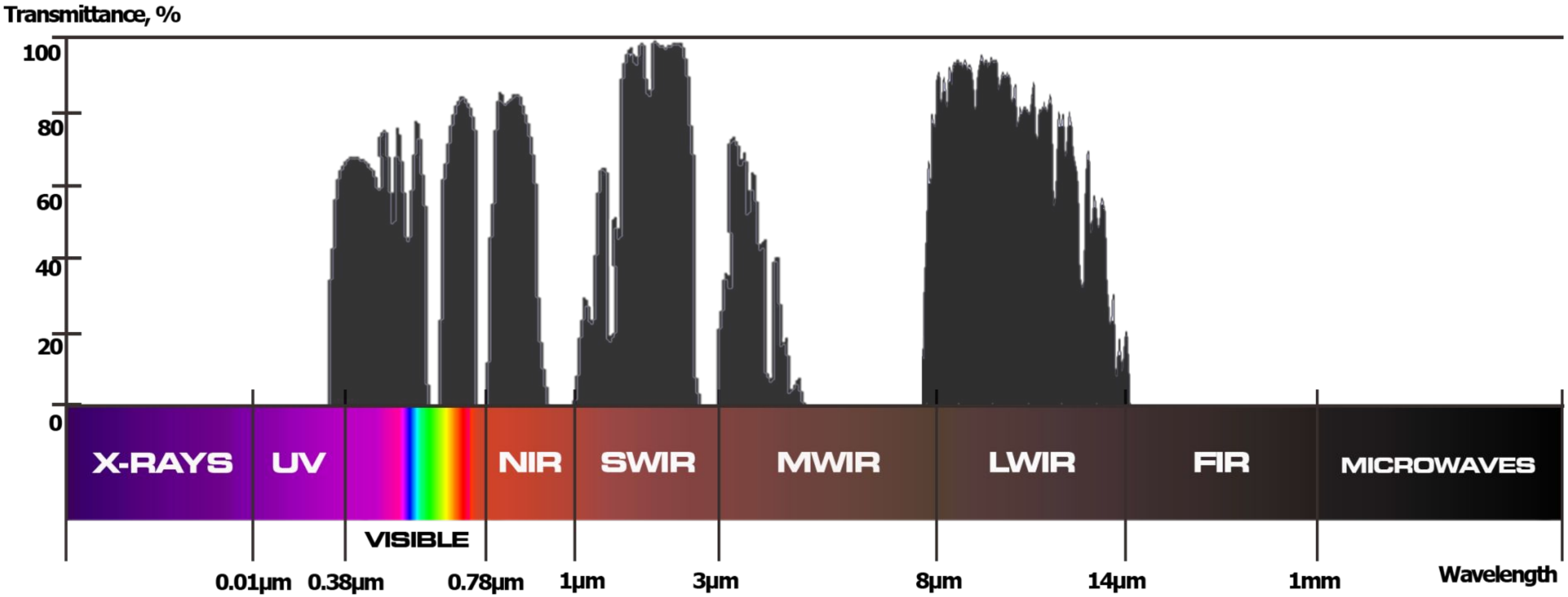
Térmico = LWIR

Espectro electromagnético



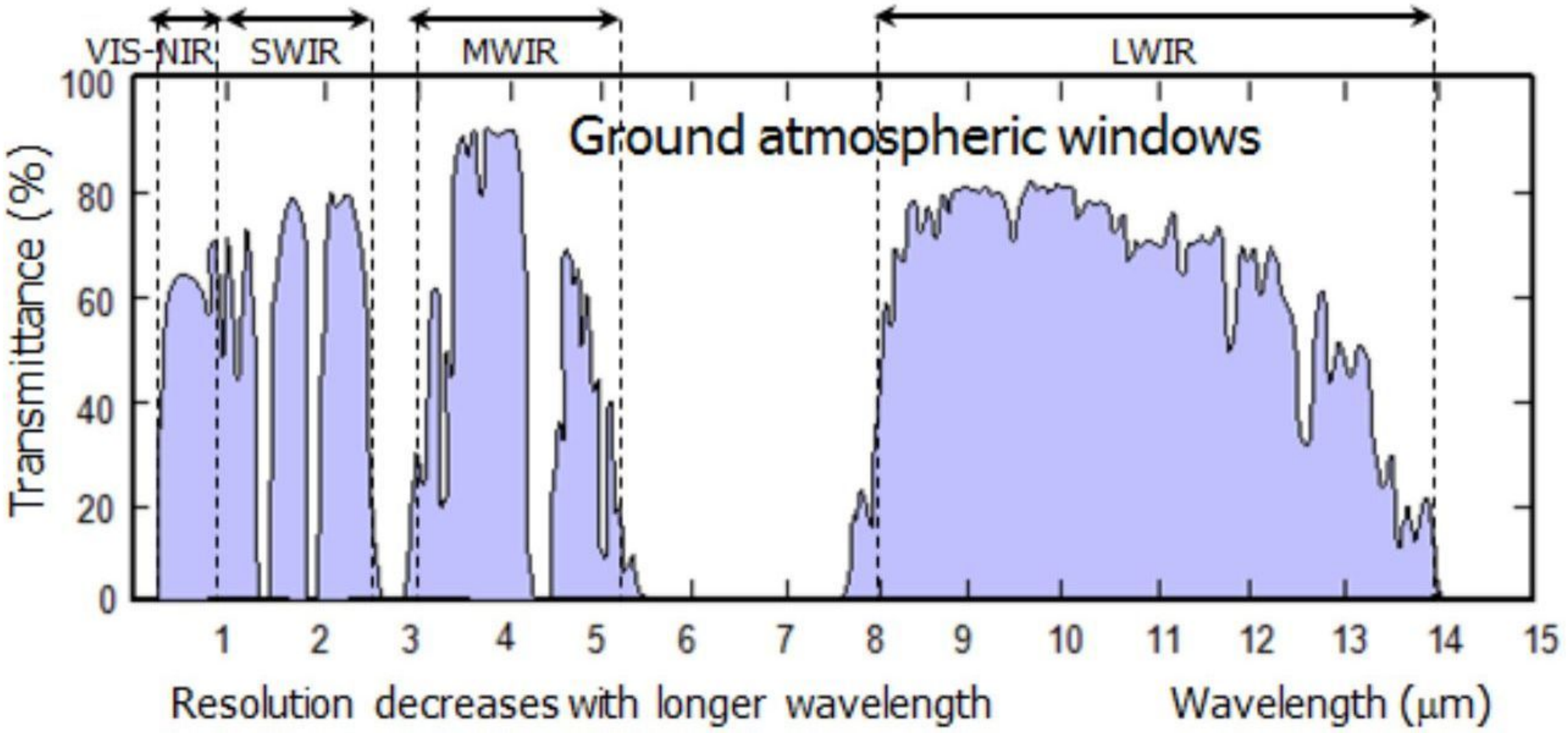
Térmico = LWIR

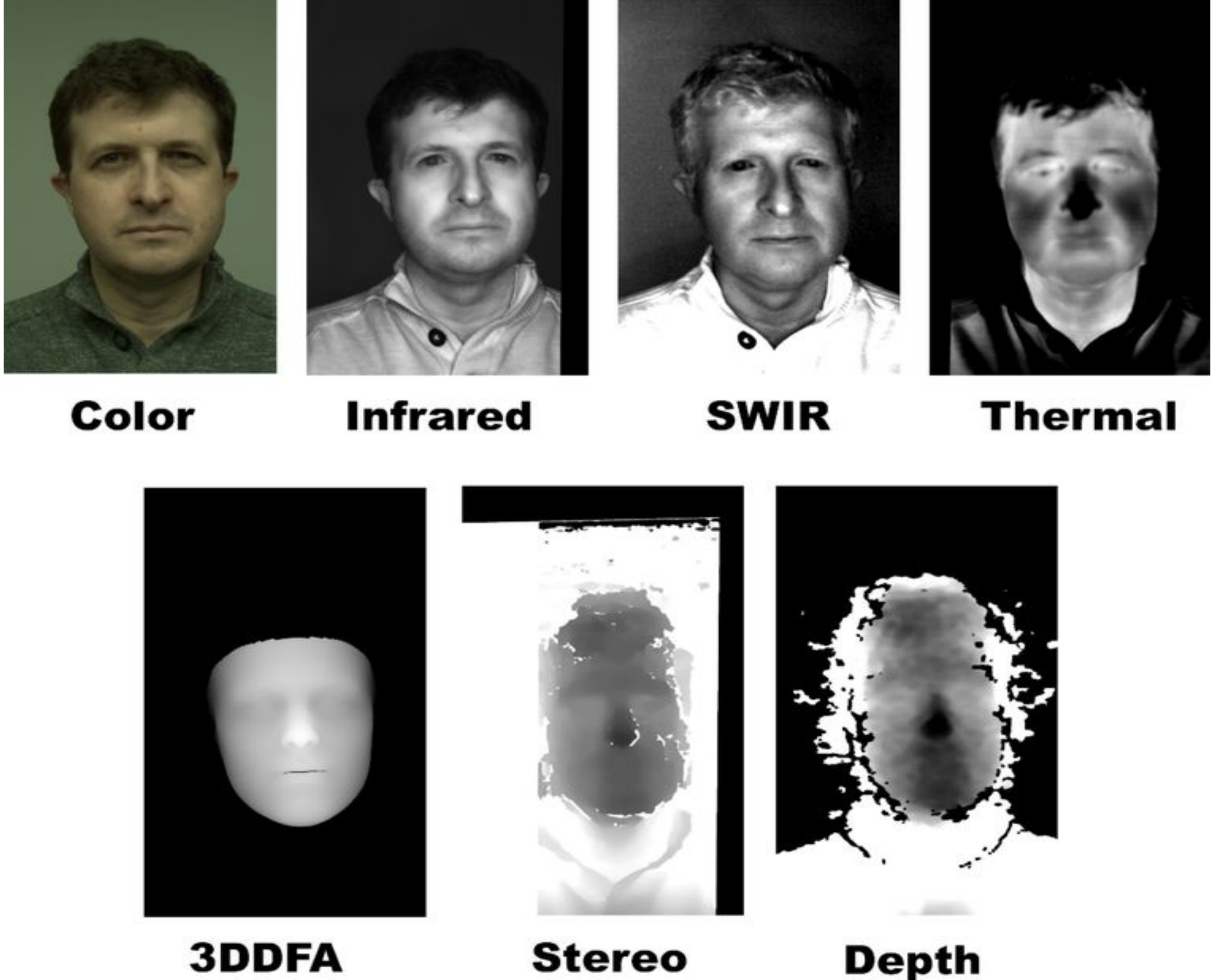
Espectro electromagnético

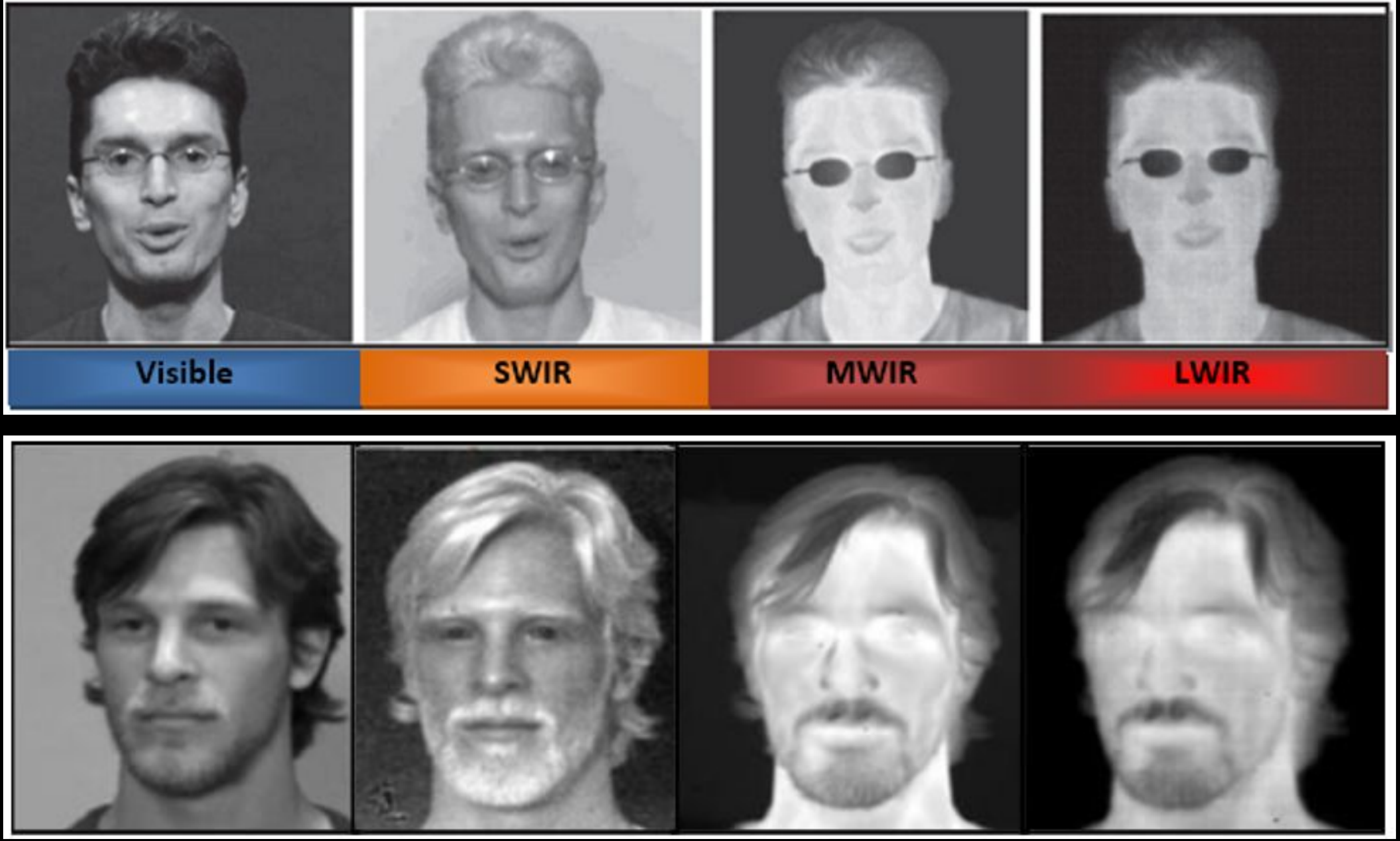


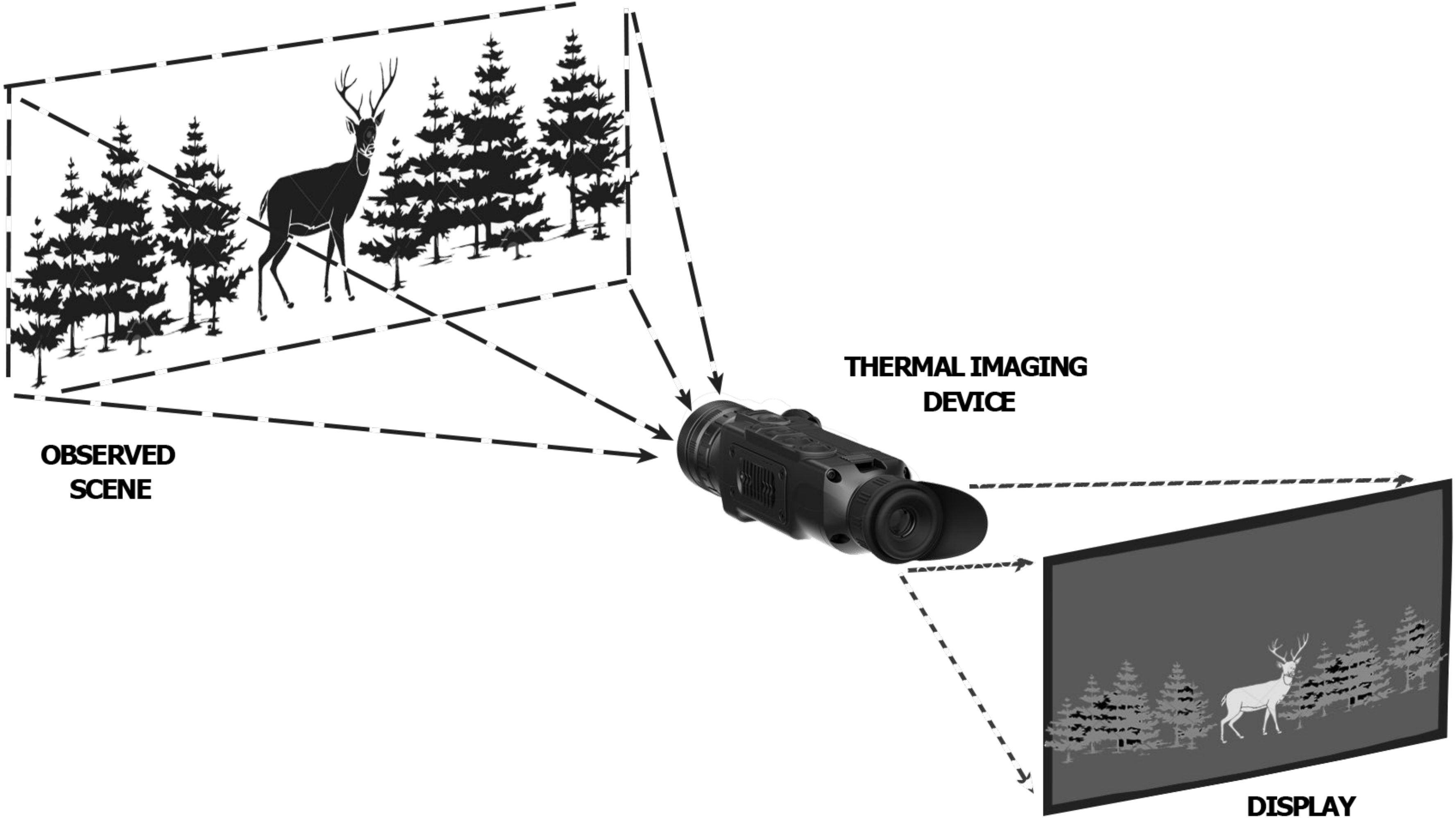
Térmico = LWIR

Importancia de la Atmósfera

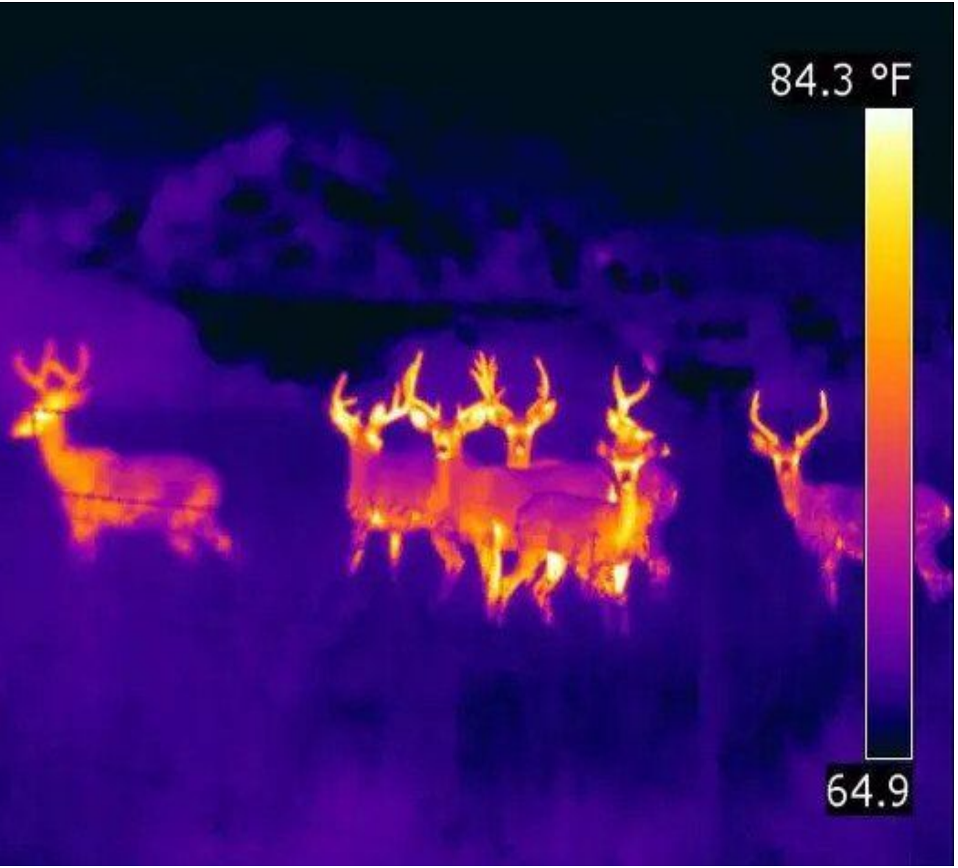



Color
Infrared
SWIR
Thermal
3DDFA
Stereo
Depth

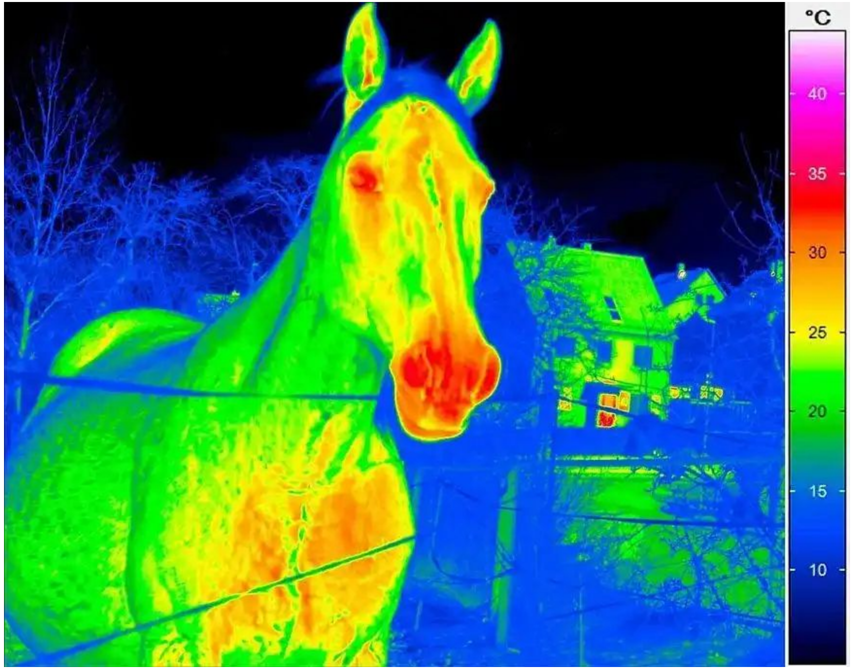

Visible
SWIR
MWIR
LWIR

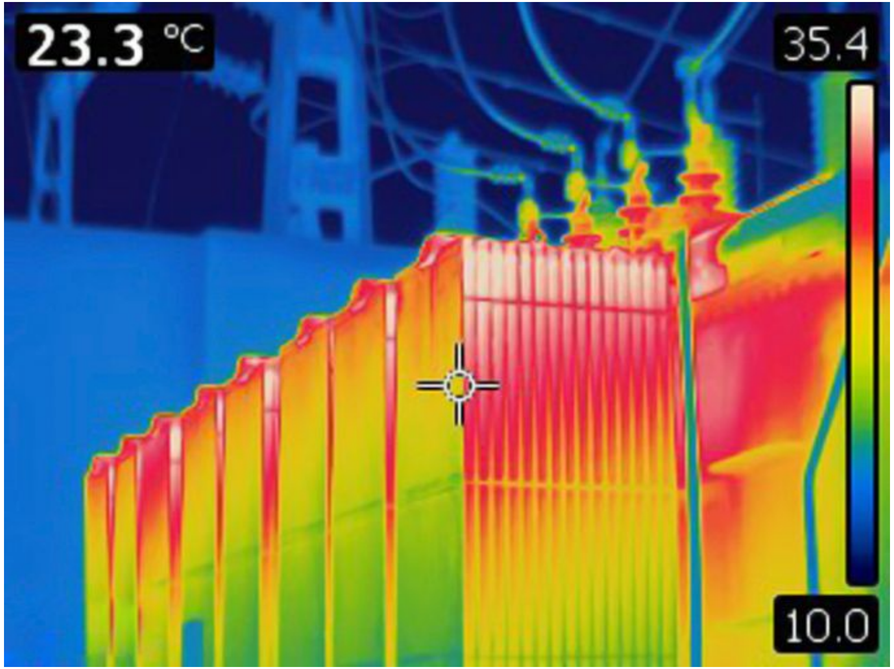

THERMAL IMAGING DEVICE
OBSERVED SCENE
DISPLAY

Imágenes térmicas



Imágenes térmicas





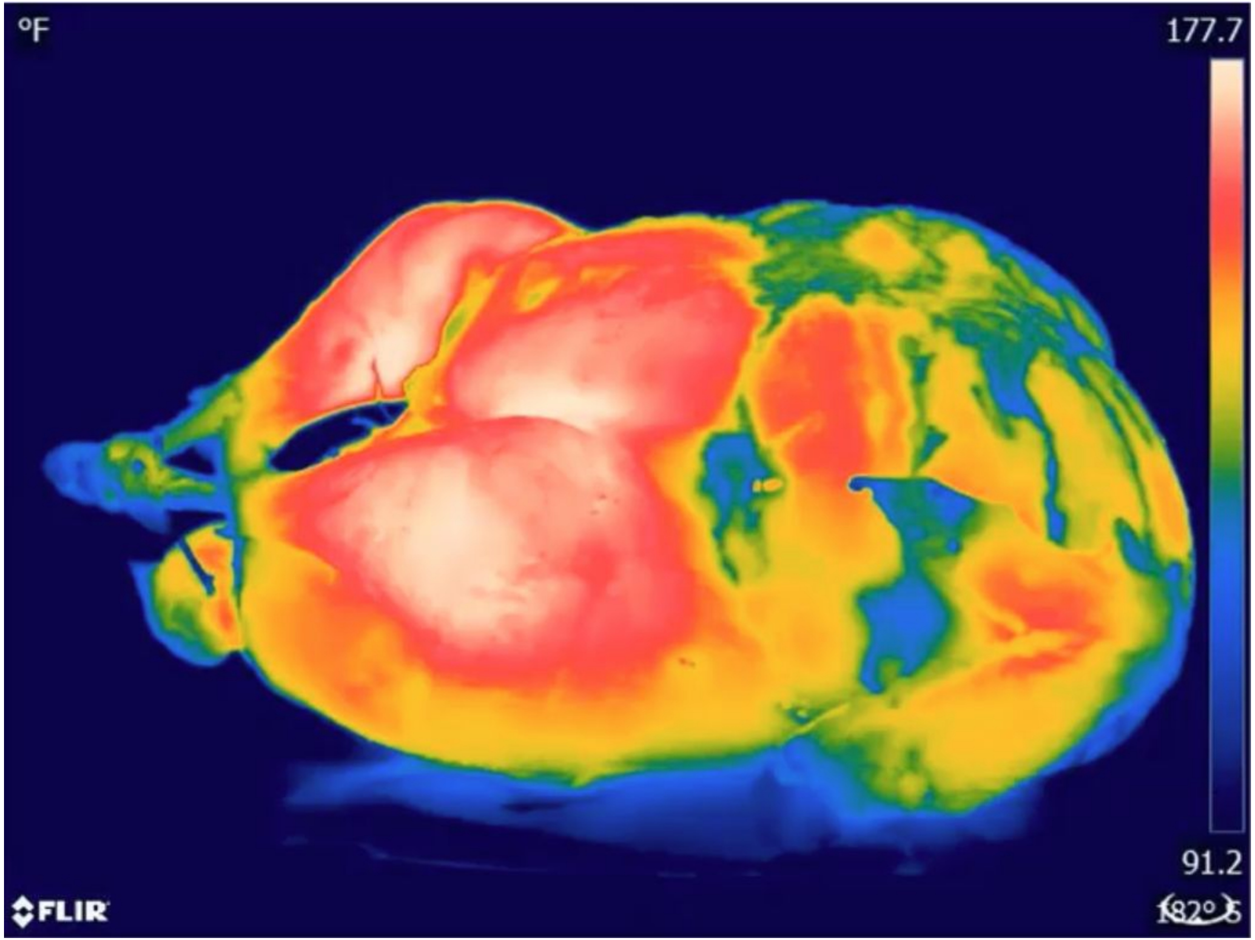
