



TSBB21

# Infrared and Multispectral Imaging

**TSBB21 Computational Photography**

**Jörgen Ahlberg**

# Contents of today's lecture

- Light, radiation, matter
- Thermal imaging
  - Cameras
  - Applications
- Multi/hyperspectral
  - What?
  - Why?
  - How?
- Demo

# Light & Radiation





From where comes the radiation that I see?

Emitted

Transmitted

Reflected

Absorbed

# F. W. Herschel



Symphony No. 15 (1762)

<https://open.spotify.com/track/okQcVlkww2LJQ49KXnklVe>



# Caroline & William Herschel

- 1 planet
- 4 moons
- 8 comets
- 5000 other objects

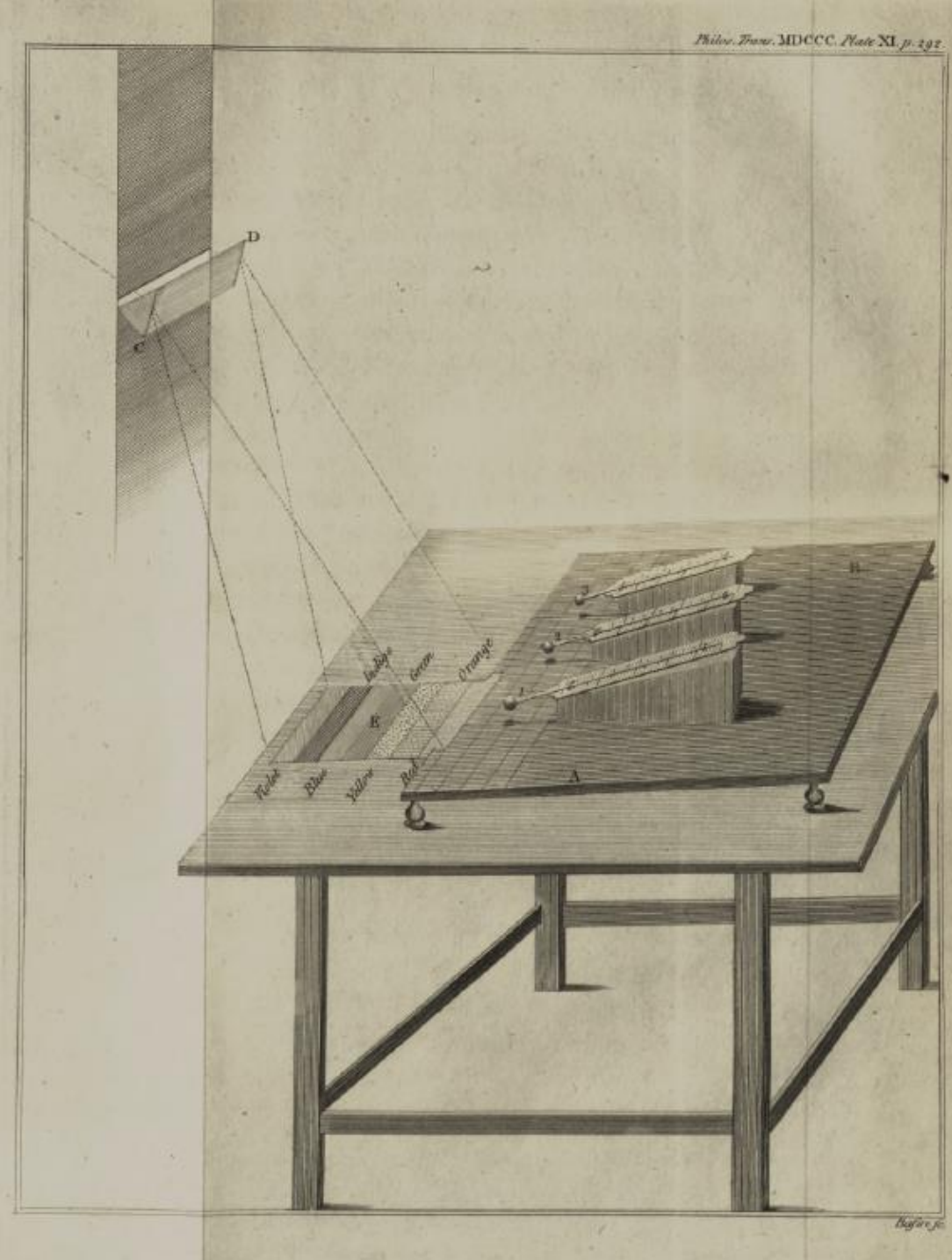


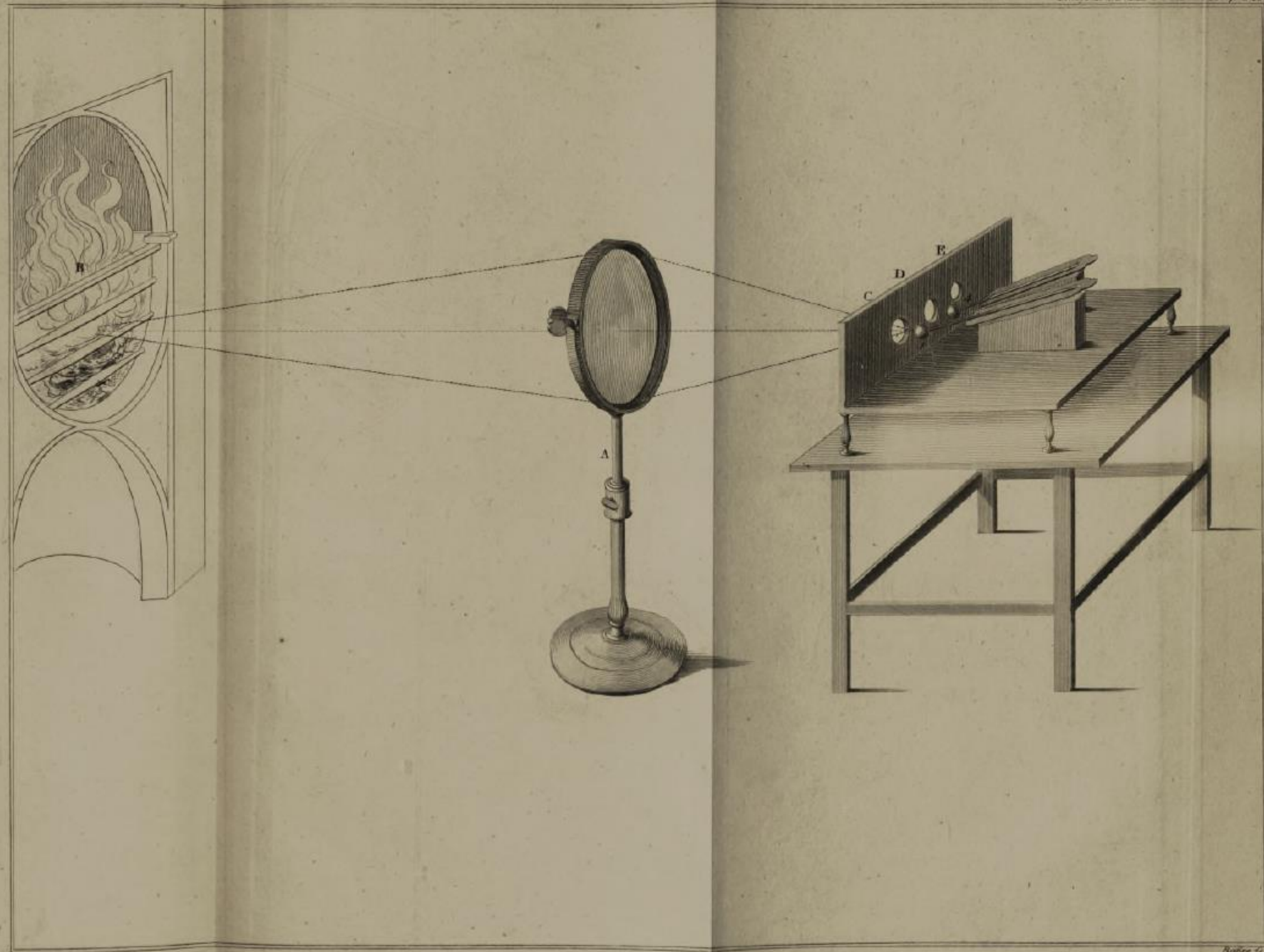


# Herschel 1800a

*“In this case, radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum as to be unfit for vision.”*

F. W. Herschel, “Experiments on the refrangibility of the invisible rays of the Sun,” *Philos. Trans. R. Soc.*, vol. 90, pp. 284–292, 1800.  
doi: 10.1098/rstl.1800.0015