- Un termograma es una representación digital de la radiación térmica emitida por los objetos
- Las cámaras termográficas permiten detectar esta radiación en forma de luz infrarroja
- Una imagen térmica nos permite detectar de forma remota la temperatura de un objeto


37,2°C
37°C
37,5°C
37,4°C
37,8°C


FLIR
Pioneer

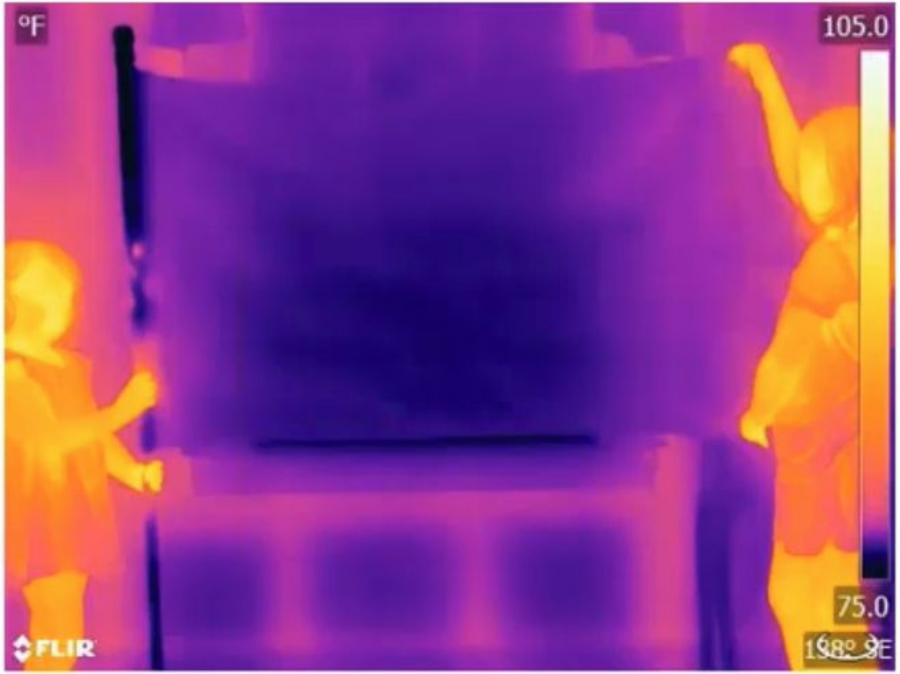
Cool stuff

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



Por qué la bandera se ve diferente?

Afuera de casa

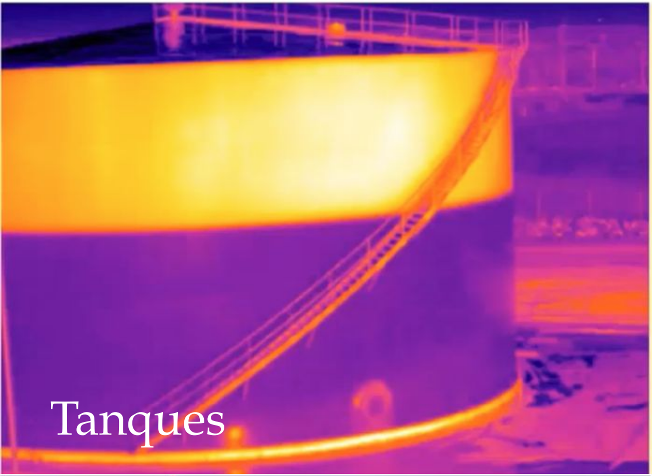


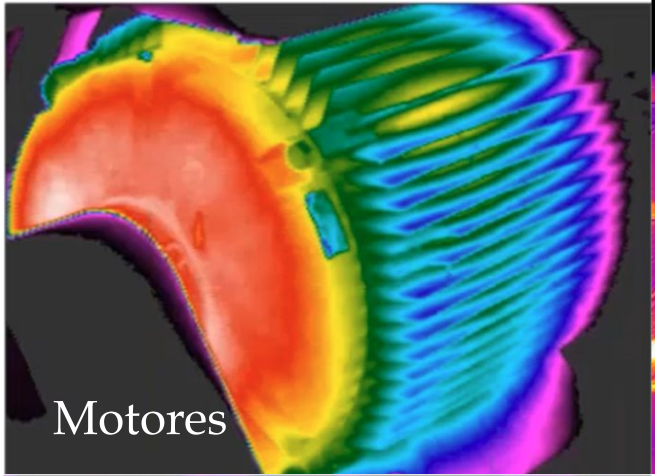
Dentro de casa

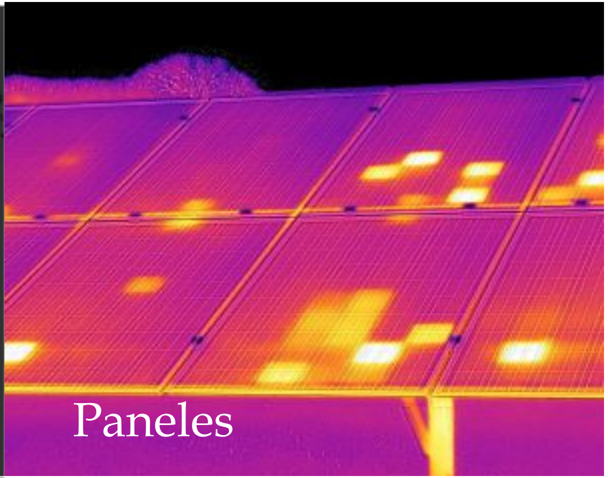
Metales reflejan luz y pueden ser difíciles de medir

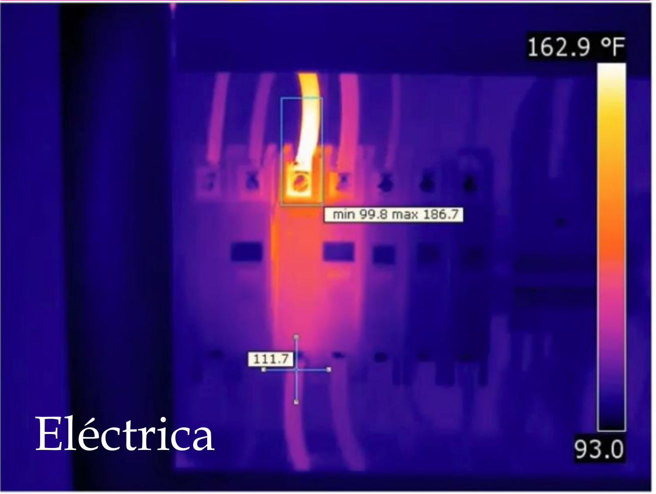
Los vidrios son opacos en el rango térmico