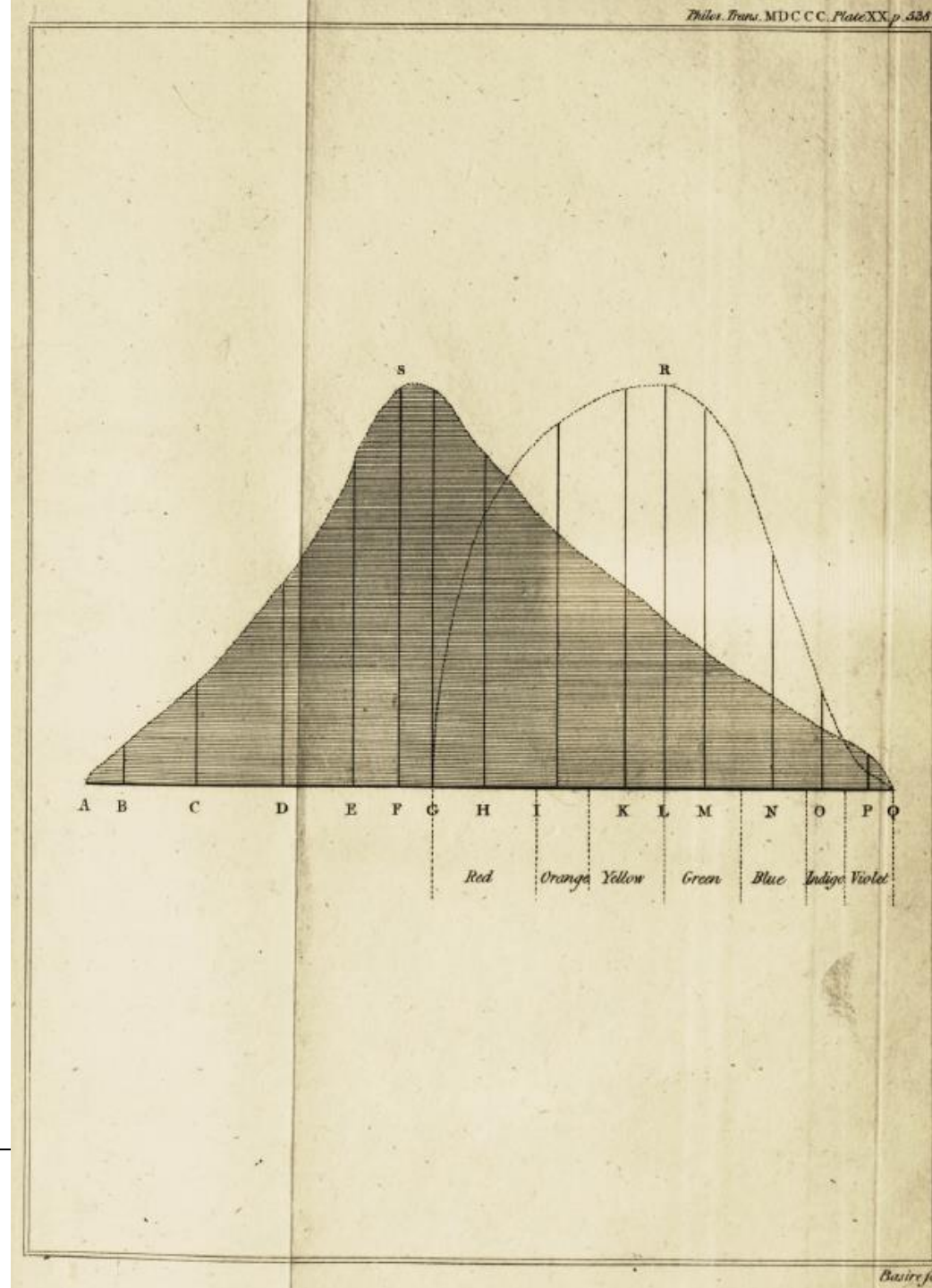


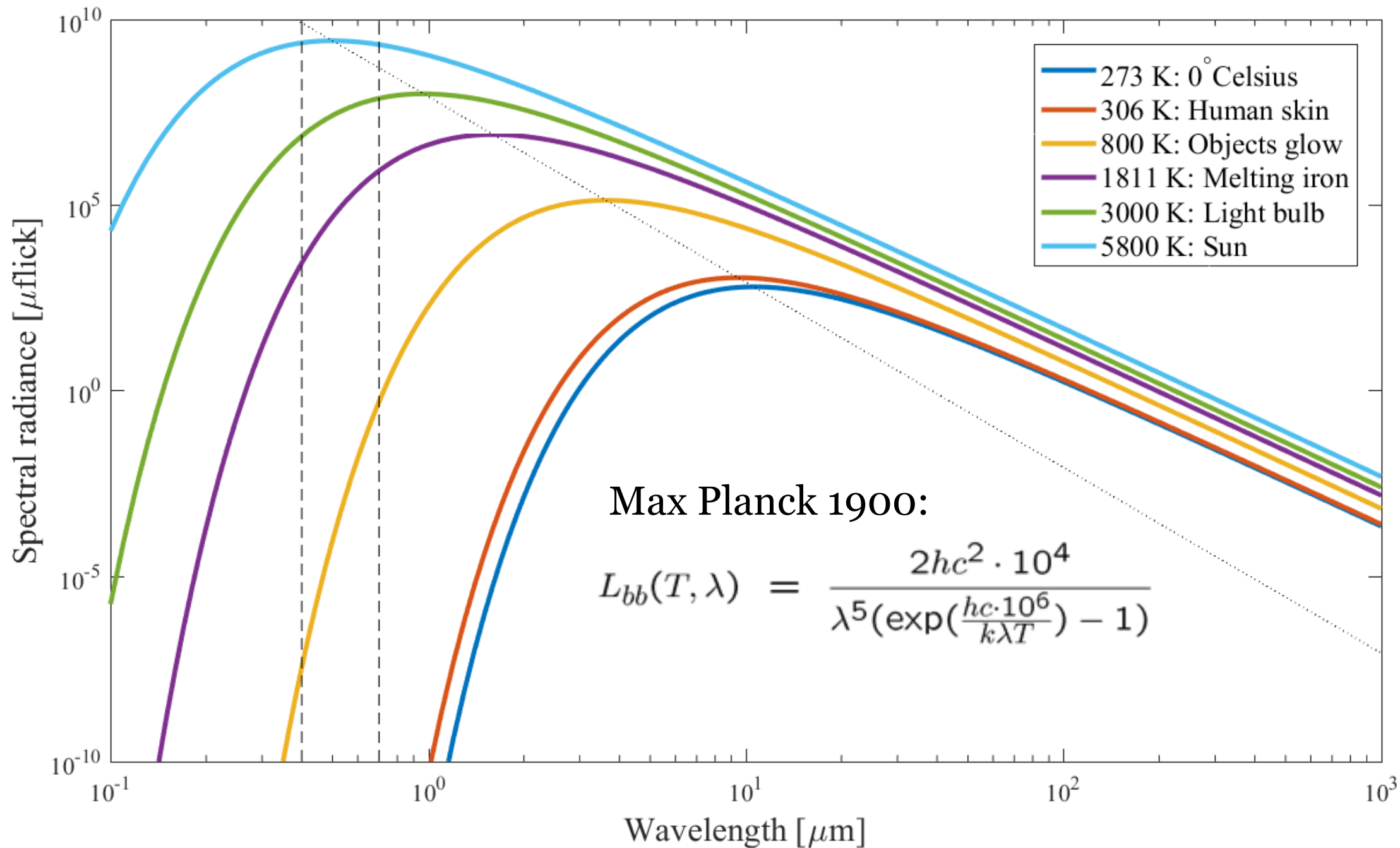


# Herschel 1800b, c

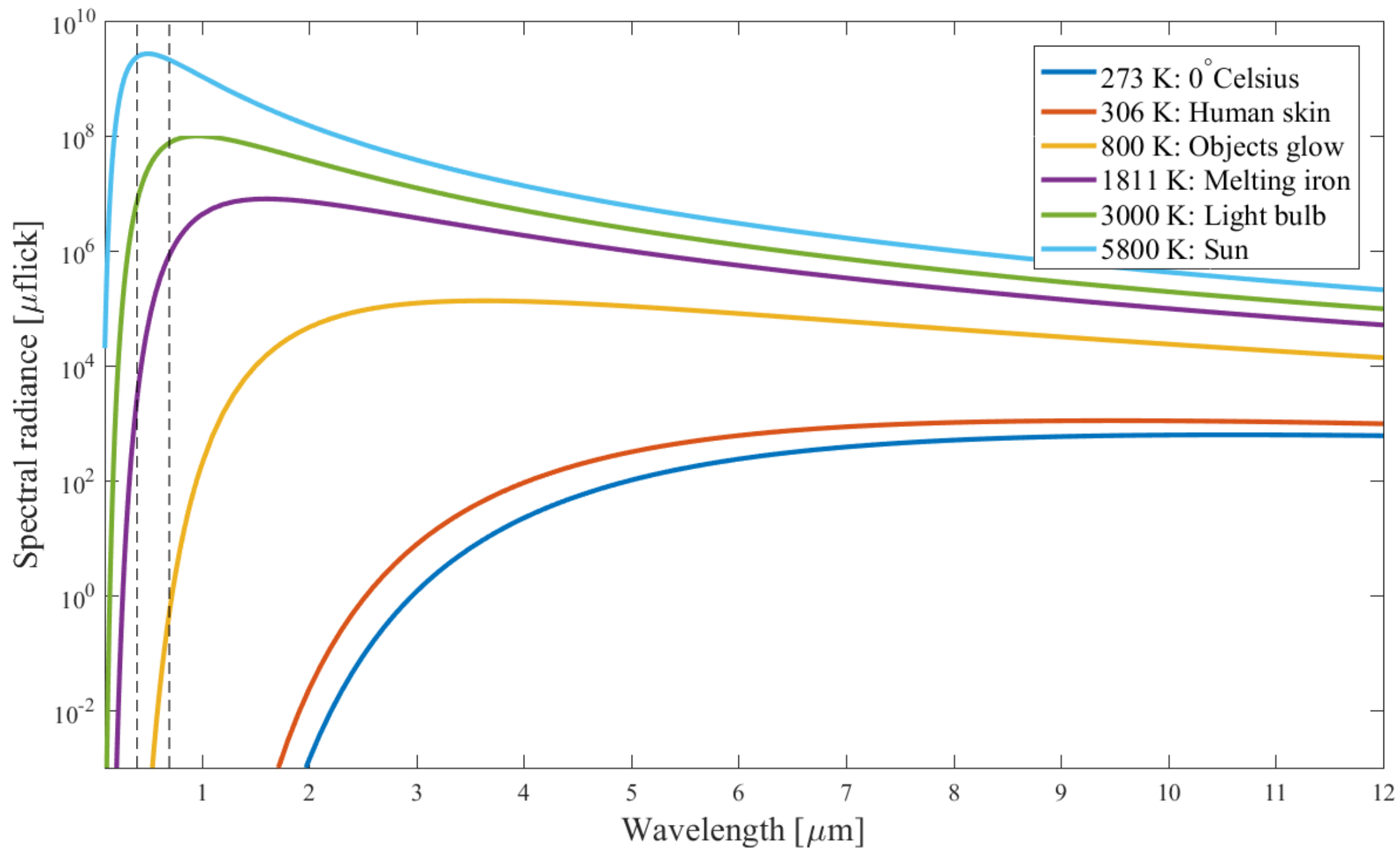
F. W. Herschel, "Experiments on the Solar, and on the Terrestrial Rays that Occasion Heat; With a Comparative View of the Laws to Which Light and Heat, or Rather the Rays Which Occasion Them, are Subject, in Order to Determine Whether They are the Same, or Different. Part I," *Philos. Trans. R. Soc. London*, vol. 90, pp. 293–326, Jan. 1800.  
doi: 10.1098/rstl.1800.0016