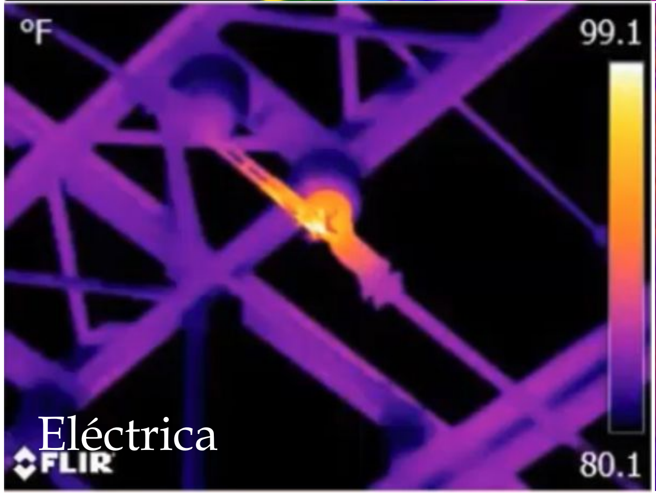
Aplicaciones



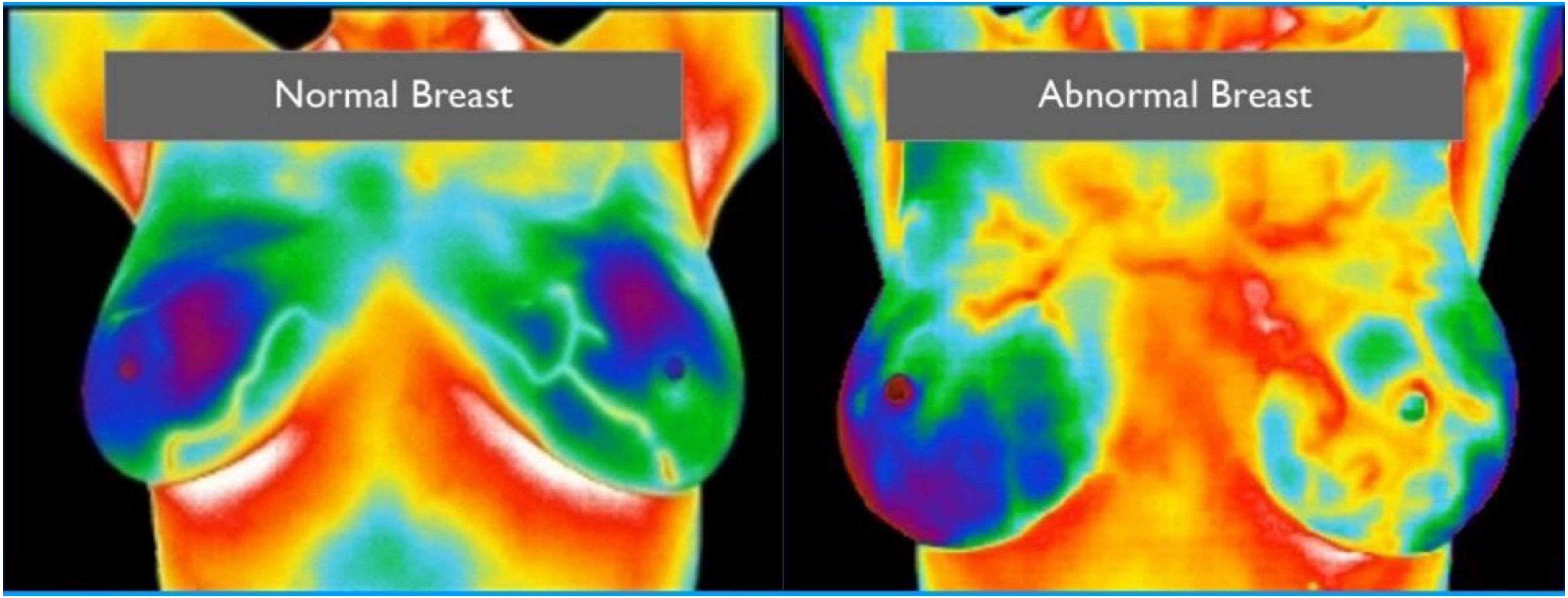






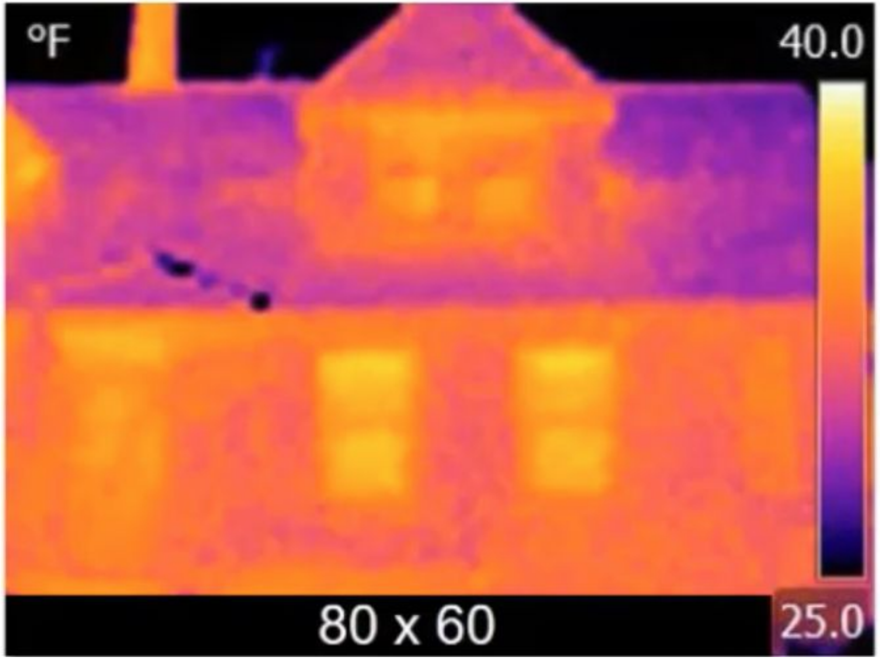


Aplicaciones en Salud



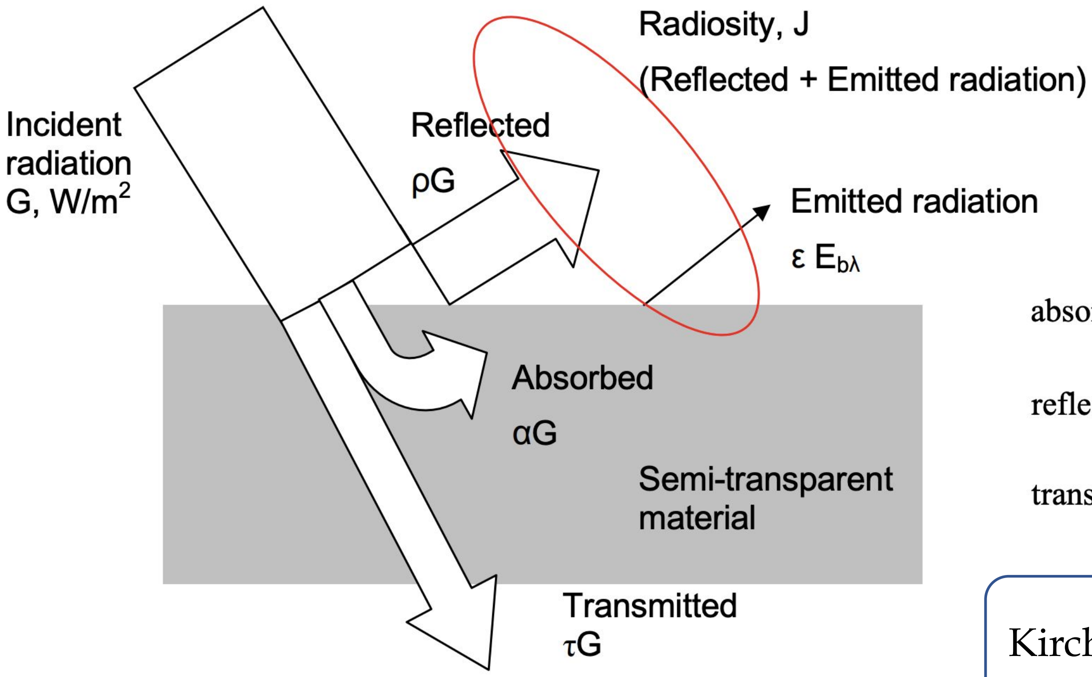

36.8ºC
36.7ºC
36.6ºC
38.3ºC
35.9ºC

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

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

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

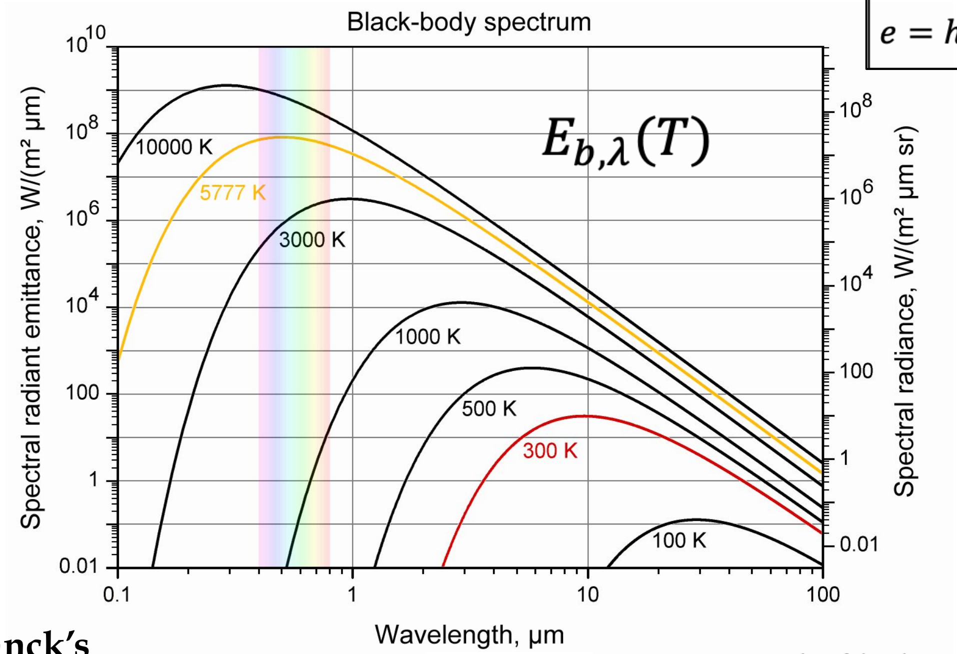
Kirchhoff's law: $\alpha = 1 - \tau$, Transparent ($\rho = 0$)
$\alpha = 1 - \rho$, Opaque ($\tau = 0$)

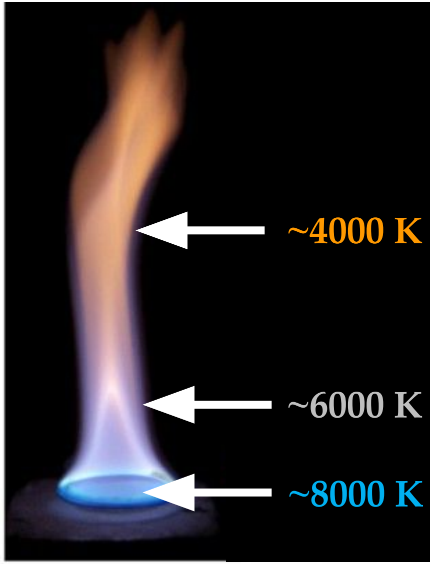
The radiation energy incident on a surface per unit area per unit time is called irradiation, G.

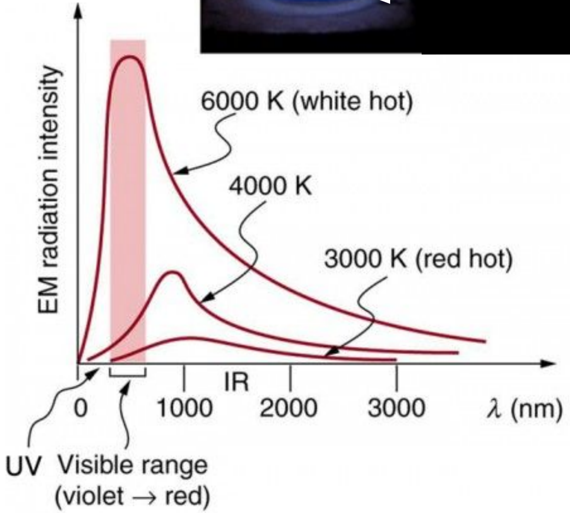
Blackbody radiation

- 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

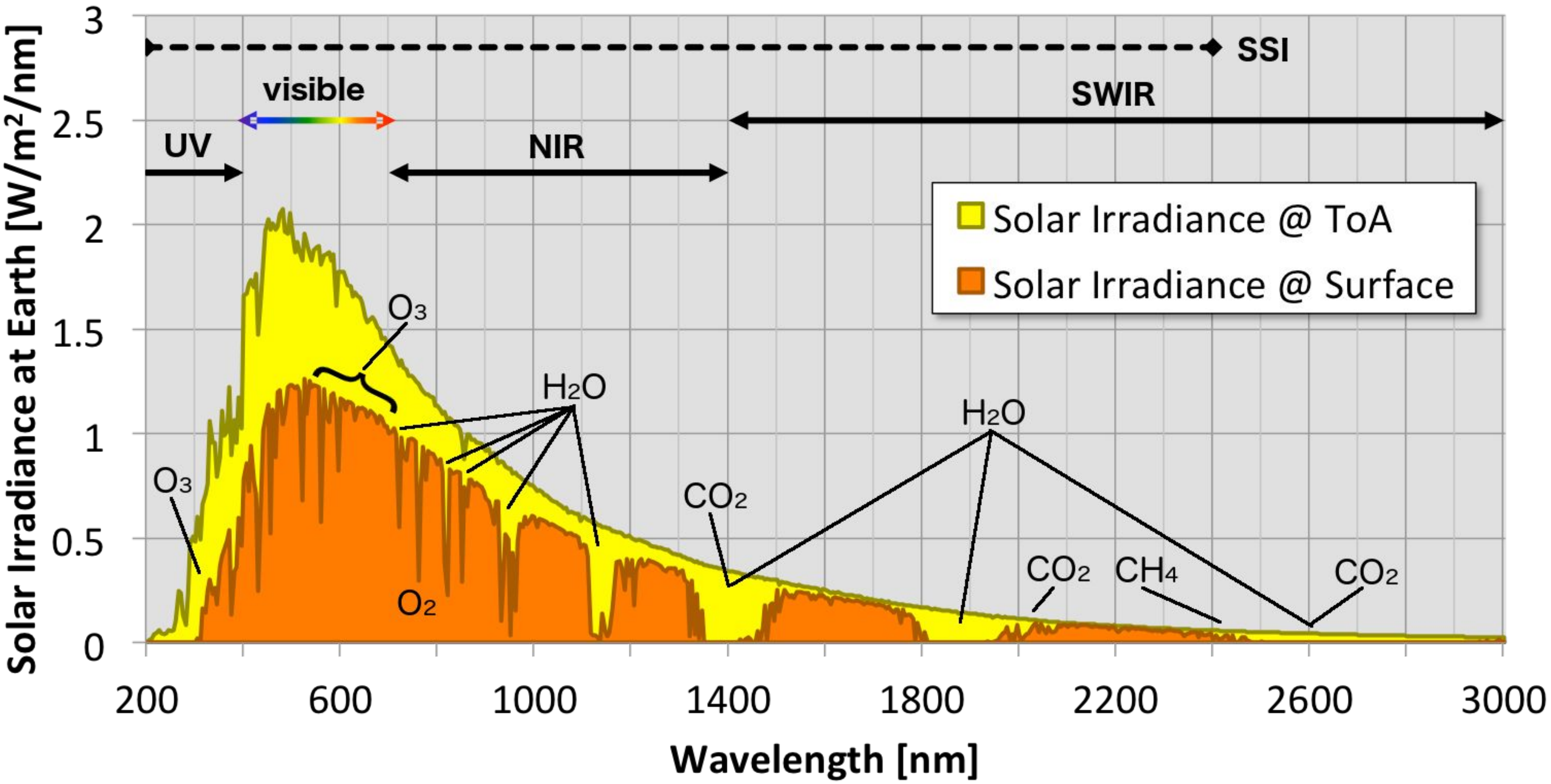
Lava 700 - 1,200 °C

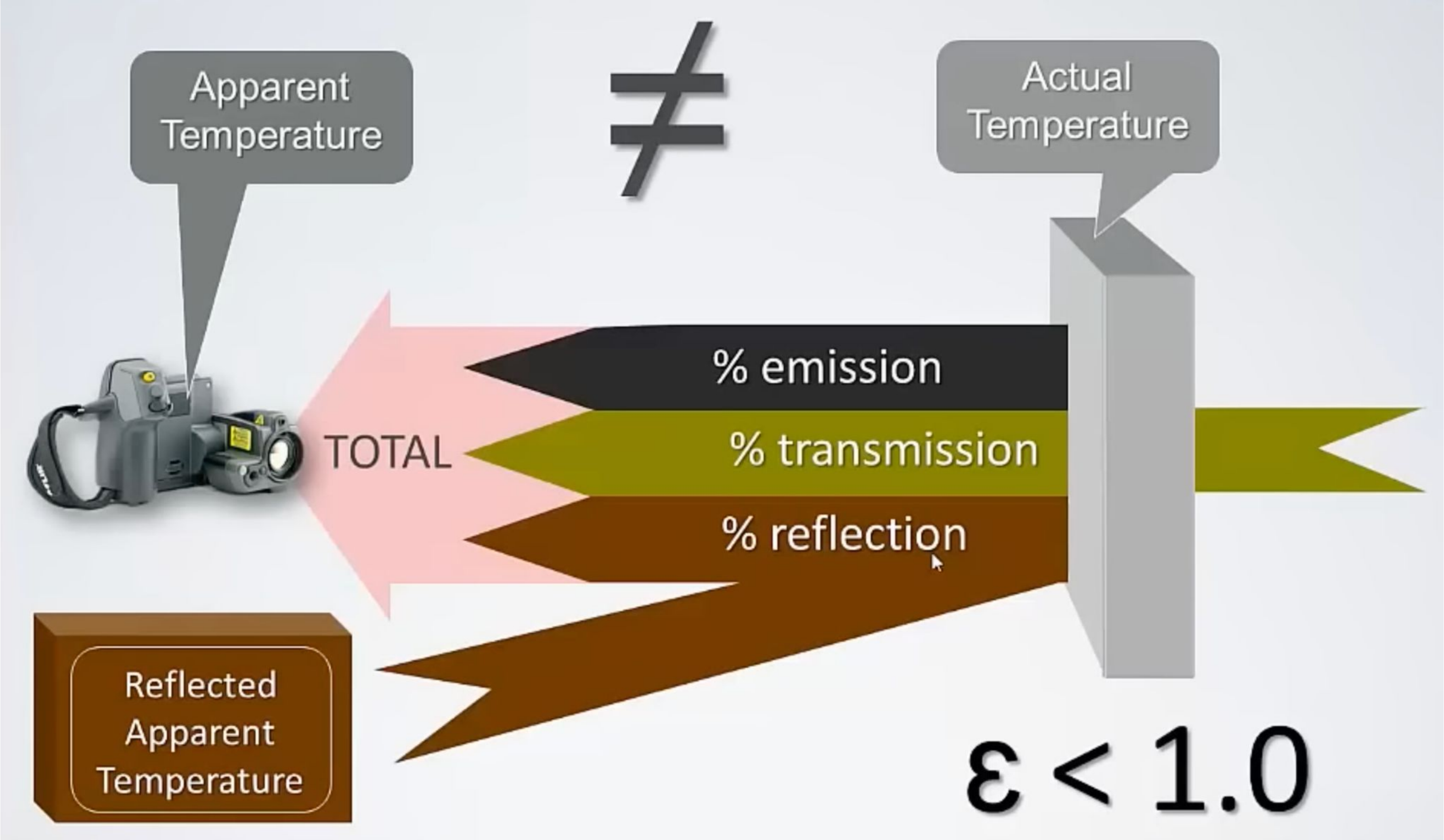
Superficie: 5600 °C; Centro: 15.000.000 °C

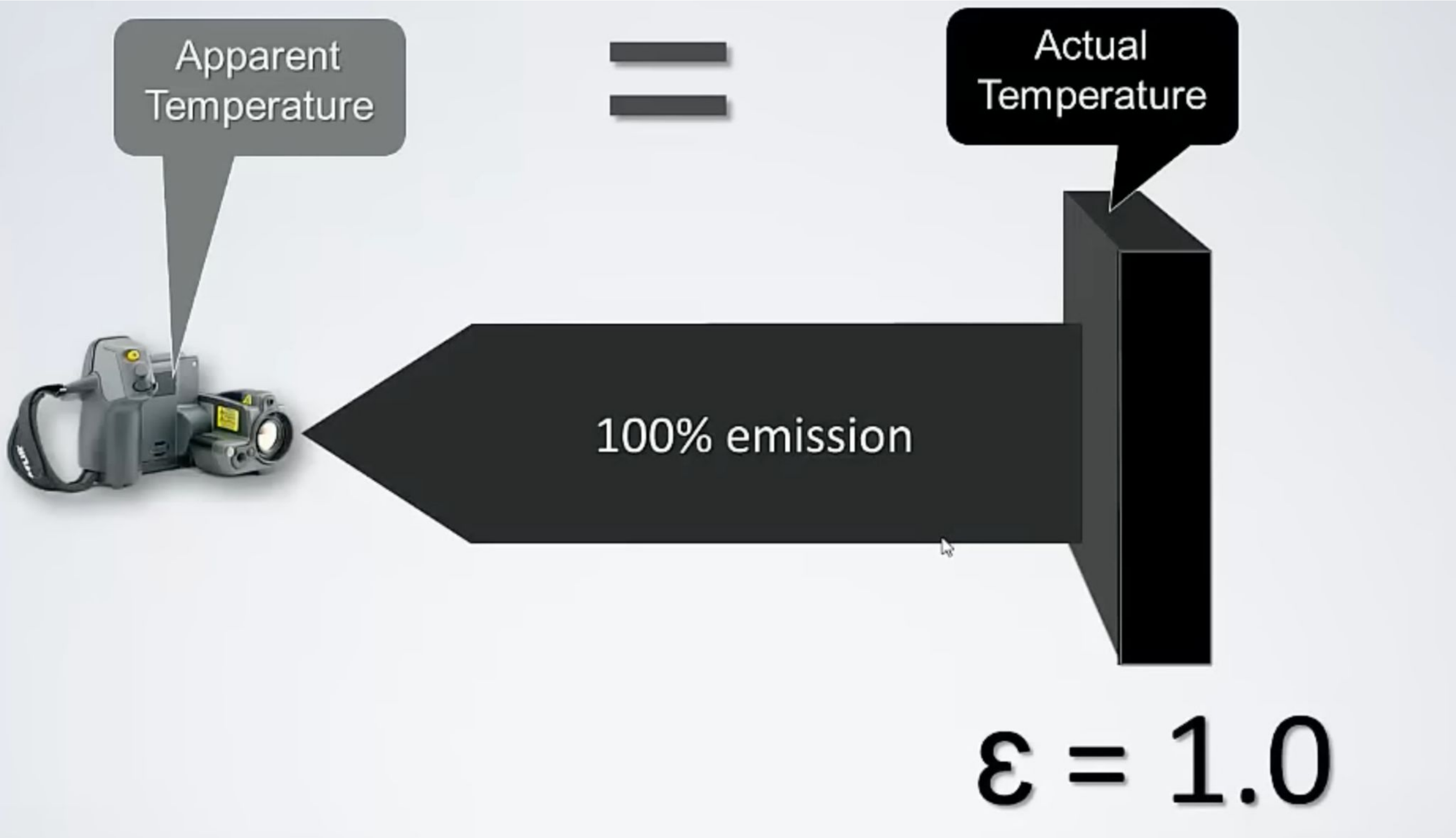
1500 to 20.000 °C

300 to 800 °C

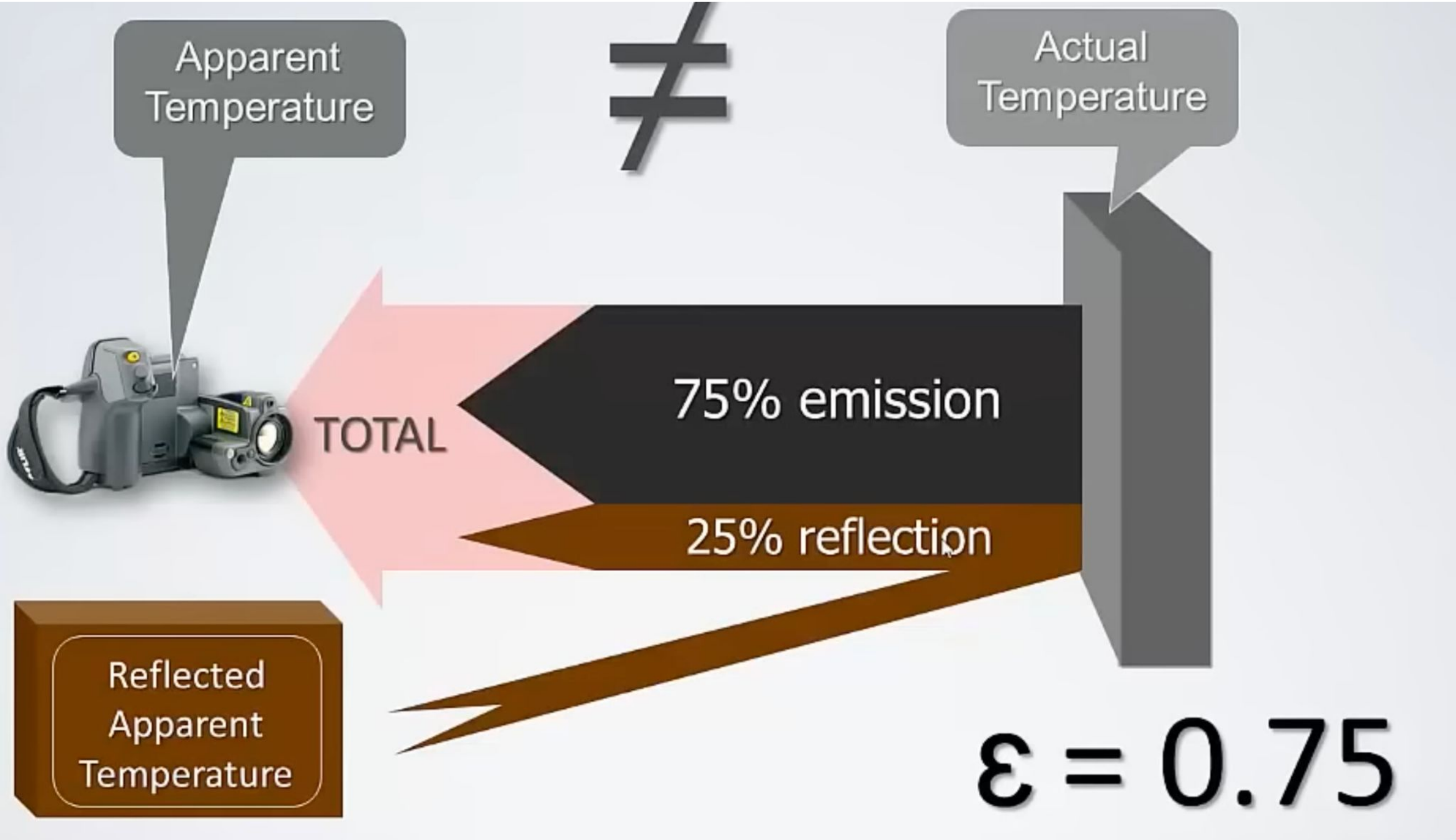
Irradiancia Solar

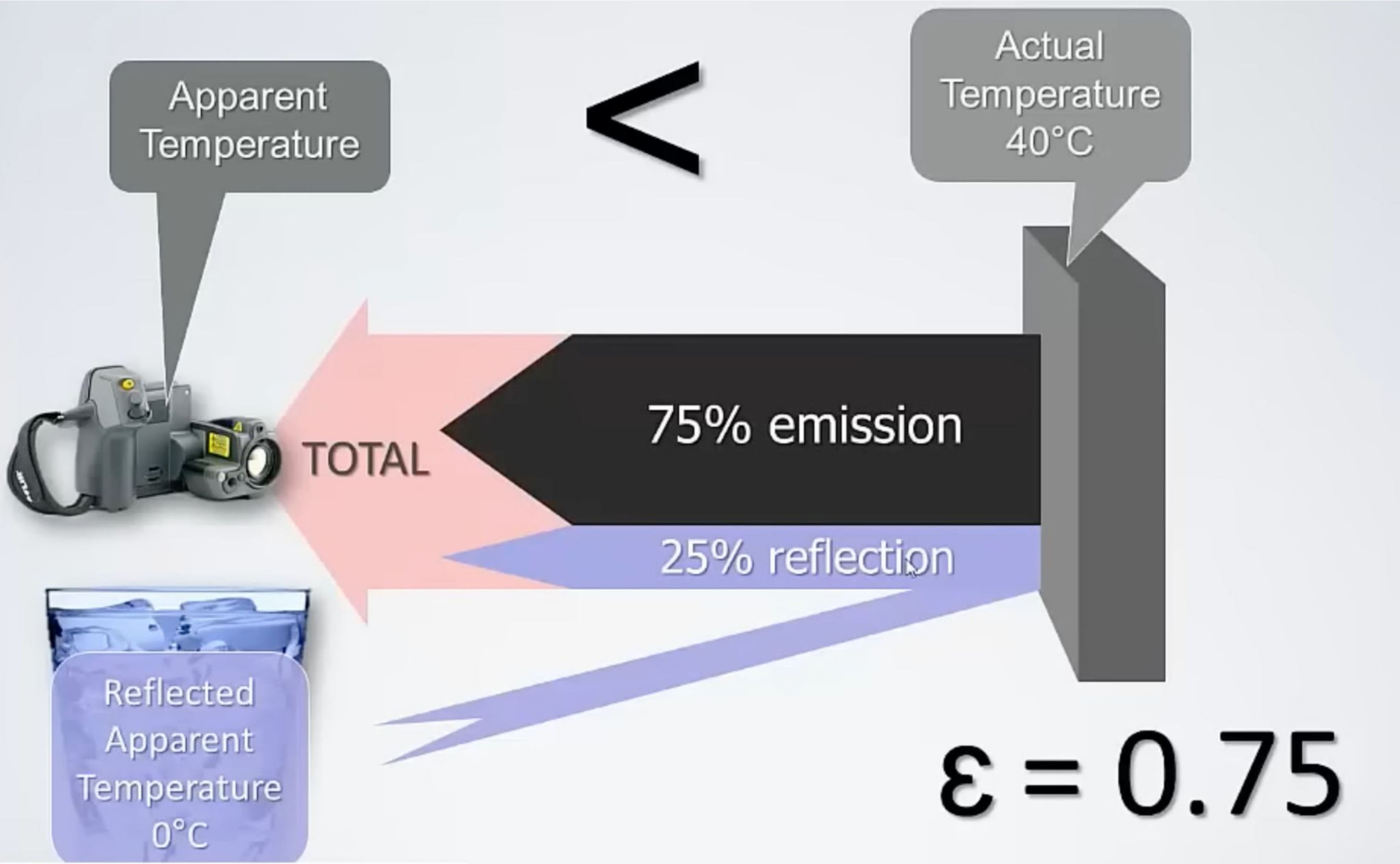


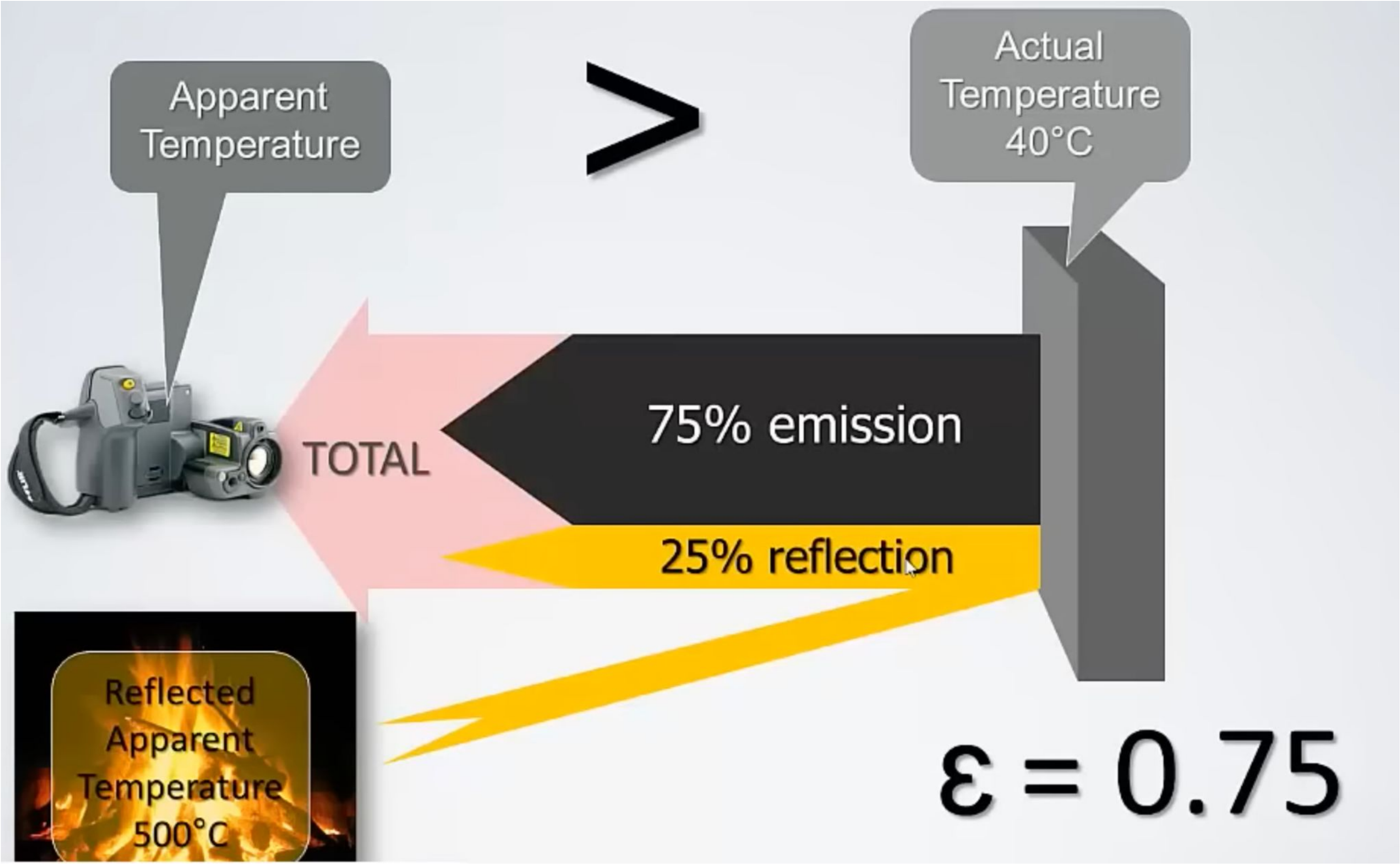

Apparent Temperature
≠
Actual Temperature
% emission
TOTAL
% transmission
% reflection
Reflected Apparent Temperature
ε < 1.0



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

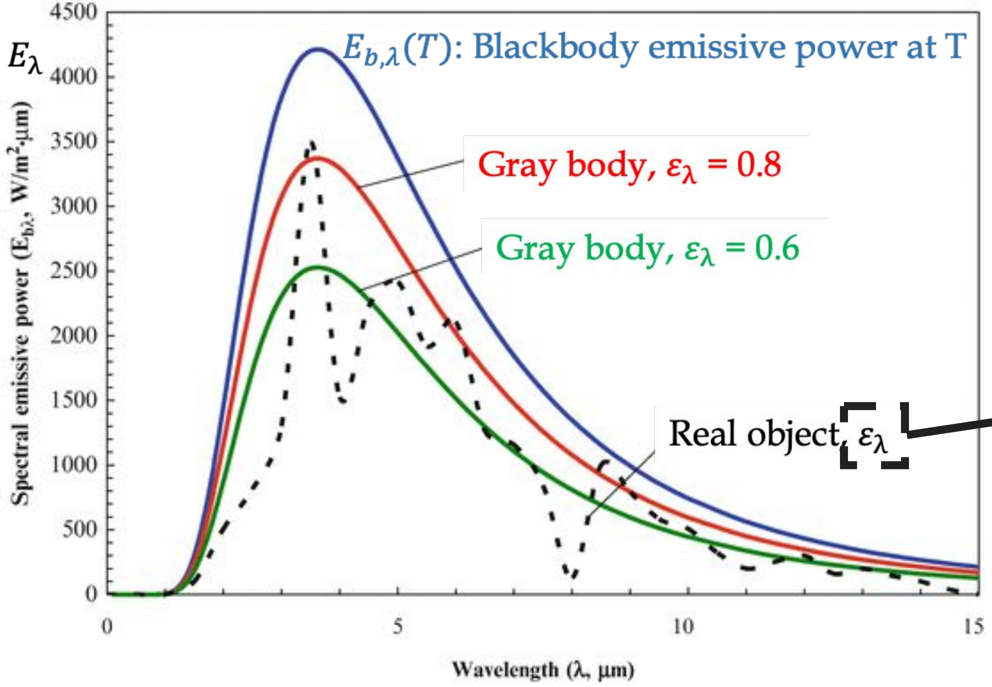
Emissivity de materiales comunes

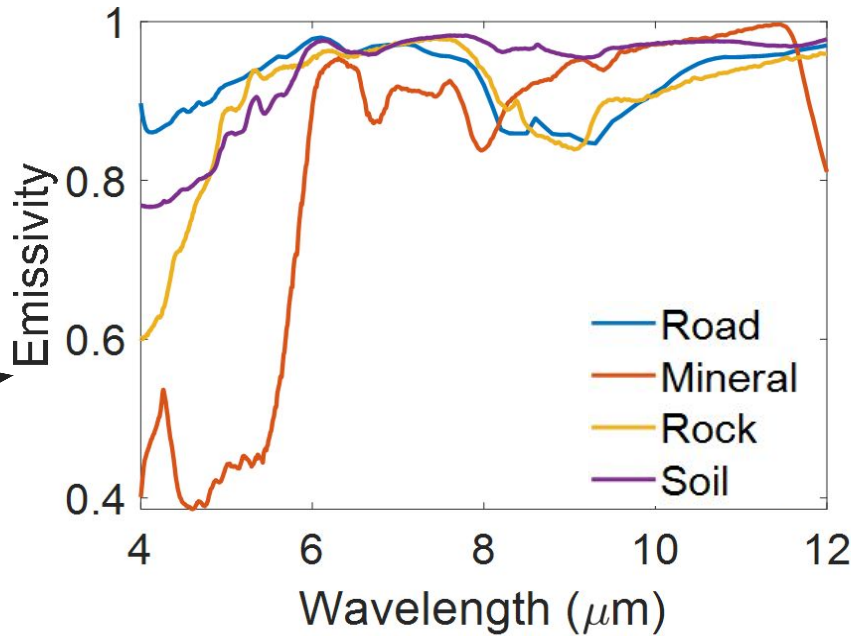
Metal	Emissivity	Non-metal	Emissivity
Bare aluminum	0.02–0.4	Concrete (rough)	0.93–0.96
Gold	0.02–0.37	Glass	0.76–0.94
Copper	0.02–0.74	Wood	0.8–0.95
Lead	0.06–0.63	Carbon	0.96
Brass	0.03–0.61	Human skin	0.98
Nickel	0.05–0.46	Paper	0.7–0.95
Steel	0.07–0.85	Plastic	0.8–0.95
Tin	0.04–0.08	Rubber	0.86–0.94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