F. W. Herschel, "Experiments on the Solar, and on the Terrestrial Rays that Occasion Heat; With a Comparative View of the Laws to Which Light and Heat, or Rather the Rays Which Occasion Them, are Subject, in Order to Determine Whether They are the Same, or Different. Part II," *Philos. Trans. R. Soc. London*, vol. 90, pp. 437–538, Jan. 1800.  
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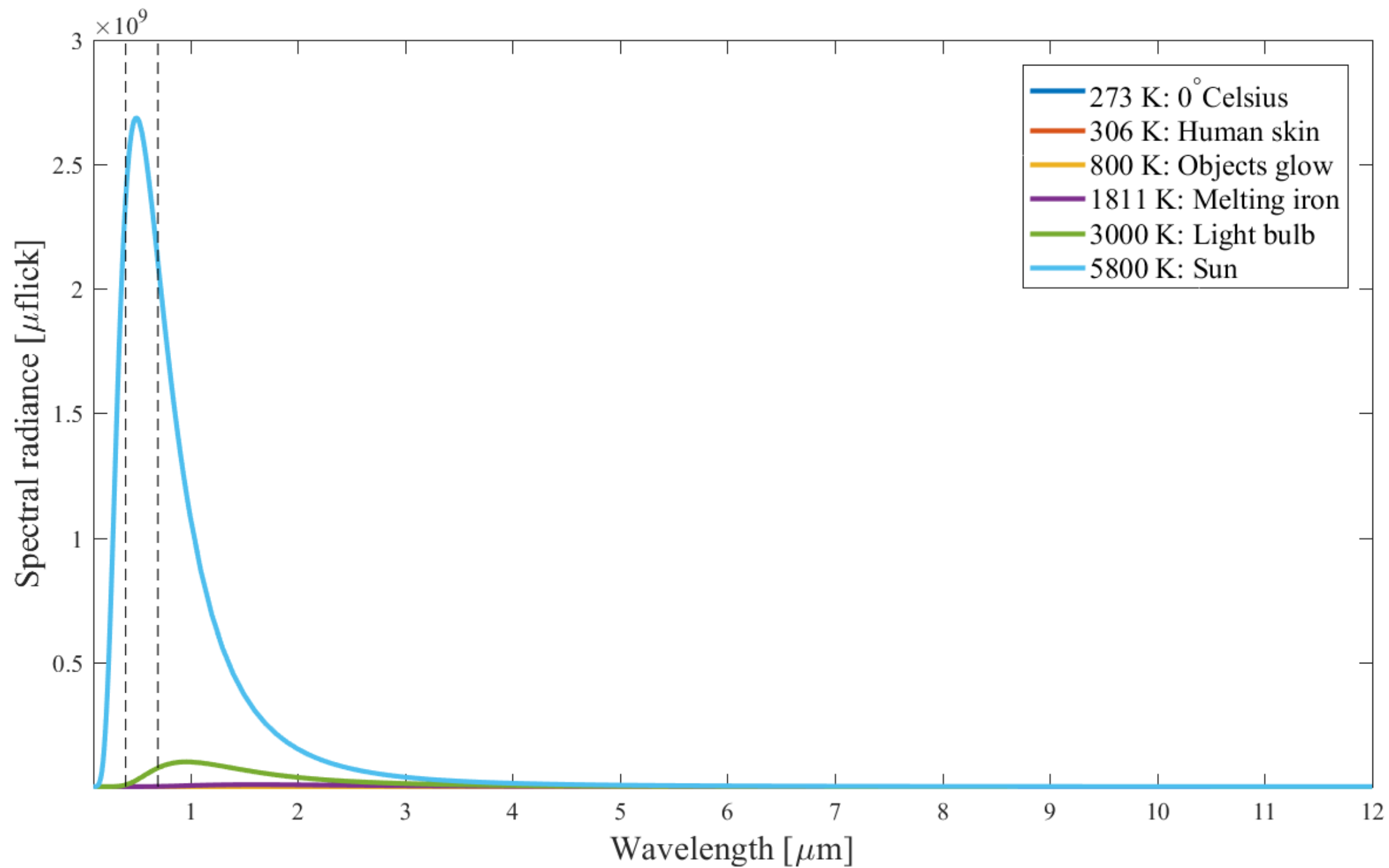