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

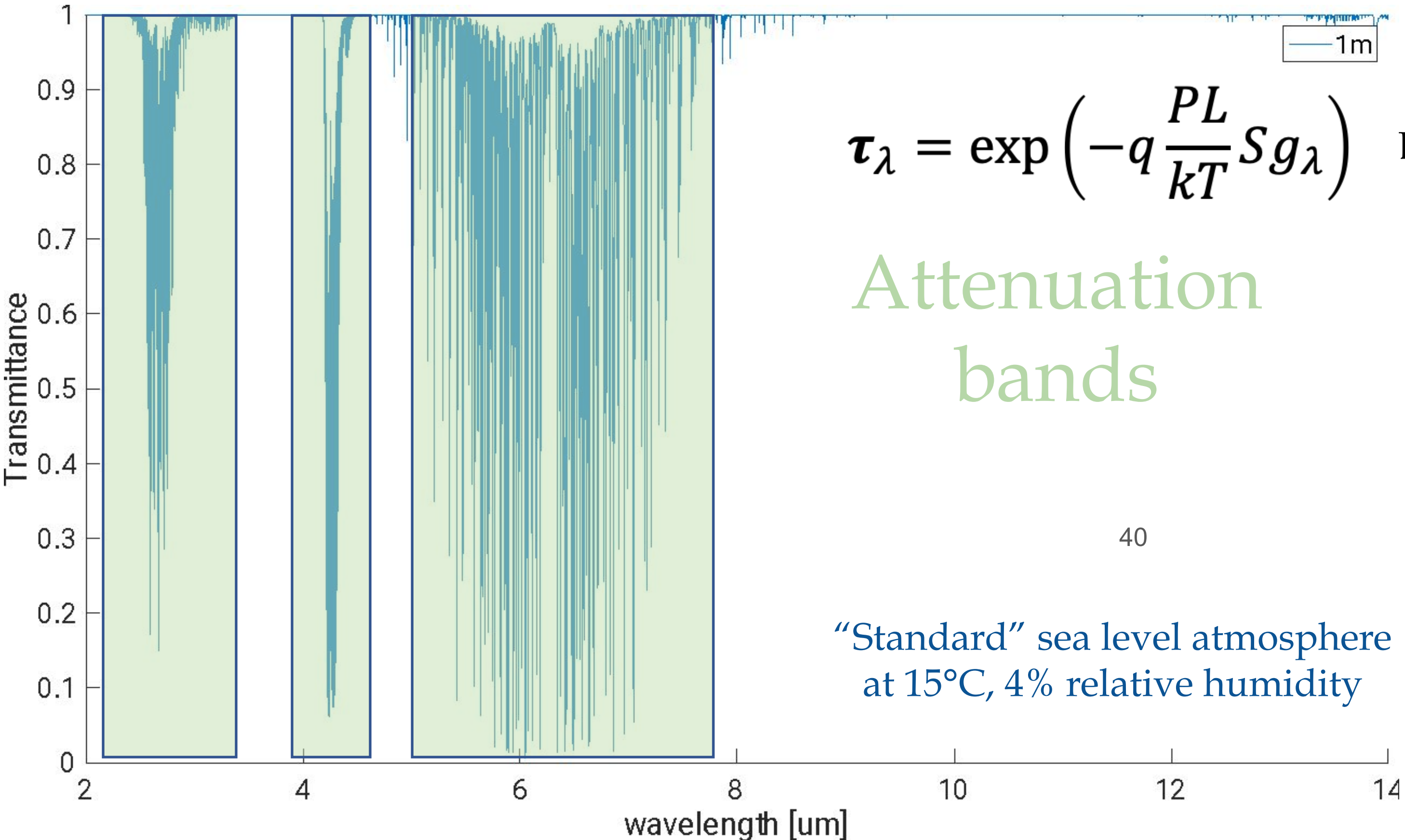




HITRANonline

Atmospheric transmittance

$\boldsymbol{\tau_\lambda}$



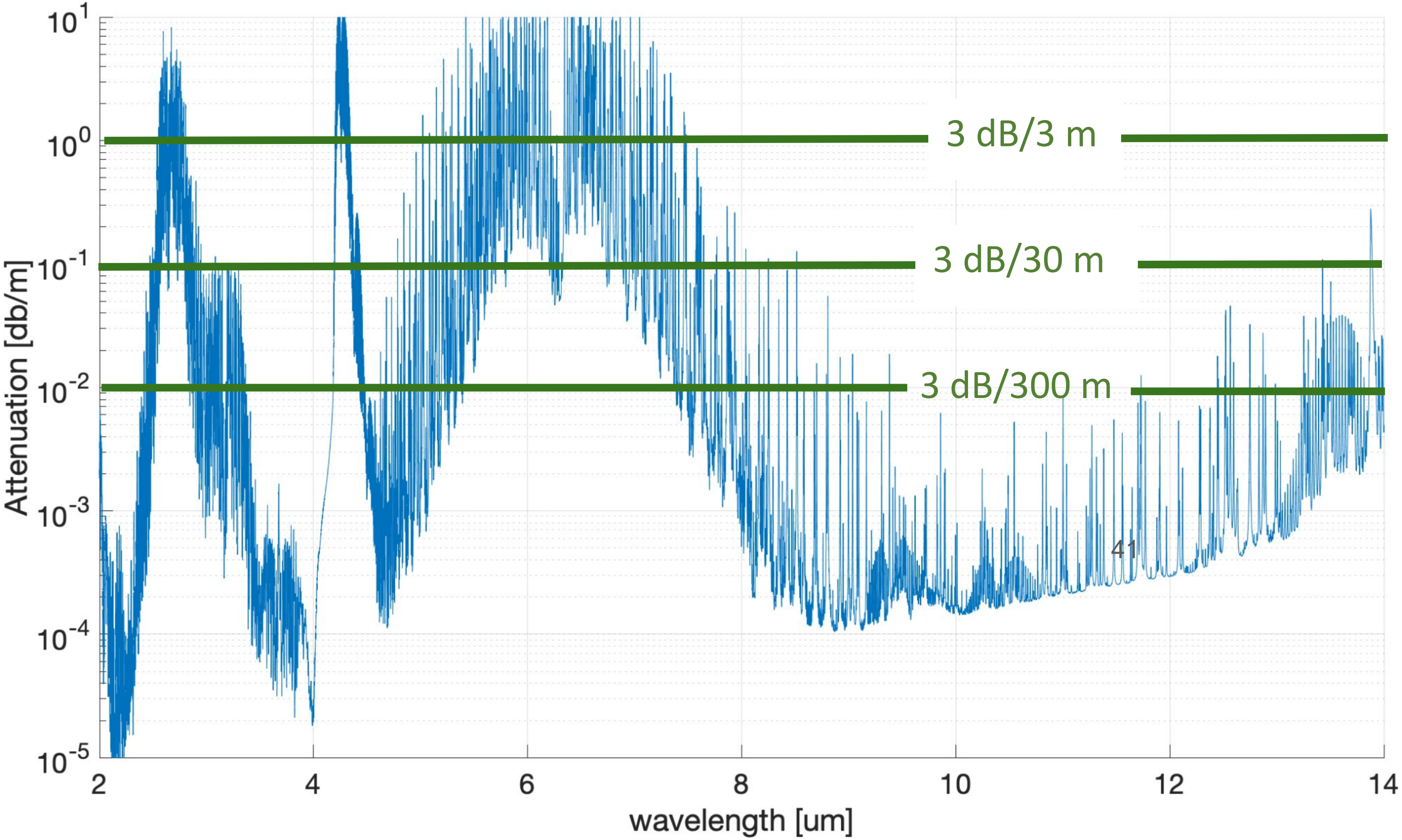
$$\boldsymbol{\tau_\lambda} = \exp\left(-q\frac{PL}{kT}Sg_\lambda\right)$$

Beer-Lambert

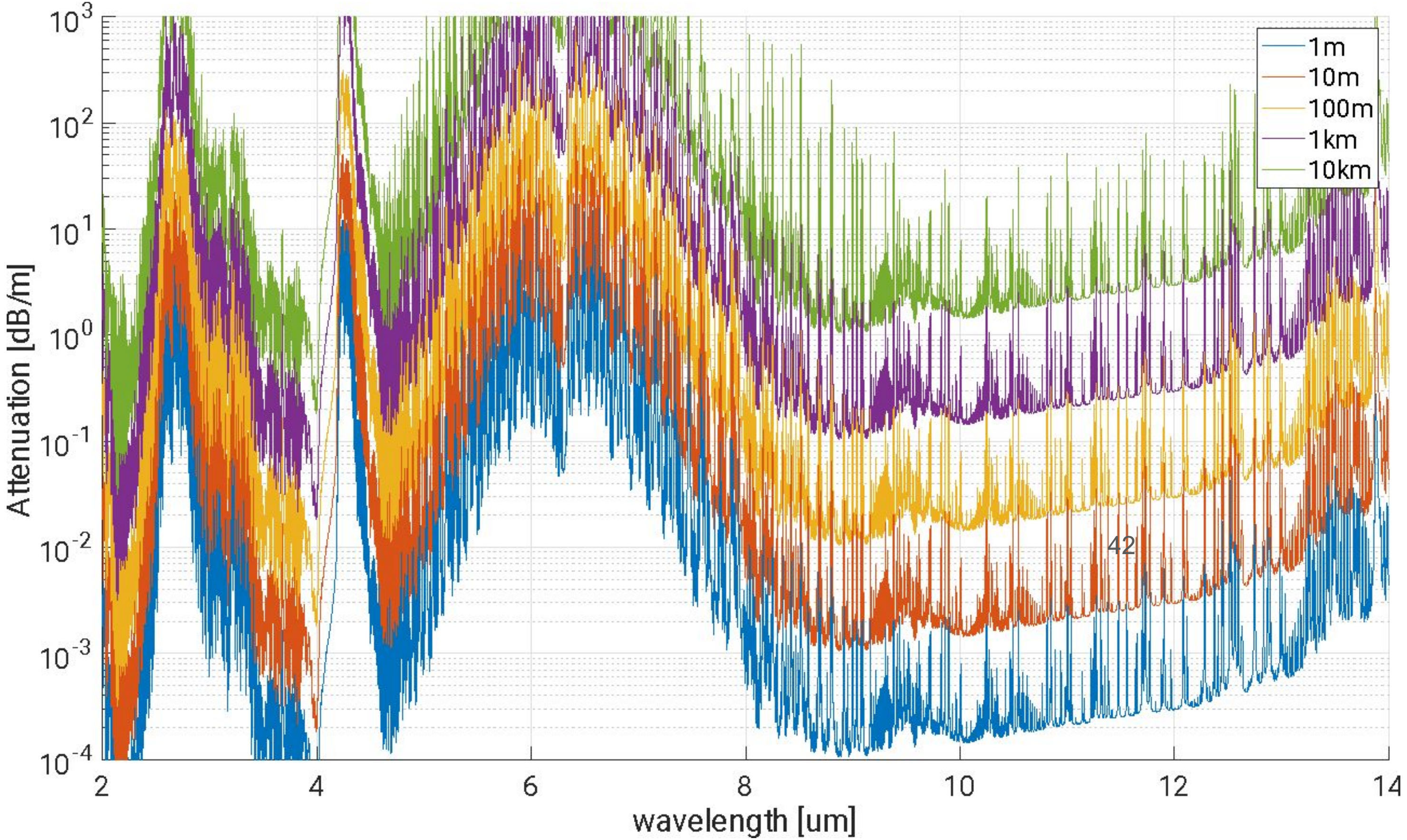
Attenuation bands

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

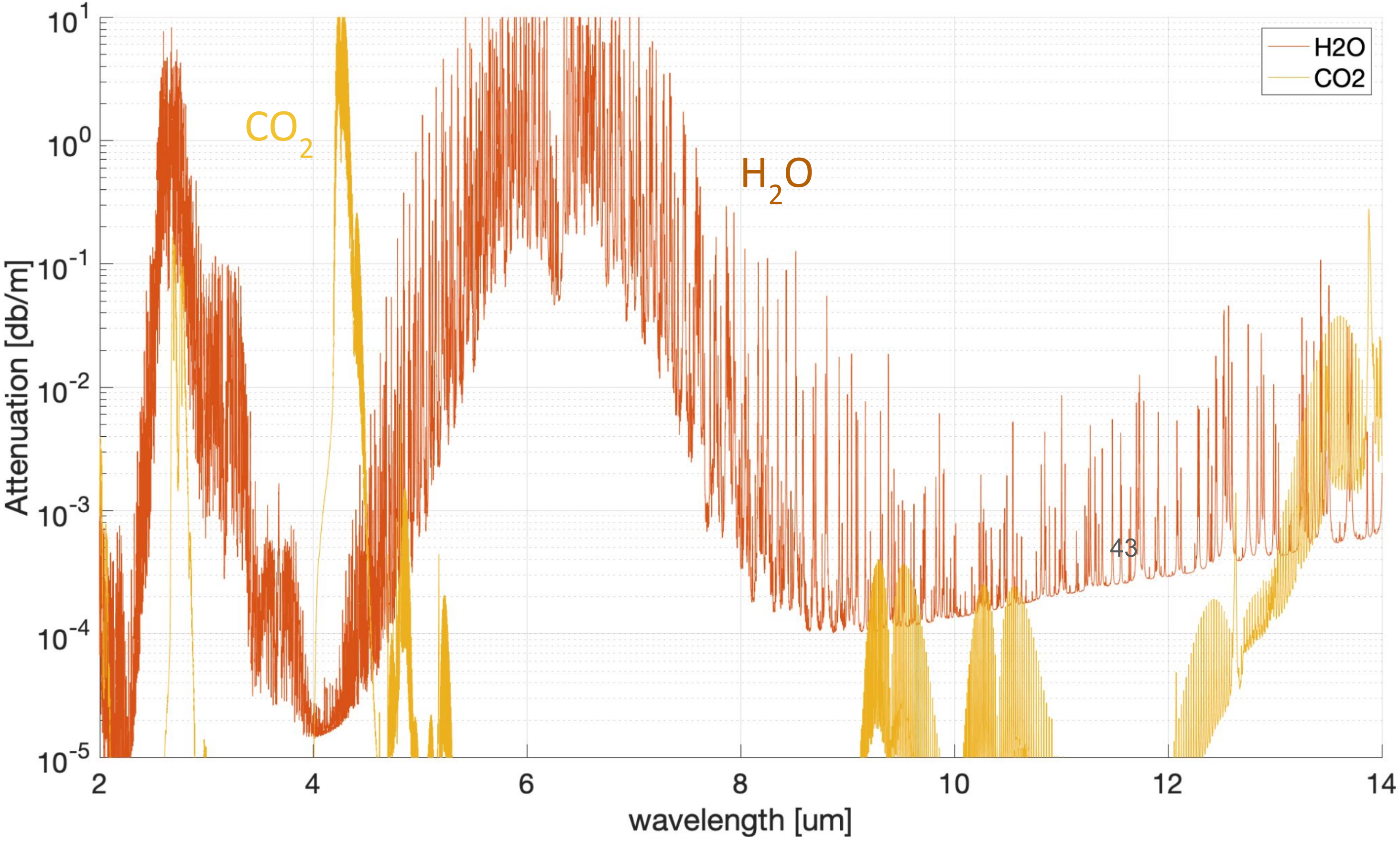
Atmospheric attenuation



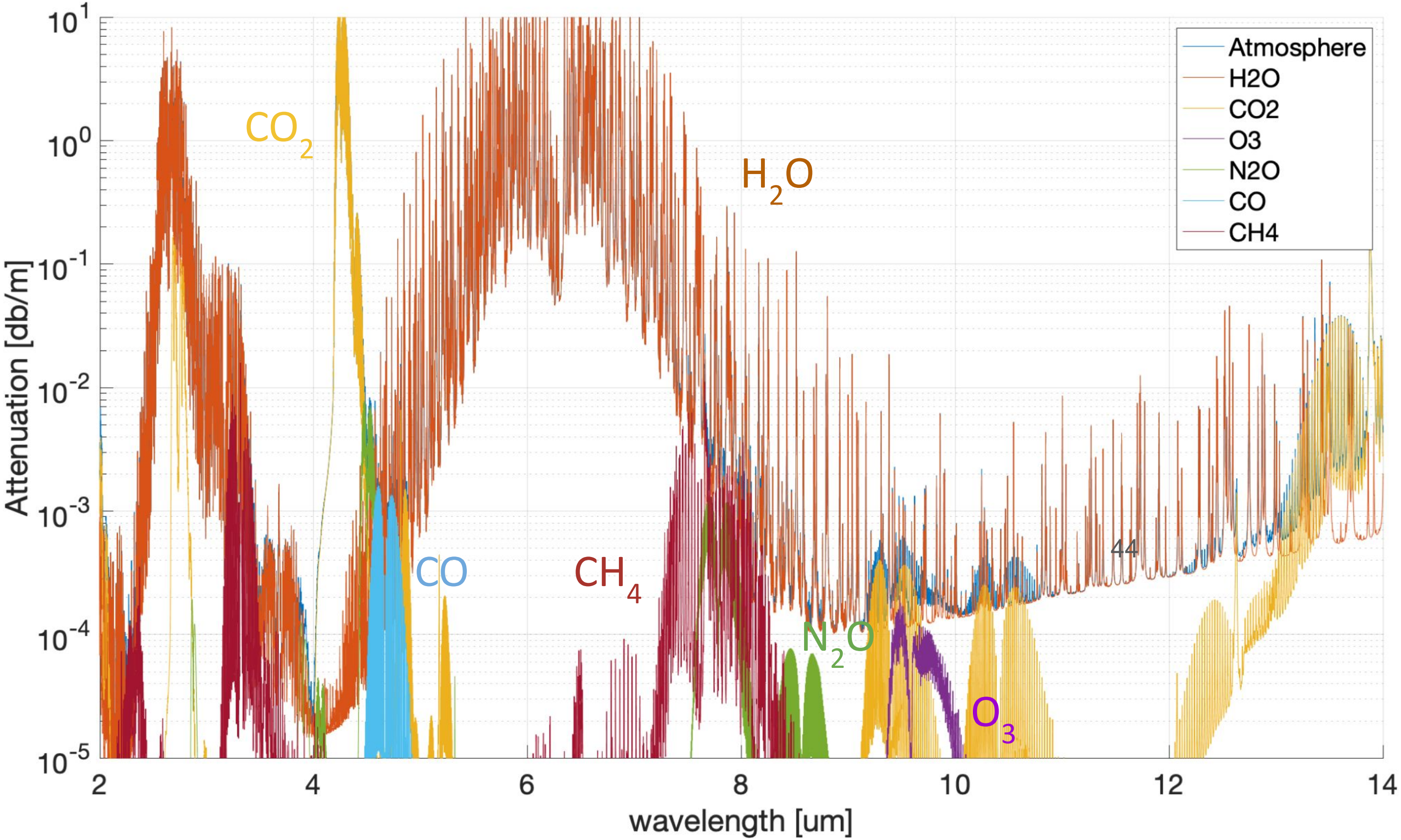
Atmospheric attenuation for different L



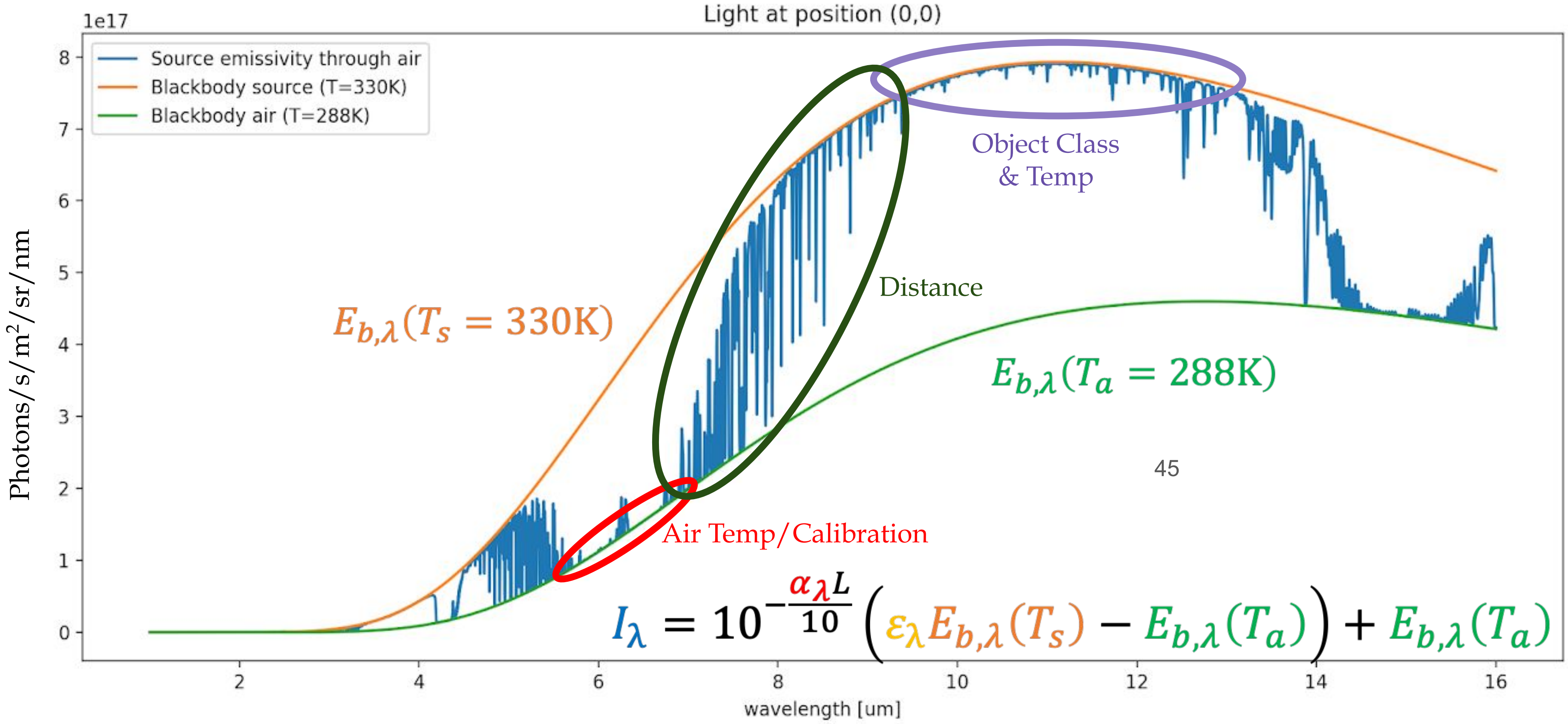
Atmospheric attenuation by gas composition