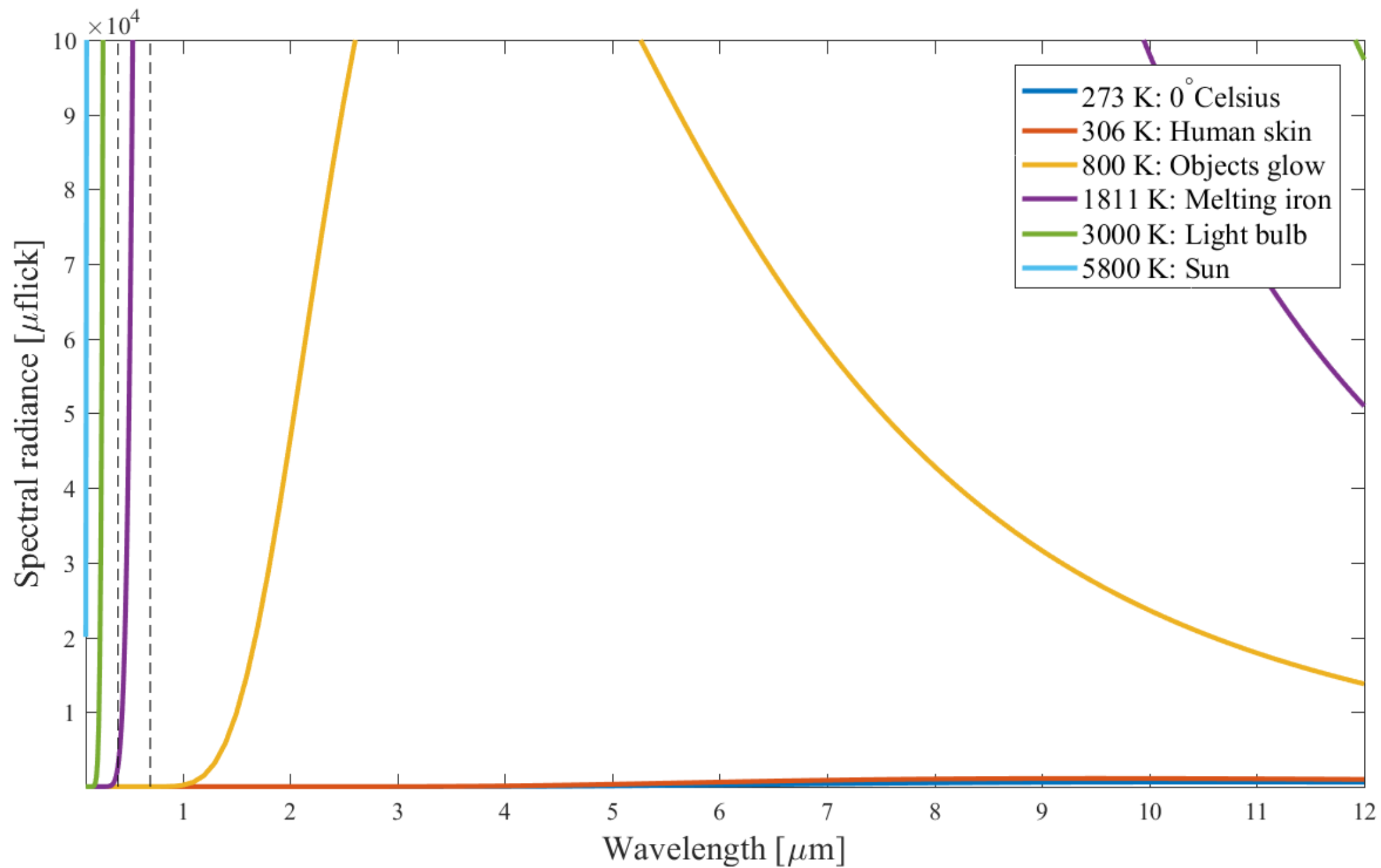




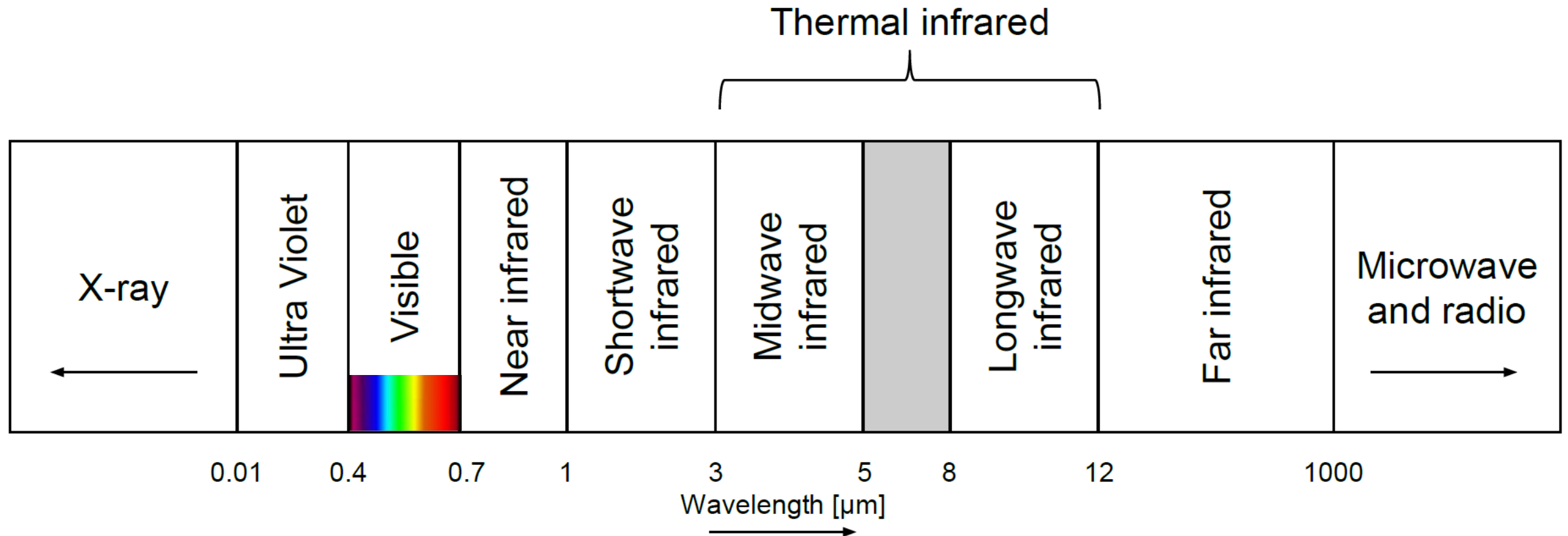




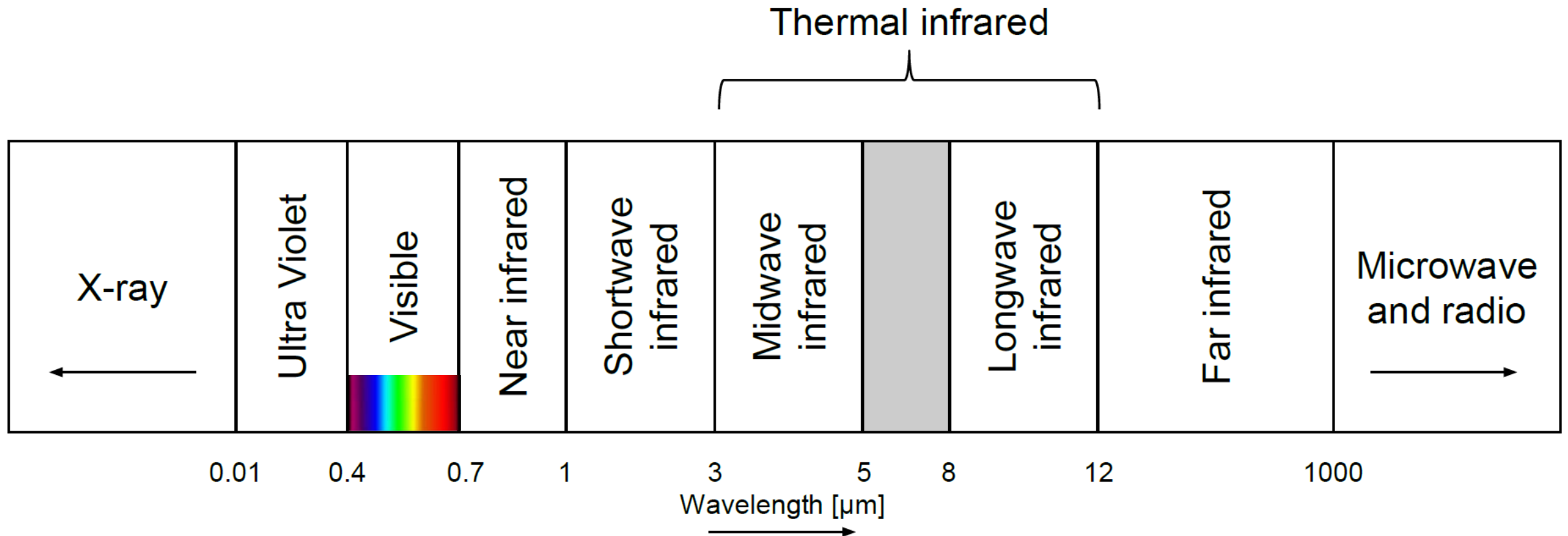




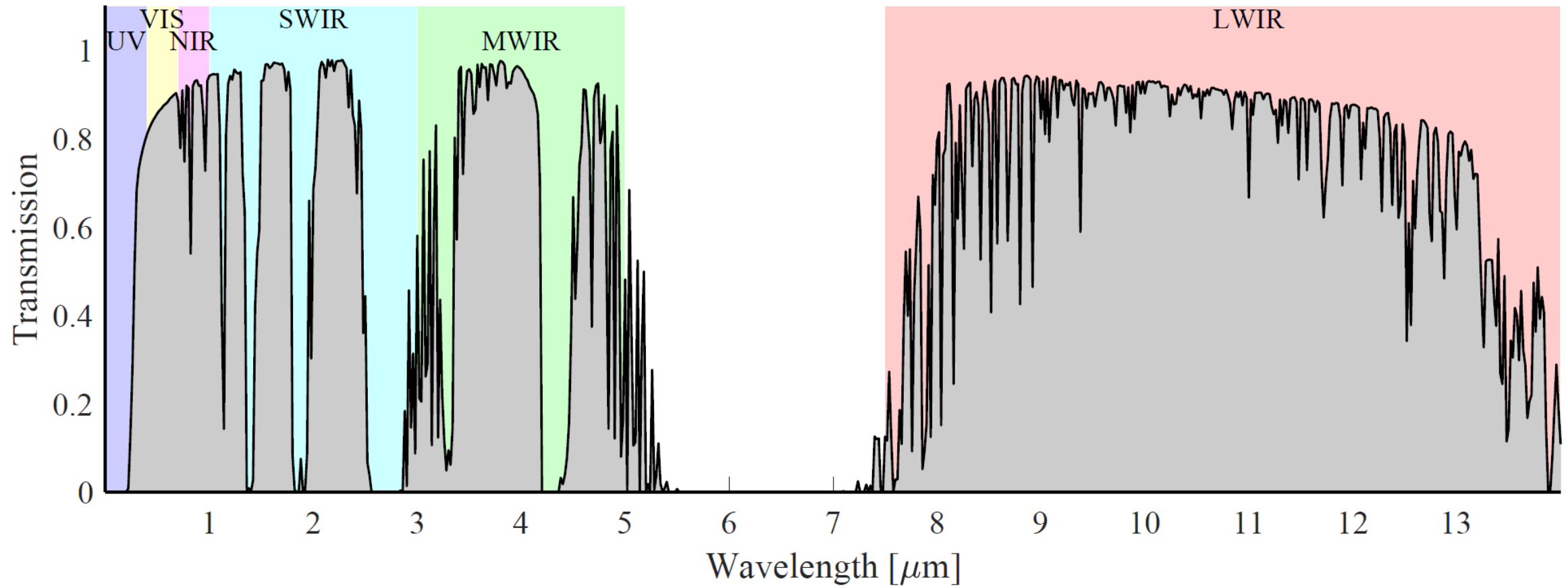
# Domains and wavelengths and bands



# Why this particular division?



# Reason 1: Atmospheric transmission





## Reason 2: Behaviour

- Reflective domain
- Emissive domain

## Reason 3: Sensors

- VNIR: Silicon (CCD, CMOS)
- SWIR: InGaAs sensors
- MWIR: InSb and MCT sensors
- LWIR: MCT and bolometer sensors

Note:

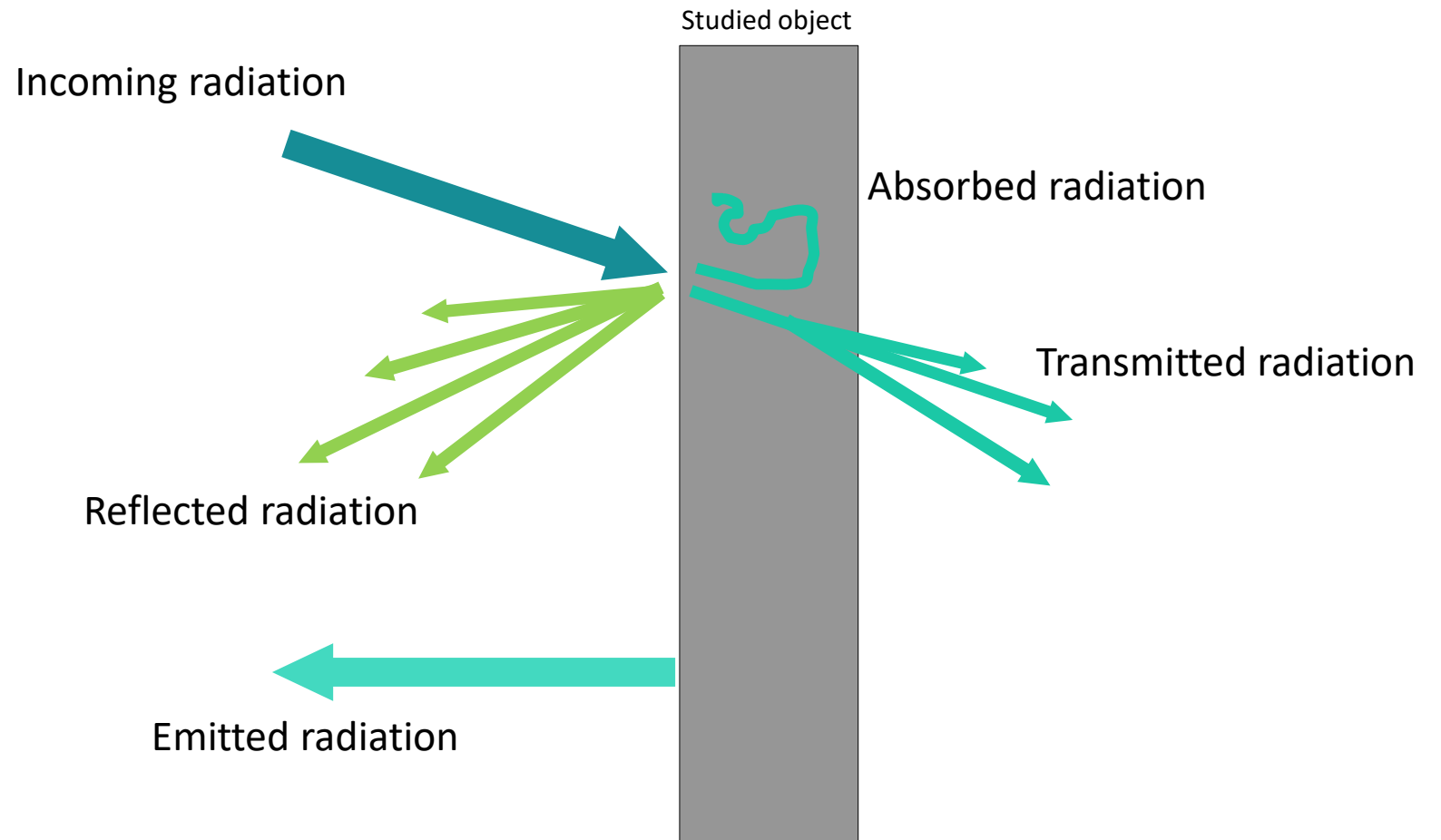
There are other subdivisions!  
For example, astronomers use:

- NIR 0.7-5
- MIR: 5-(25...40)
- FIR: (25-40)-

# Radiation & Matter

# Radiation and matter

- Absorbed
- Reflected
- Transmitted
- Emitted
- Scattered
- Diffracted



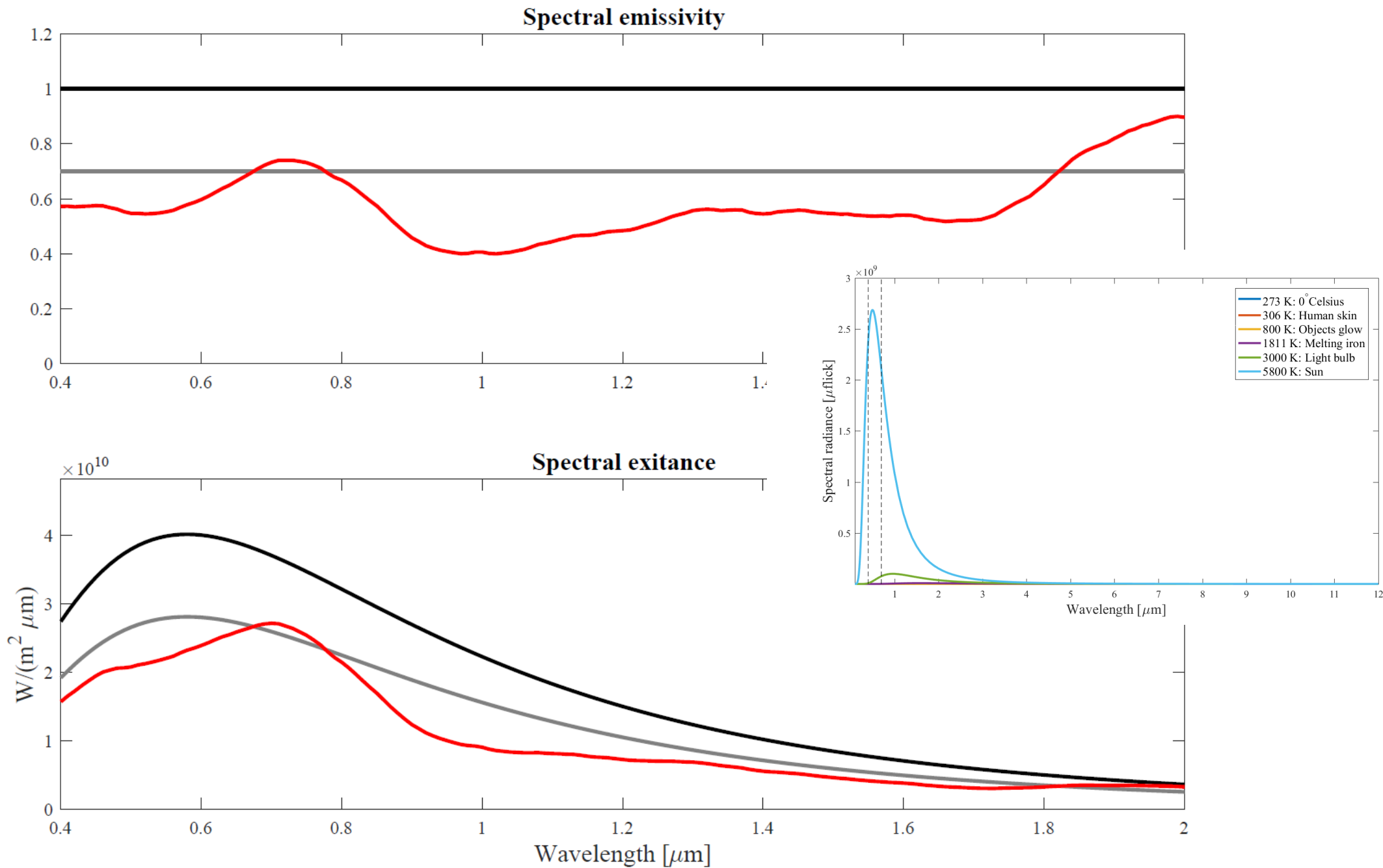
$$\alpha + \tau + r = 1$$

$$\alpha(\lambda) + \tau(\lambda) + r(\lambda) = 1$$



# Emissivity ( $\varepsilon$ )

$$\alpha = \varepsilon$$



- Absorptivity  $\alpha$
- Emissivity  $\varepsilon$
- Transmittance  $\tau$
- Reflectance  $r$

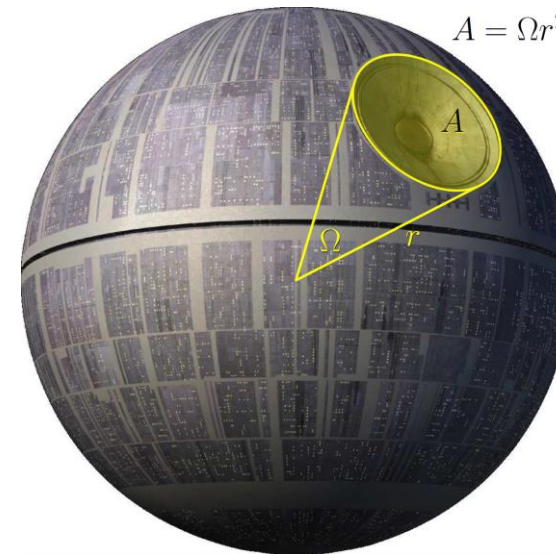
- $\alpha + \tau + r = 1$
- Dependent on wavelength and angle!
- Commonly:  $\tau$  or  $r$  close to zero.