Atmospheric attenuation by gas composition



Emissivity through air



Forward (sensing) model

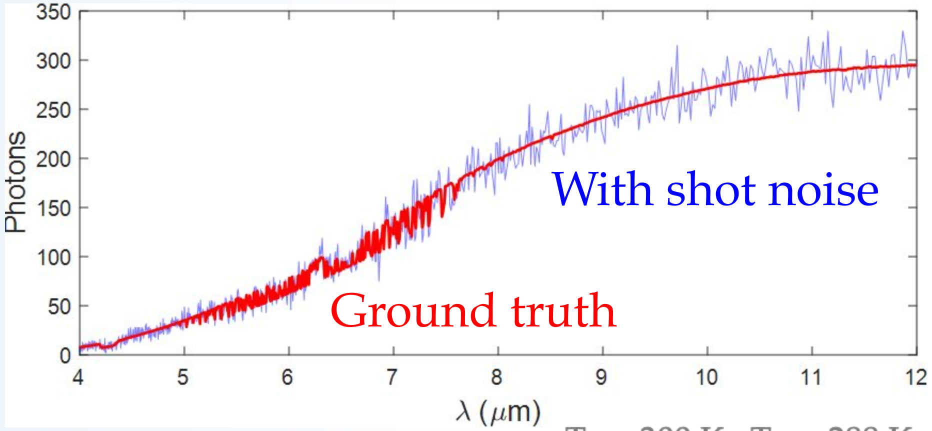
Physics

Kirchhoff's law: $\alpha_\lambda = \varepsilon_\lambda = 1 - \tau_\lambda$

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

Planck's law: $E_{b,\lambda}(T) = \dfrac{2hc^2}{\lambda^5\left(\exp\left(\frac{hc}{\lambda kT}\right) - 1\right)}$

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



Ts = 300 K; Ta = 288 K
ε_λ = 1; L = 100 m

Sensor

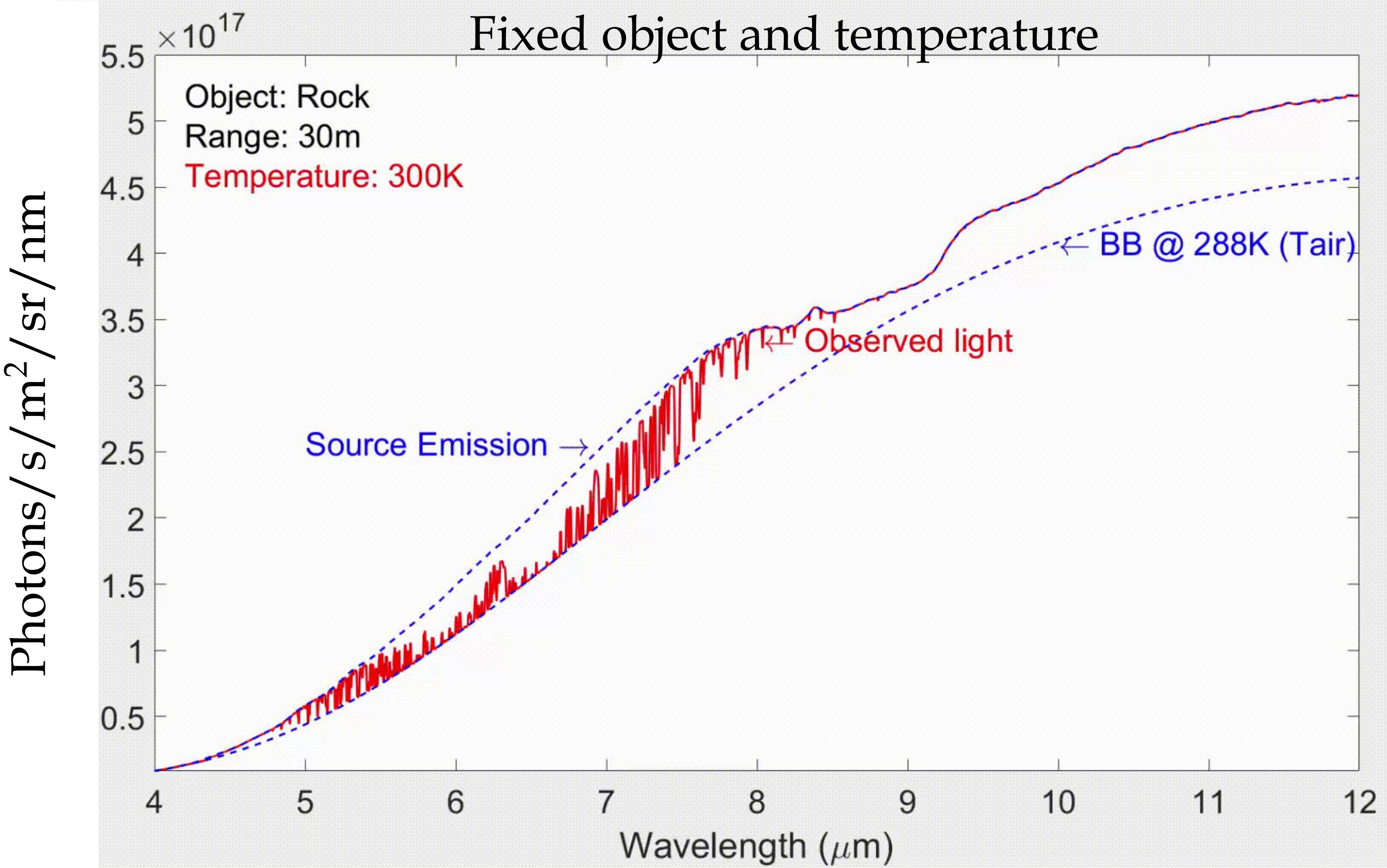
Rate at sensor: $\rho_i = A\Omega t_d \int_{\lambda_i}^{\lambda_{i+1}} I_\lambda \, d\lambda$

Measurements: $\boldsymbol{y} = \mathcal{P}(\boldsymbol{\eta\rho}) + \cancel{\boldsymbol{n}}$

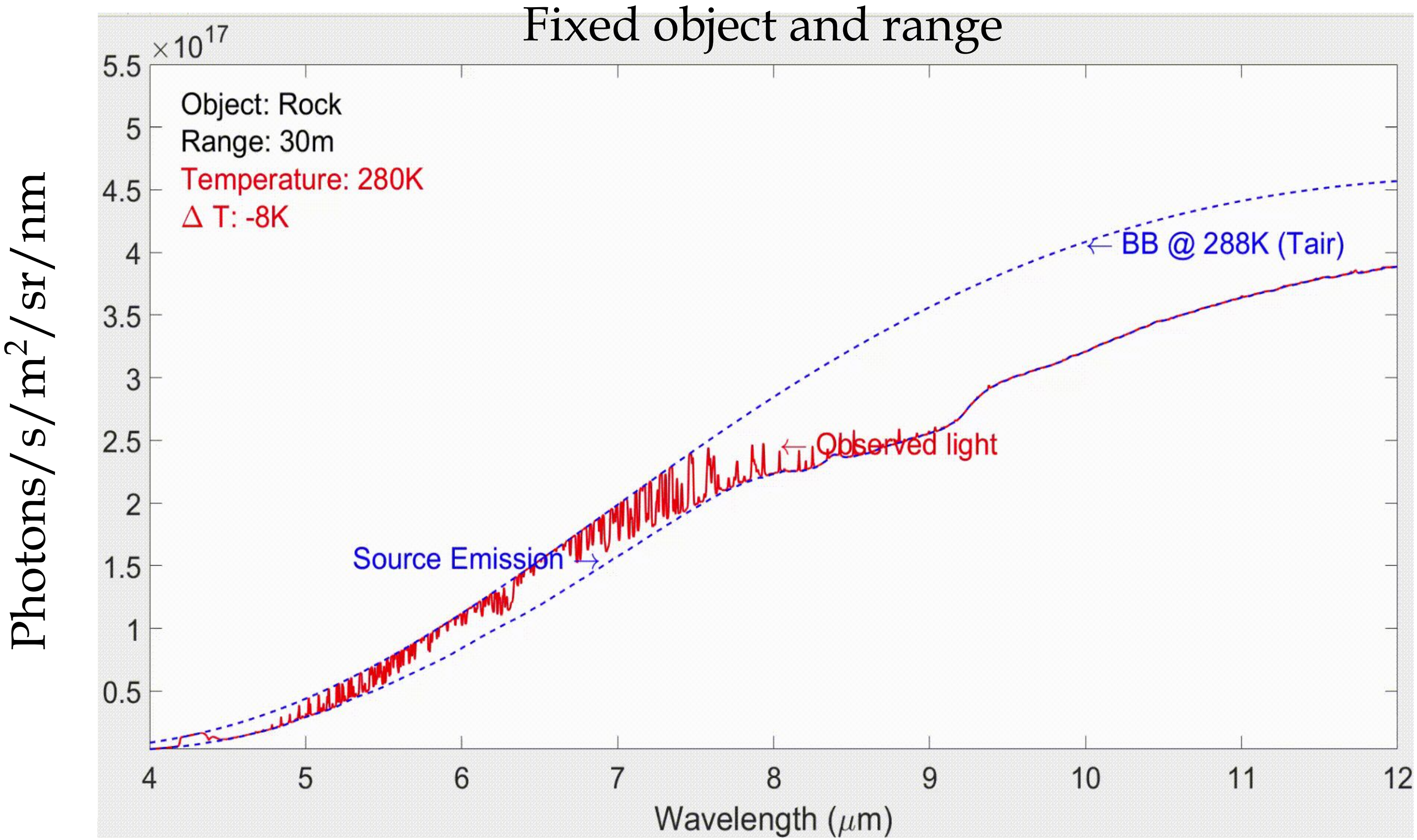
R = 1,000 (Δλ = 6 nm)
A = 10x10 μm² pixels
Ω = f/2.9 cold f-stop
t = 10 μs integration
η = 80%

SNSPD: Superconducting nanowire single-photon detector

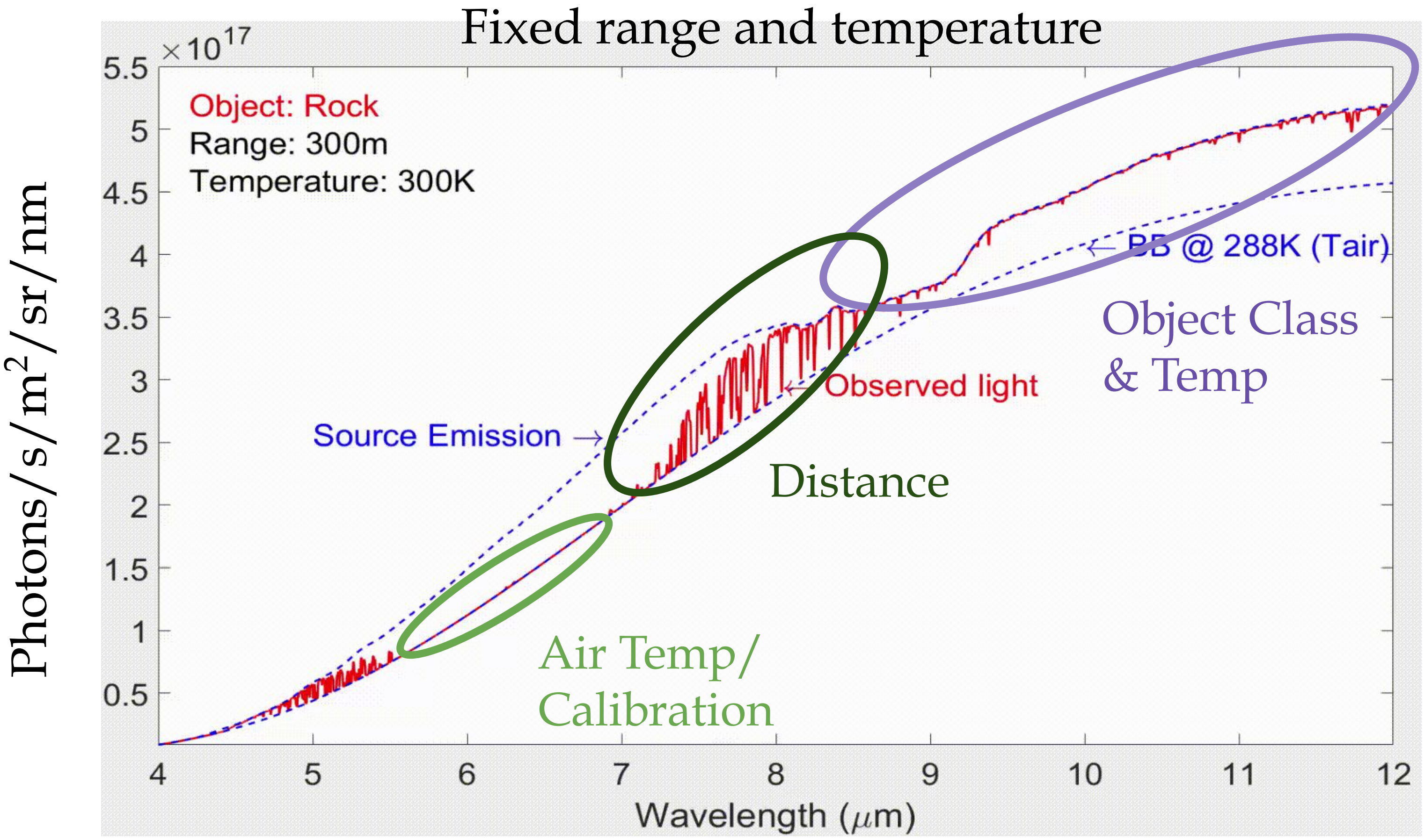
Range variation



Temperature variation



Emissivity variation

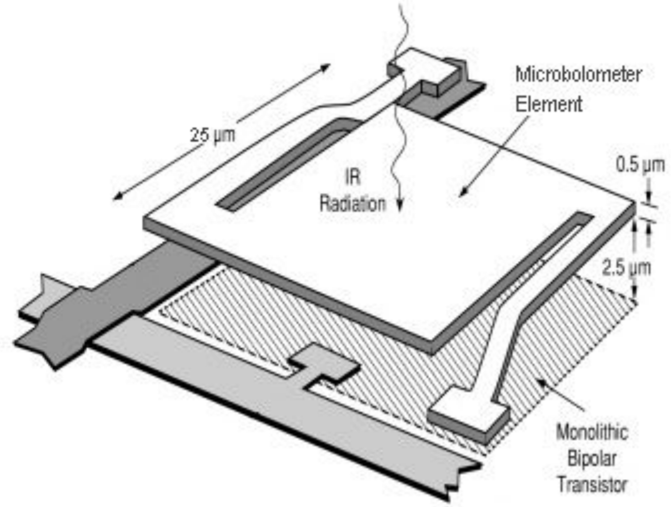


4. Sensores infrarrojos


How does a thermal
imaging camera work?

Thermal radiation through fog or smoke

Microbolómetro



Germanium (metal en vez de vidrio para el lente)

Cooled vs Uncooled

5. Thermal & CV

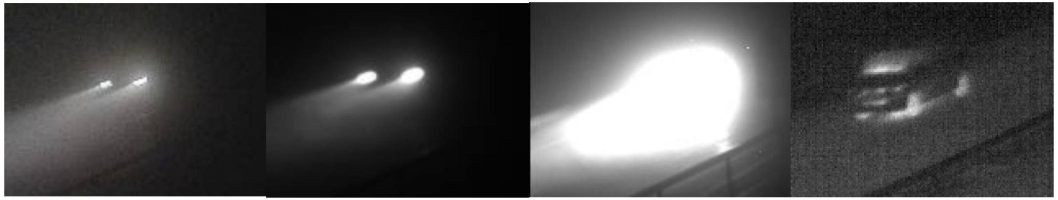

The international journal of science / 27 July 2023
nature
NIGHT VISION
Thermal physics and AI combine to let machines see in the dark
Turing point
The hunt for better ways to test the intelligence of chatbots
A place out of the sun
Why planning for shade is key to keeping cool in hot cities
Parasite restrained
A sustainable way to tackle the snails behind schistosomiasis

Let me ask you something …

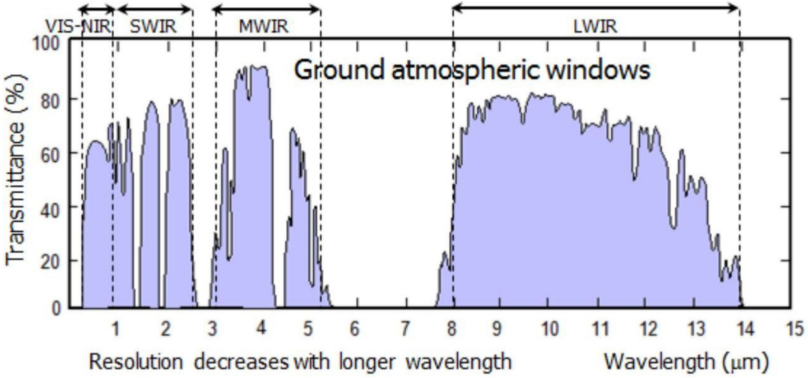
- How can we estimate the range at which objects are?
  - Passive methods: Stereo, light fields, another?
  - Active methods: Structured light, ToF, another?