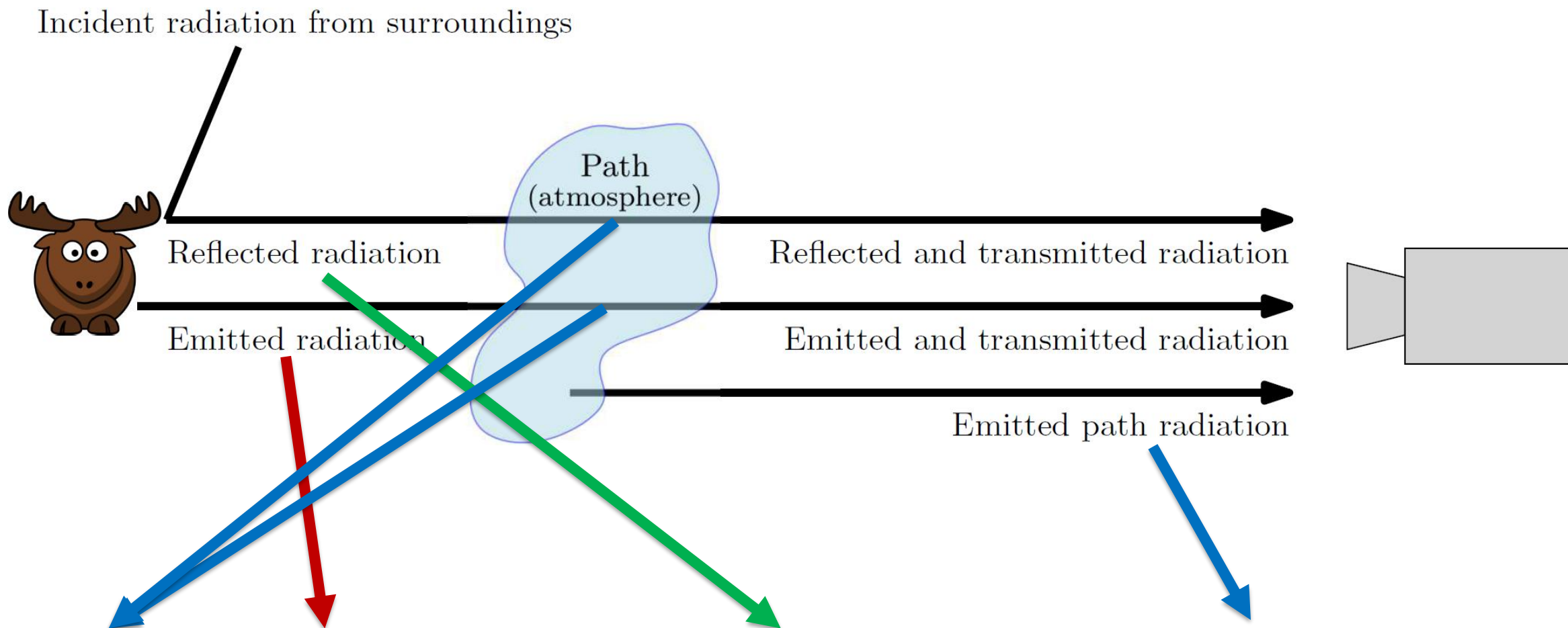
*Outgoing radiation*

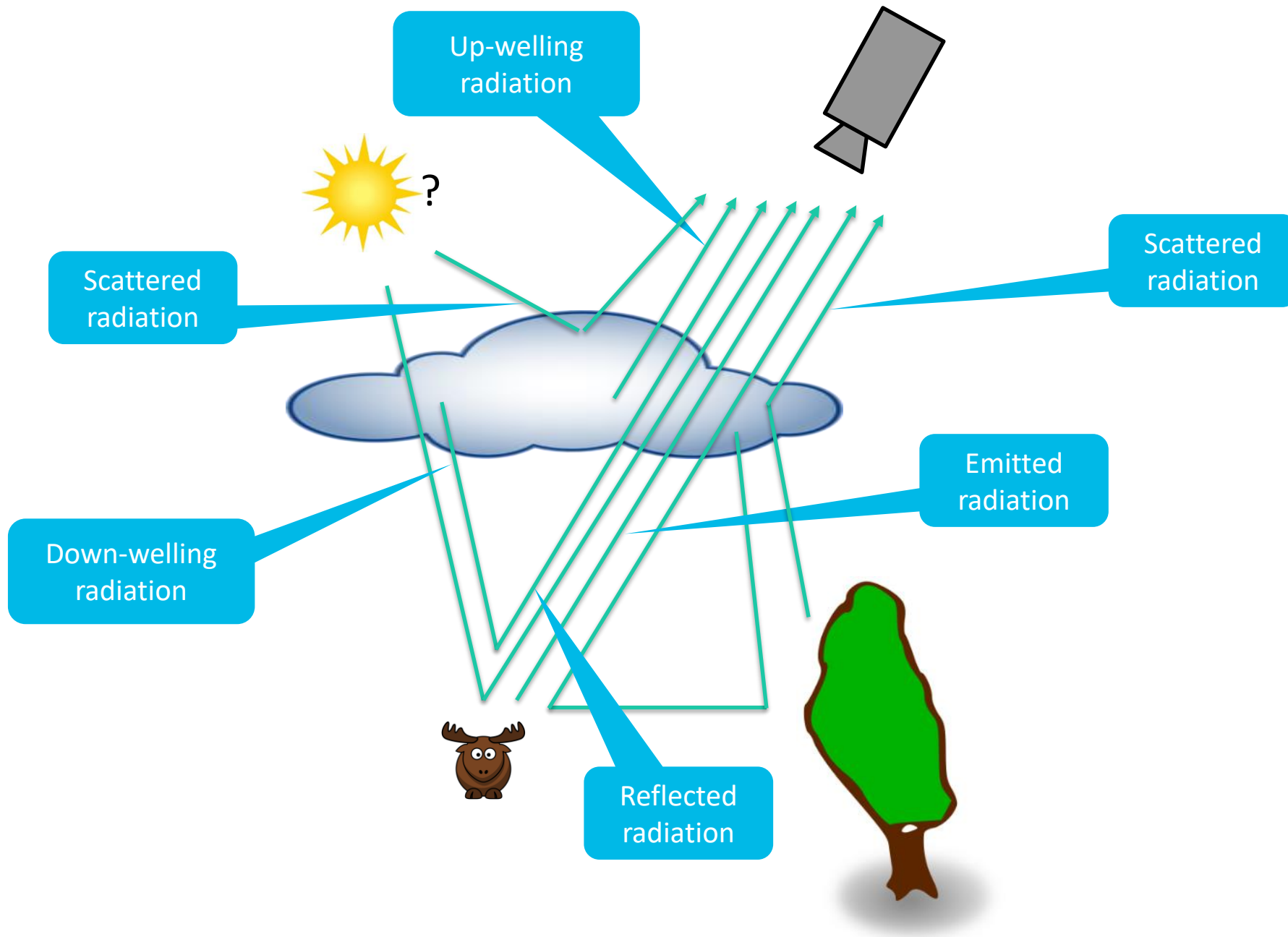
- (Radiant) Flux  $\Phi$  [W]
- Irradiance  $E$  [W / m<sup>2</sup>]
- Exitance  $M$  [W / m<sup>2</sup>]
- Radiance  $L$  [W / m<sup>2</sup> sr]

*Incoming radiation*

*steradian*







# From object to sensor

- A sensor integrates the incoming energy over a certain bandwidth.
- The at-sensor radiance is (mainly and typically) the sum of
  1. Radiation emitted by the object and transmitted through the path;
  2. Radiation reflected by the object transmitted through the path;
  3. Radiation emitted by the path;
  4. Radiation scattered by the path.
- This does not equal the temperature of the object!


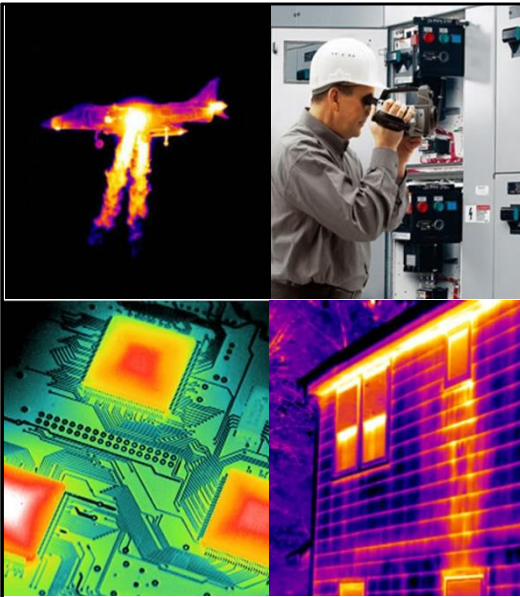
# Summary: Light and radiation

- Radiators: Blackbodies, greybodies, general objects.
- Properties: Emissivity, absorptivity, reflectance, transmittance.
- Radiation often measured as flux, radiance, and irradiance.
- Domains: Reflective vs emissive.
- Bands: UV, VIS, NIR, VNIR, SWIR, MWIR, LWIR, TIR, FIR.



# Thermal cameras

# Thermal cameras

			
Defence		Thermography	
Imaging (non radiometric)		Temperature measuring (radiometric)	

## Handheld



## Industrial



## High-end (defence)



## High-end (science)



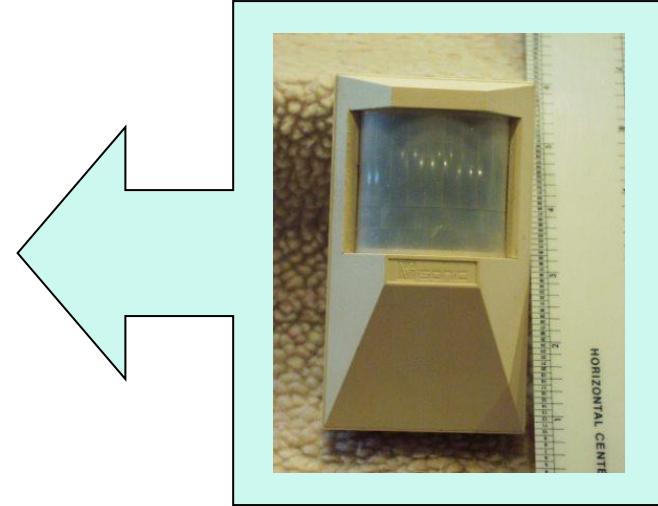
# Cooled and uncooled cameras

Sensor type / material		Used for
<b>Cooled</b>		
Mercury cadmium telluride	MCT	SWIR – LWIR
Indium antimonide	InSb	NIR – LWIR
Strained Layer Superlattice	SLS	MWIR, LWIR
<b>Un-cooled</b>		
Charged-coupled device	CCD	VNIR
Active-pixel sensor	APS / CMOS	VNIR
Indium gallium arsenide	InGaAs	NIR, SWIR
Microbolometer		LWIR

# Uncooled cameras

- Pyro-electric detectors
- Microbolometers

The common detector in handheld and industrial IR cameras.