- But, what if we don't want to be detected?
  - Passive

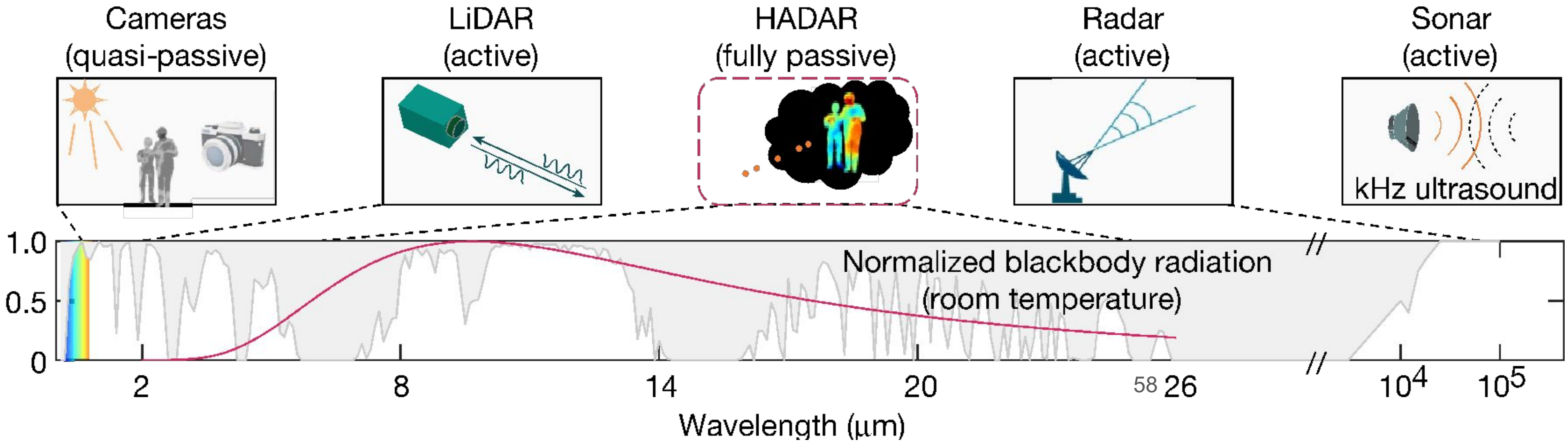
- Need to work 24/7 and at varying conditions?
  - LWIR + Atmospheric absorption



VIS NIR SWIR LWIR



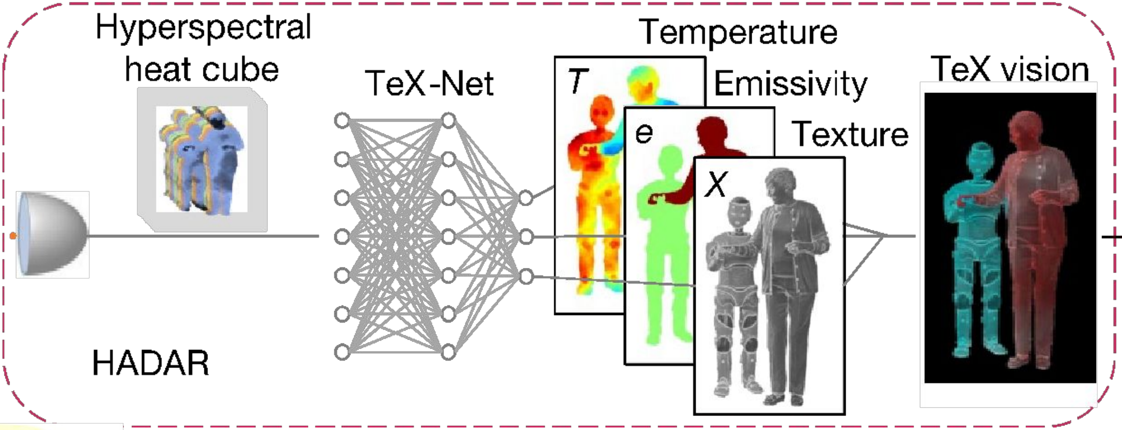
Radar, Sonar, Lidar, Hadar (**passive**)



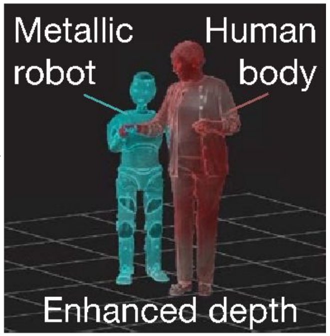
Goal: HADAR (24/7) = RGB (At daylight)

TeX Vision: Temperature, emissivity, teXture

Ghosting effect
(TeX degeneracy)



HADAR perception



On (textureless)

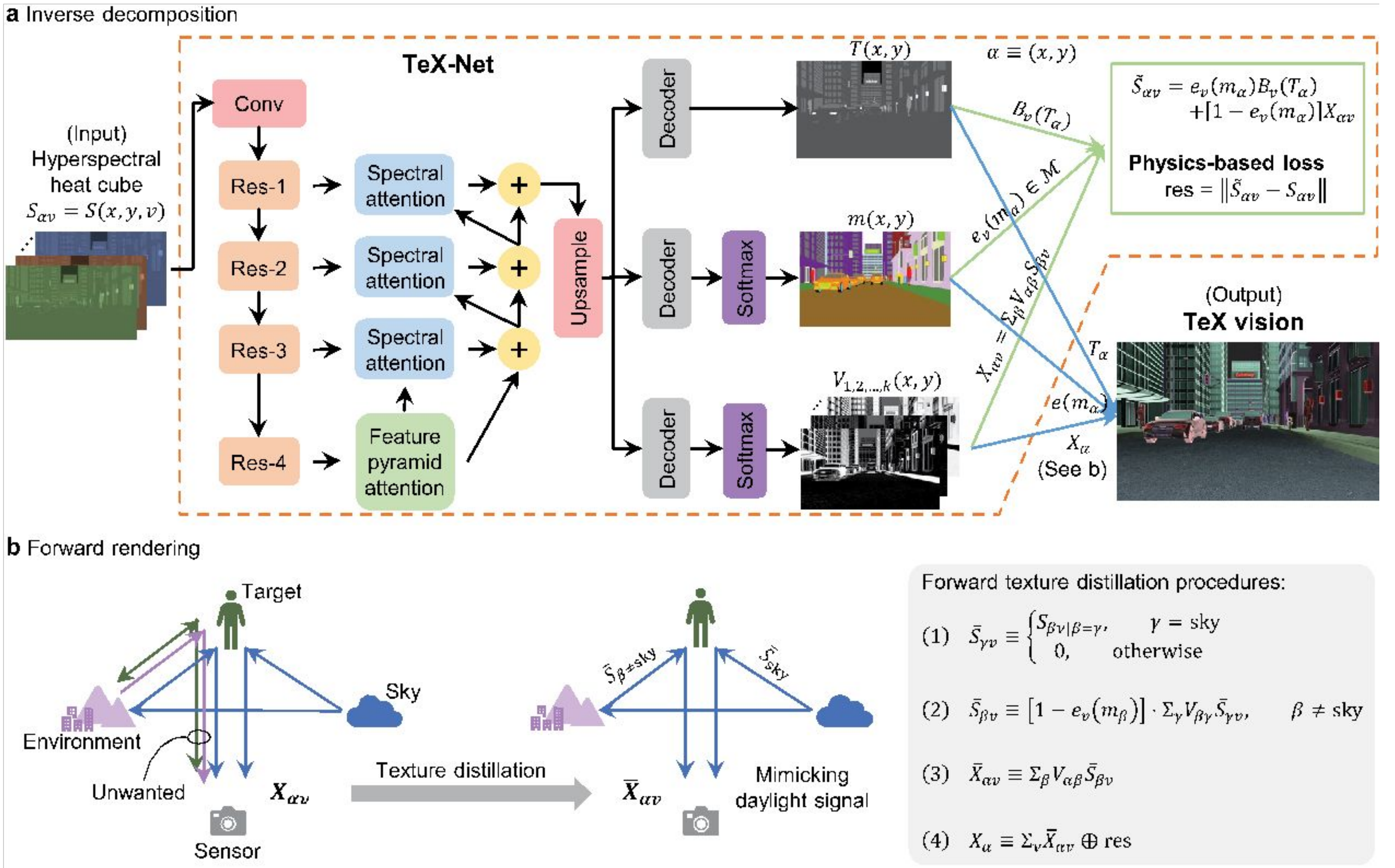
Off (textured)

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

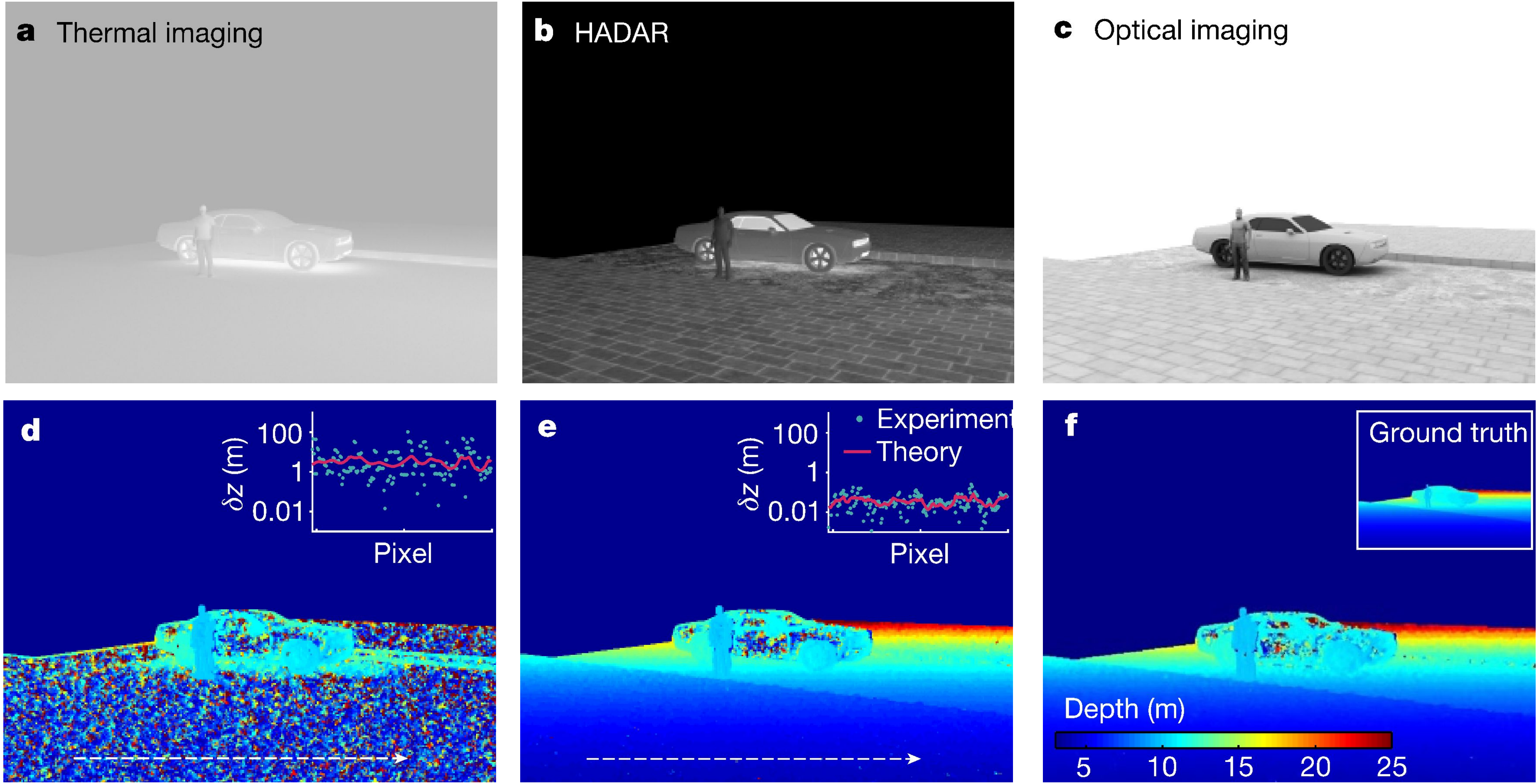
$$I_\lambda = 10^{-\frac{\alpha_\lambda L}{10}}\Big(\varepsilon_\lambda E_{b,\lambda}(T_s)\Big) + \Big(1 - 10^{-\frac{\alpha_\lambda L}{10}}\Big)E_{b,\lambda}(T_a)$$

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

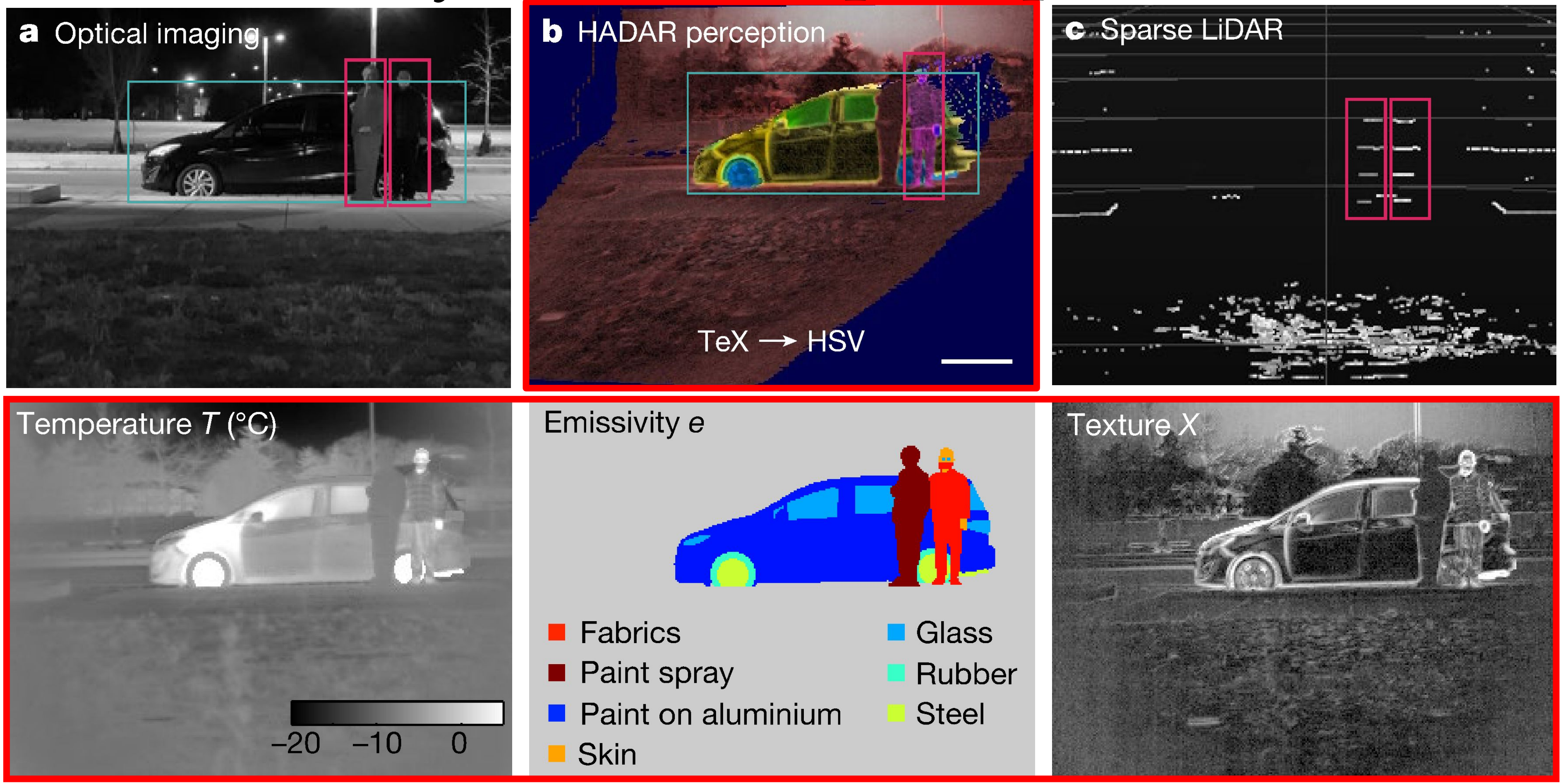
TeX-Net


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

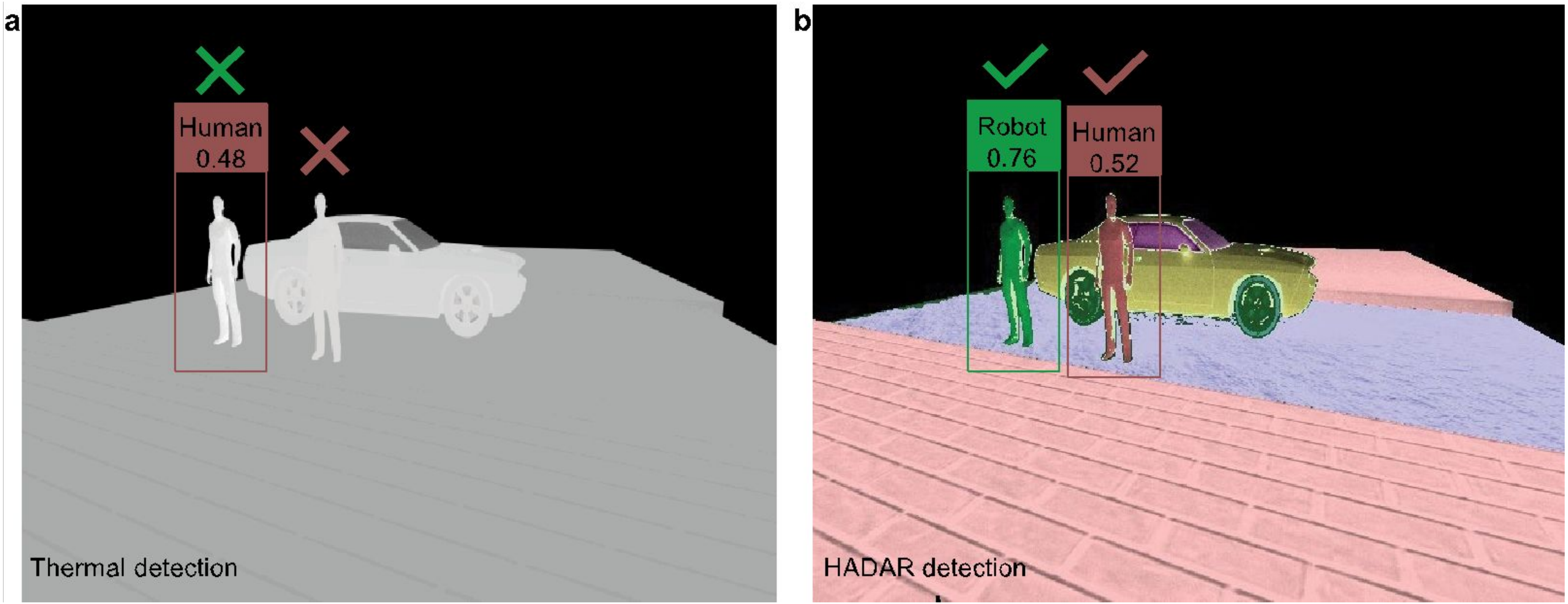
HADAR: Fundamental limits in **ranging**



HADAR: Physics-driven **perception**



Thermal detection (thermal-YOLO-V5)