# Internal radiation

- Much of the radiation hitting the sensor is emitted by the camera
  - 90% is a realistic value
- Thus:
  - One or more internal thermometers
  - On-board processing





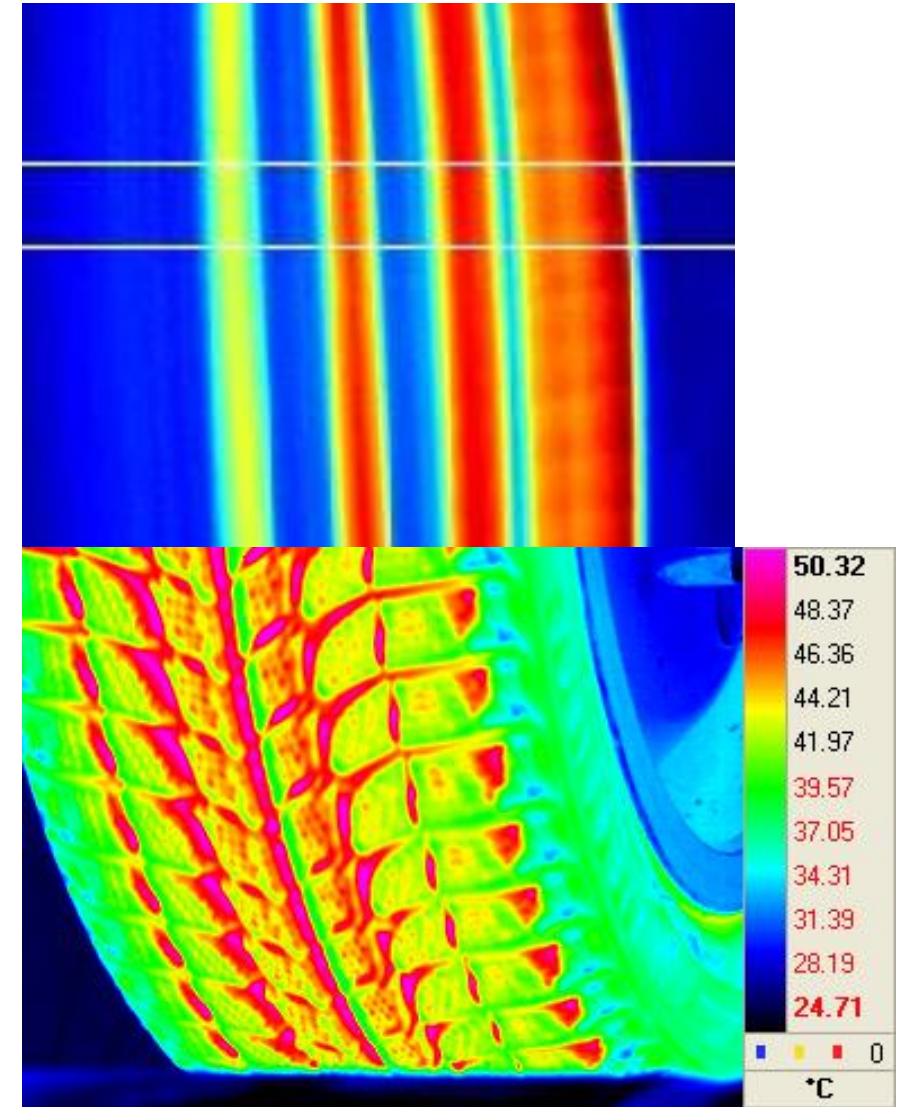
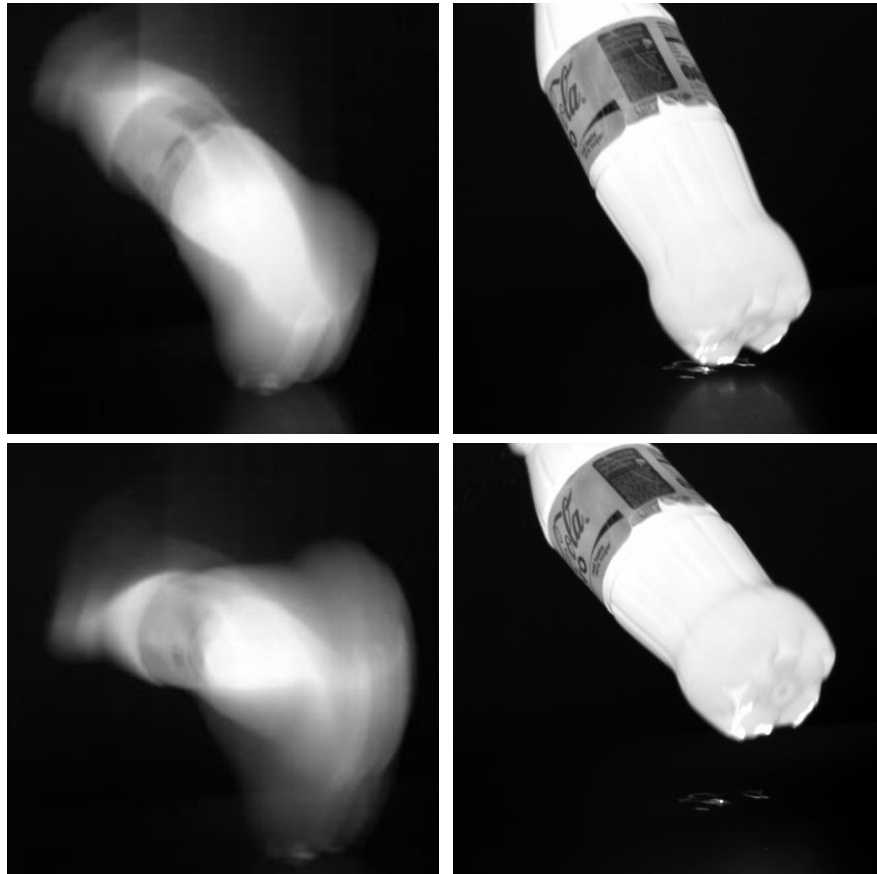
# Cooled cameras

- High spatial resolution
- High temperature resolution
- Fast
- Loud
- Heavy
- Large
- Expensive



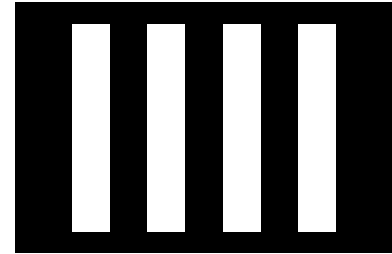


# Cooled vs uncooled



# Performance measures

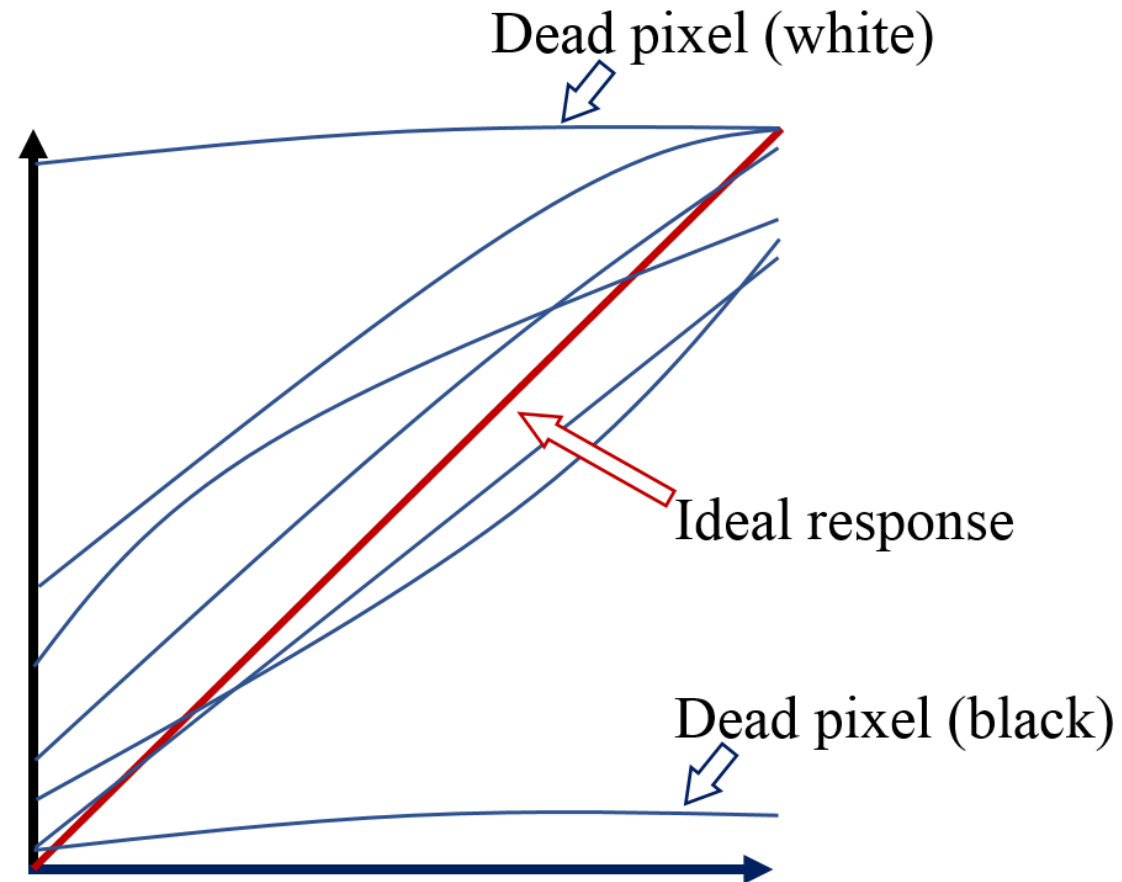
- NETD: Noise Equivalent Temperature Difference
- MRTD: Minimum Resolveable Temperature Difference
- NEP: Noise Equivalent Power
- Normalized Detectivity  $D^*$ 
  - Independent of detector size and speed