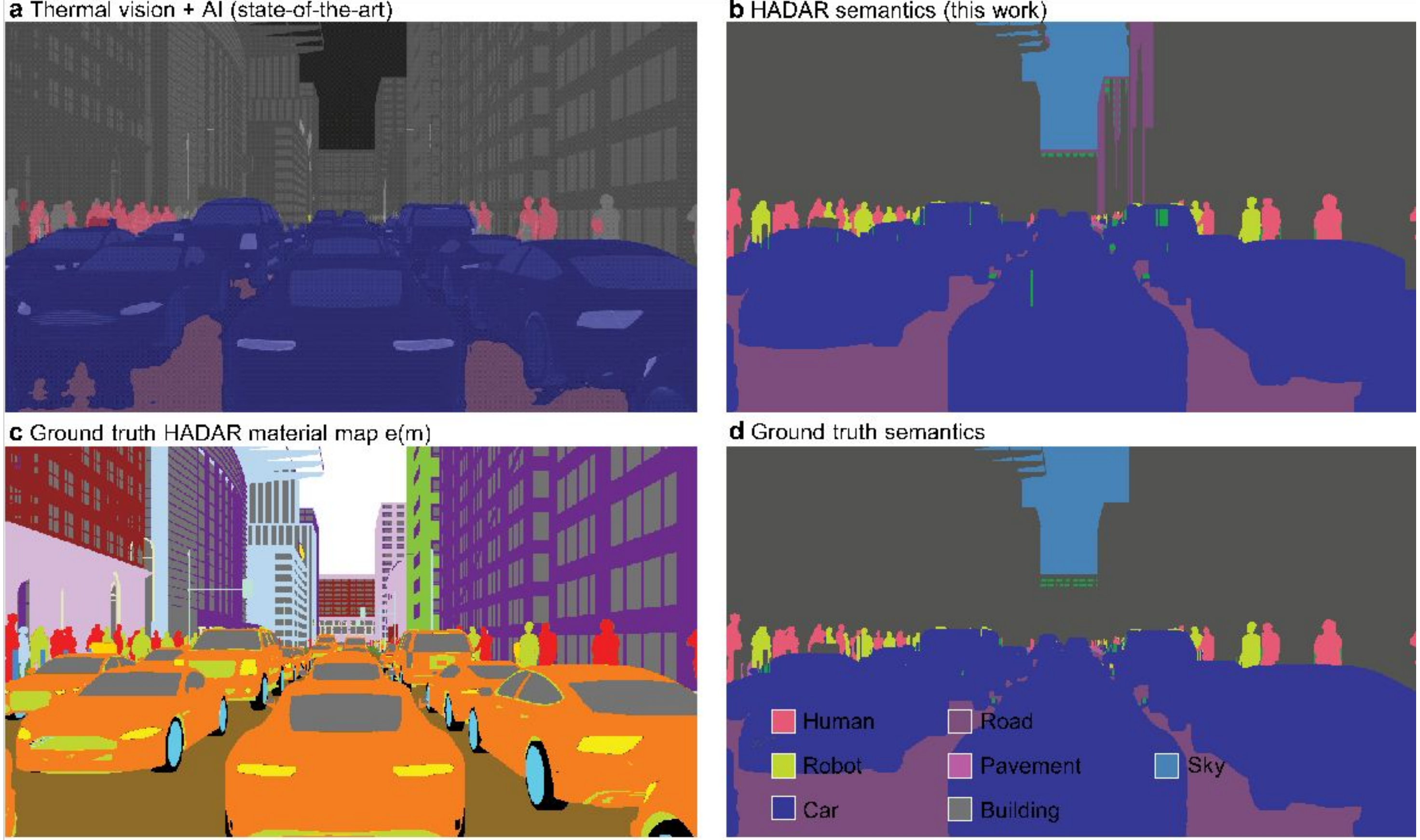


We first extract the material regions corresponding to human and robot, then we perform people detection individually and, combine detection results to form the final HADAR detection (**b**).

Thermal Semantic Segment.

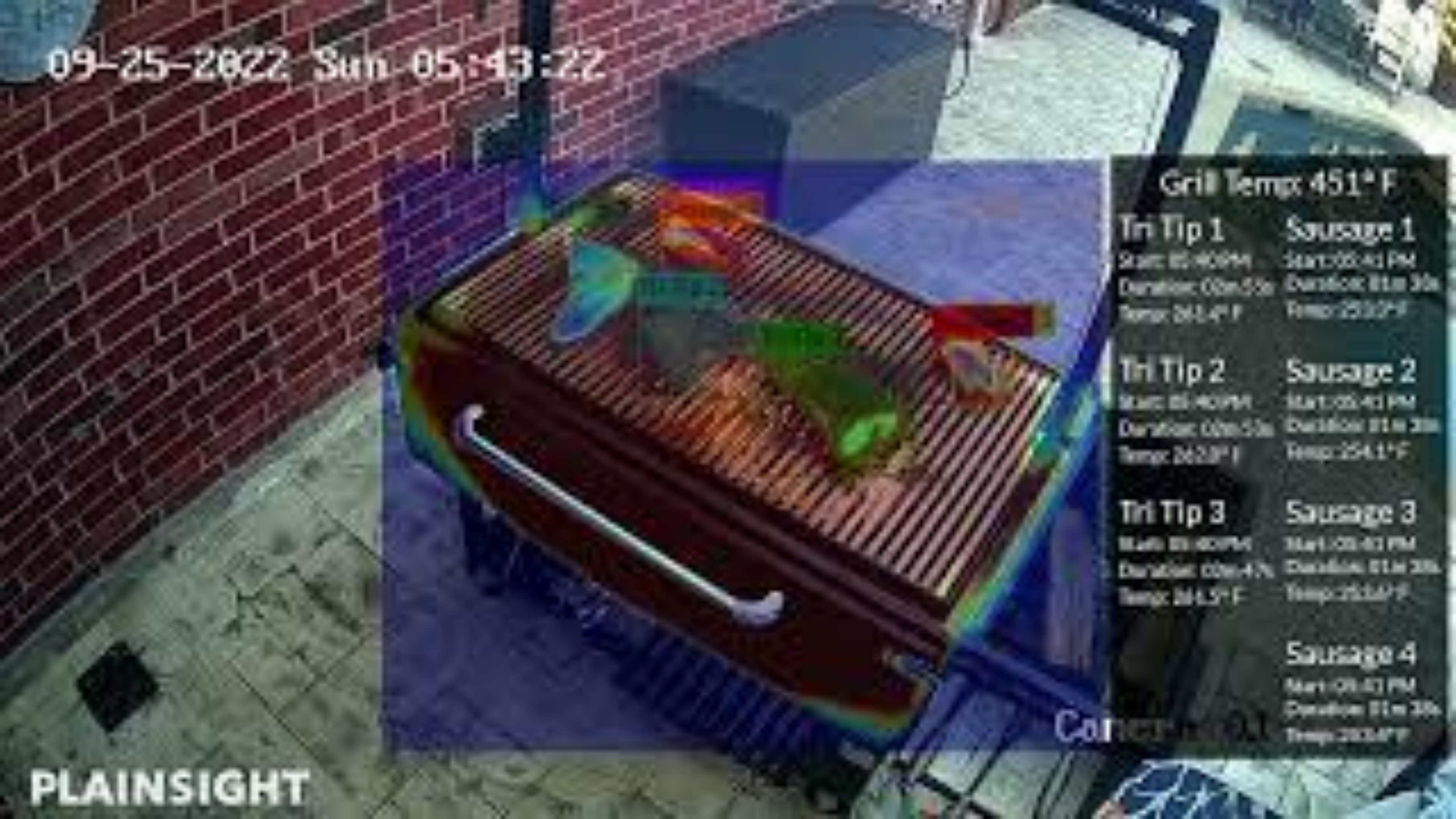
(DANet)

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

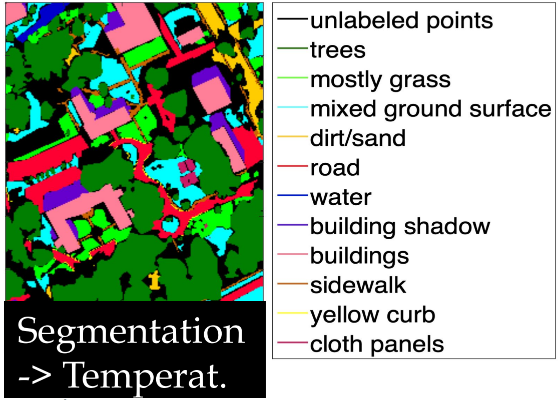
Navigation

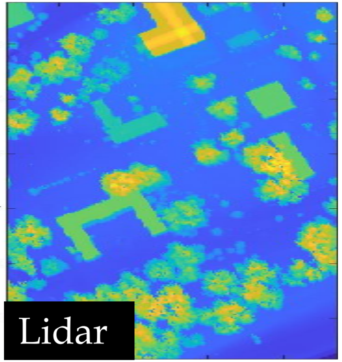

vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
vehicle
person
alwaysAI

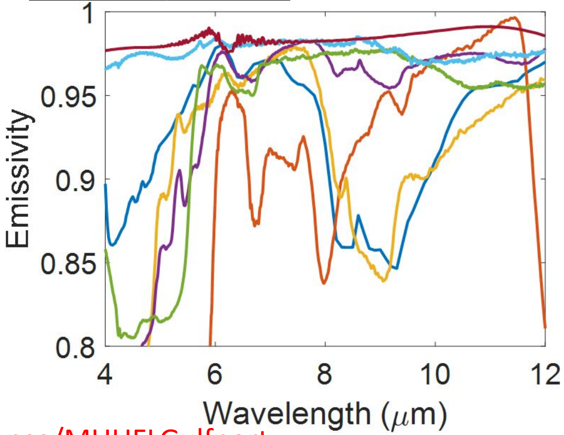
Material Segmentation (Cooling-in, Cooling-off)

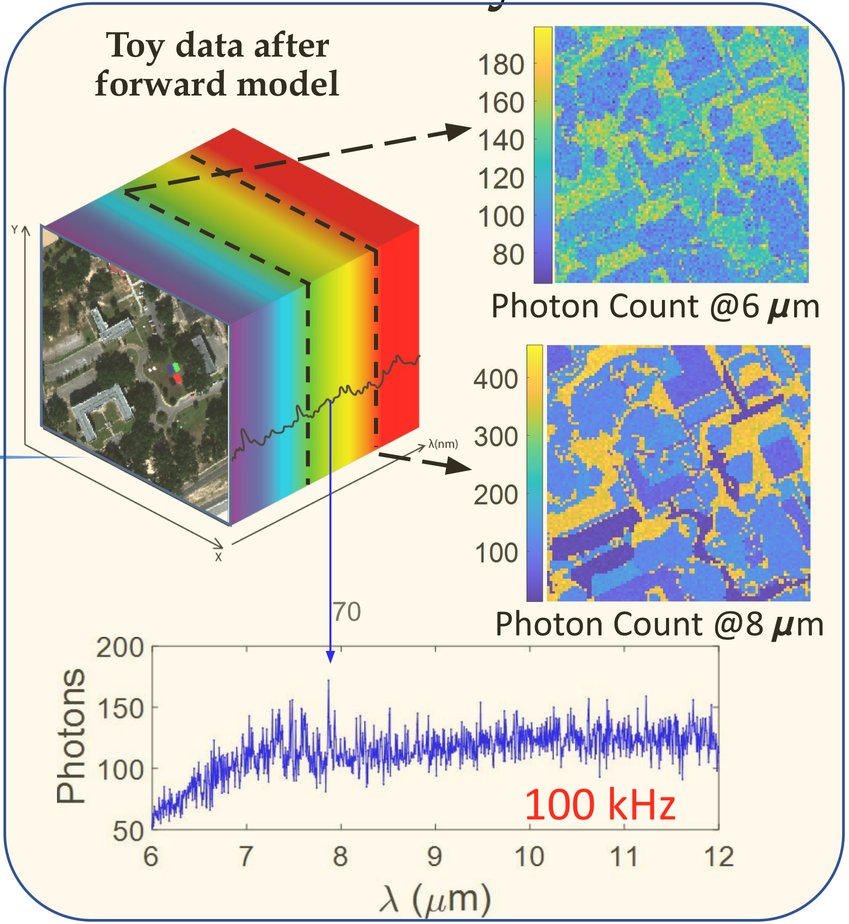
6. Hands-on: Thermal Imaging

Computational image formation and analysis





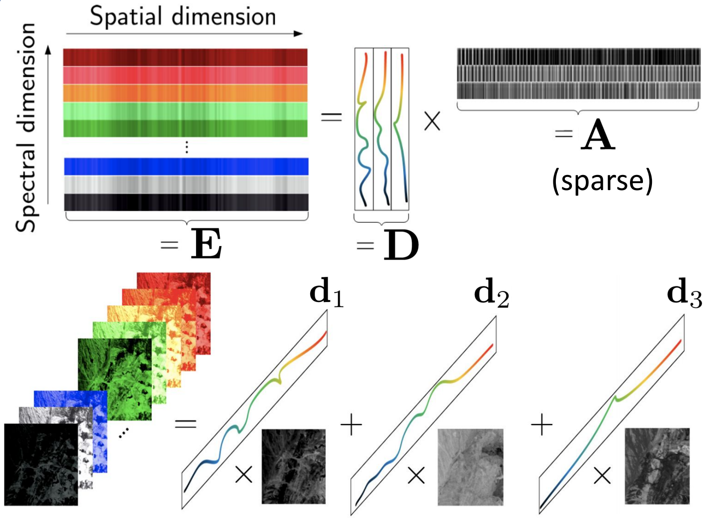




https://github.com/GatorSense/MUUFLGulfport

Computational image estimation — Overview

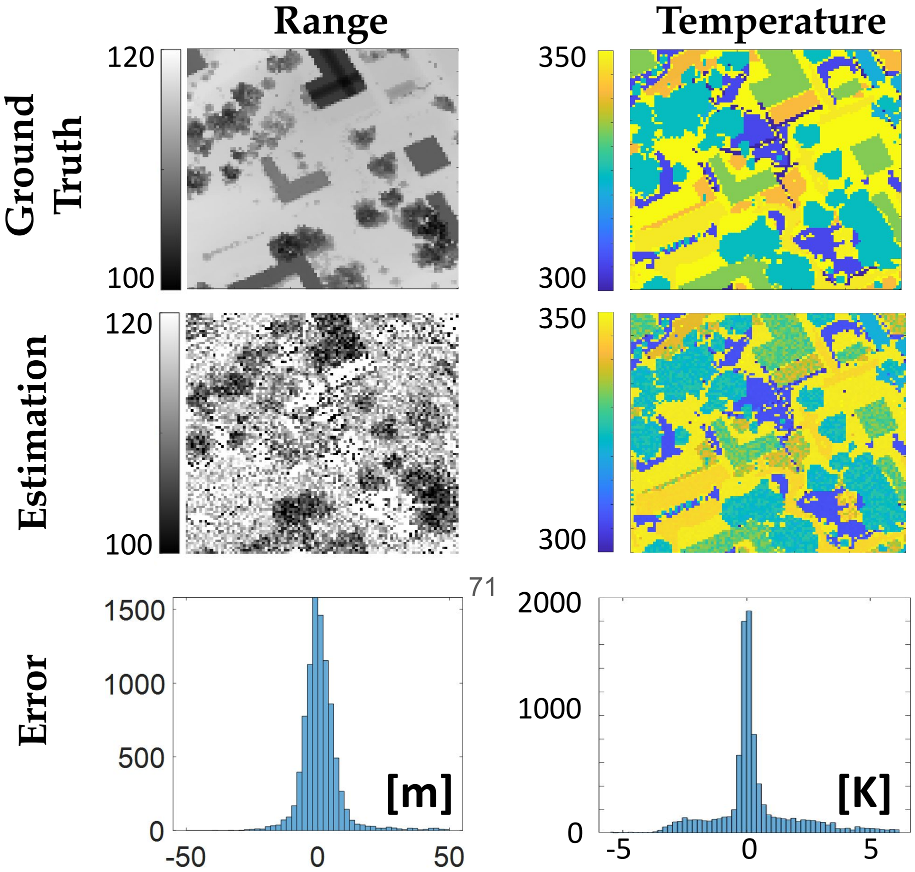
Linear mixing model (LMM)



Inverse problem: $\underset{\boldsymbol{\rho}}{\operatorname{argmin}} \ \mathcal{L}(\mathbf{y}|\boldsymbol{\rho})$
(MLE Poisson)

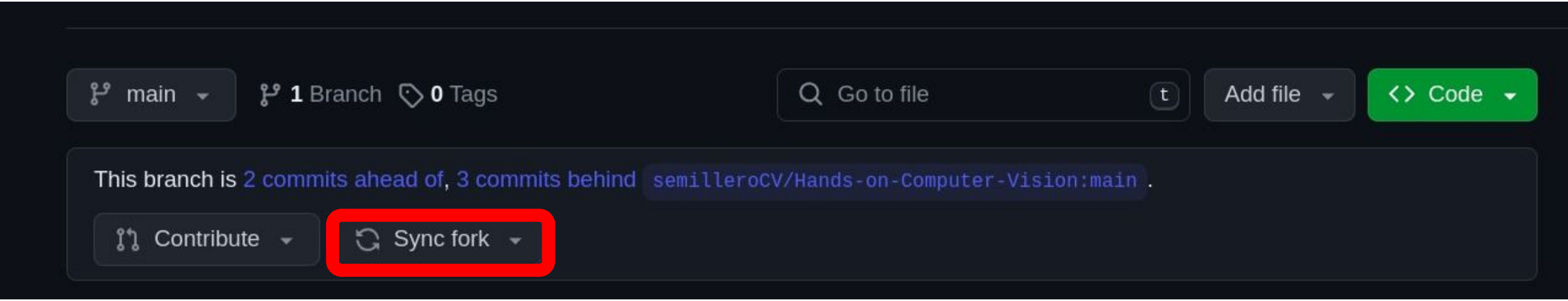
With LMM: $\underset{\mathbf{L},\mathbf{T},\mathbf{A}}{\operatorname{argmin}} \ \mathcal{L}(\mathbf{y}|\mathbf{L},\mathbf{T},\mathbf{A}) + \beta\|\mathbf{A}\|_1$

"Solved via gradient-descent ADMM"

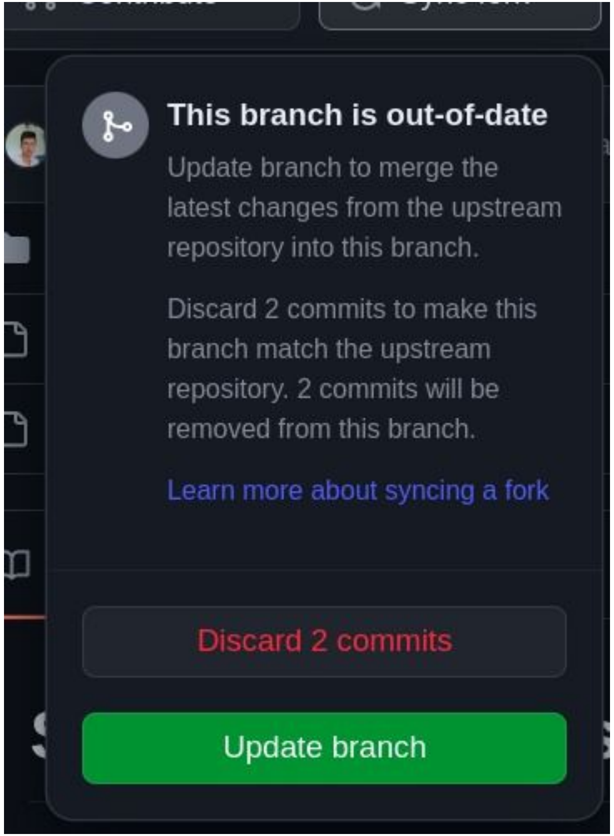


The majority of distances are estimated with <10% error and temperatures are estimated with <1 K err

Actualicemos el repositorio!



Actualicemos el repositorio!



Actualicemos el repositorio!