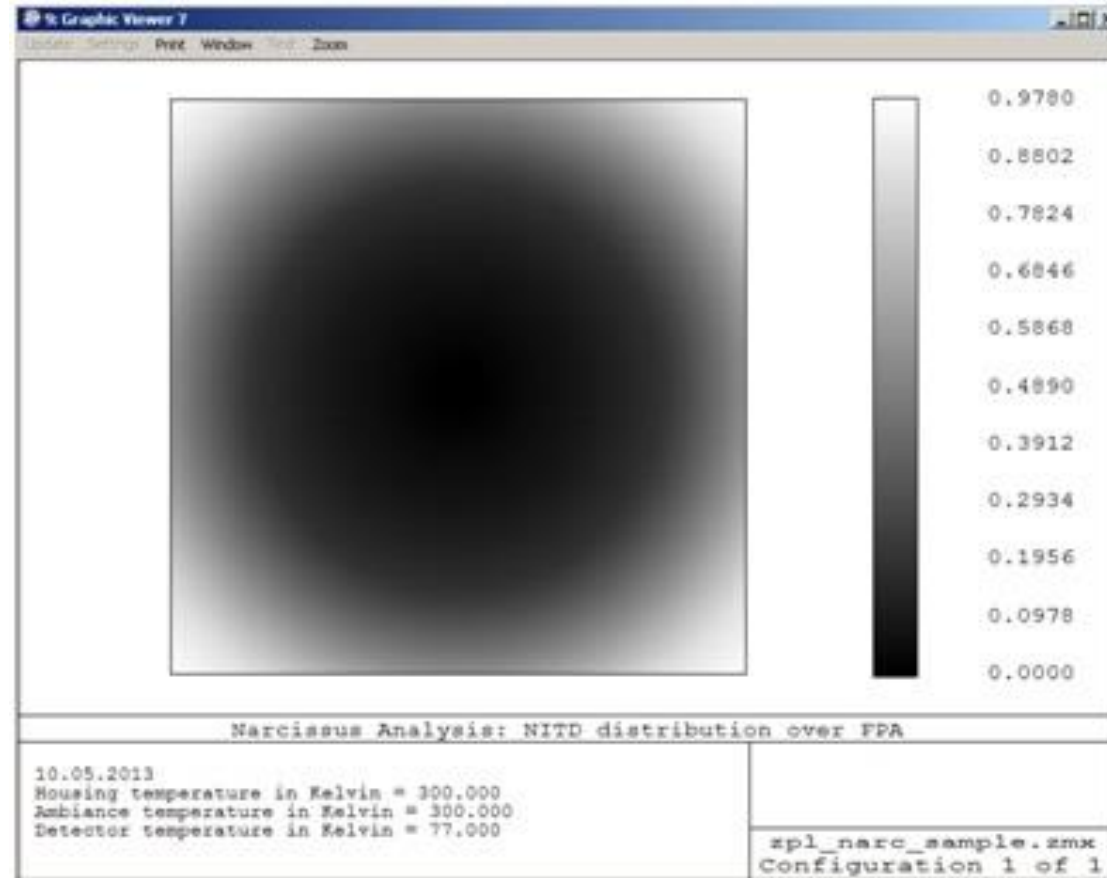
$$\text{NEP} = \frac{\sigma^2}{R} \left[ \frac{\text{W}}{\sqrt{\text{Hz}}} \right]$$

$$D^* = \frac{\sqrt{A} \Delta f}{\text{NEP}} = \frac{R \sqrt{A}}{\sigma^2} \left[ \frac{\text{cm} \sqrt{\text{Hz}}}{\text{W}} \text{ or Jones} \right]$$

# Calibration and NUC



# Narcissus

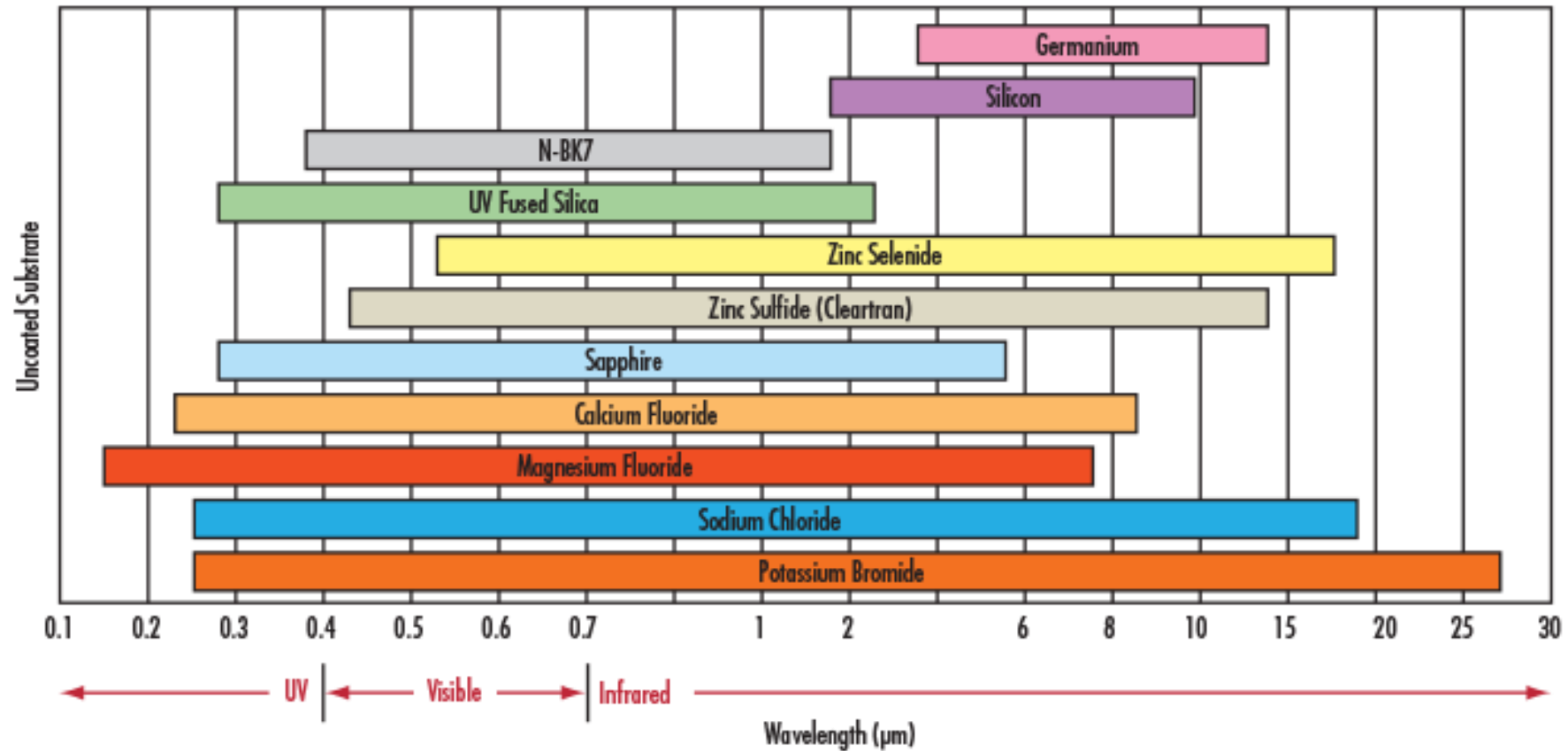


# Optics for thermal cameras

# Parameters

- Durability
- Refractive index
- Variability due to heat
- Cost
- Transmittance

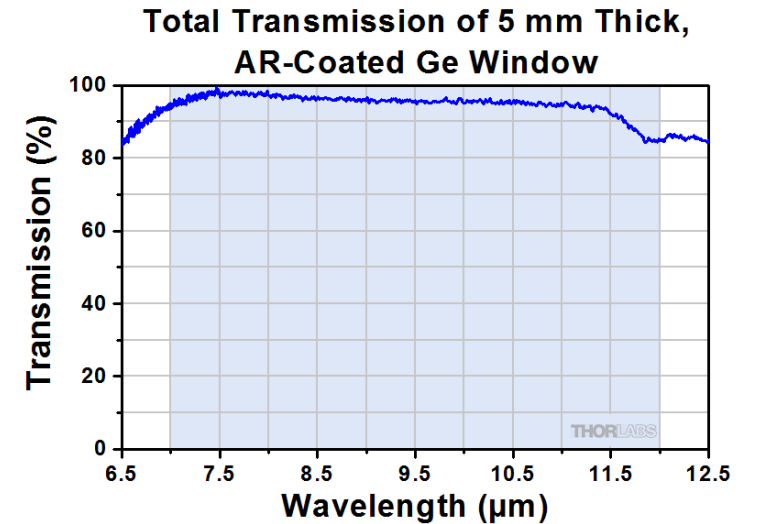
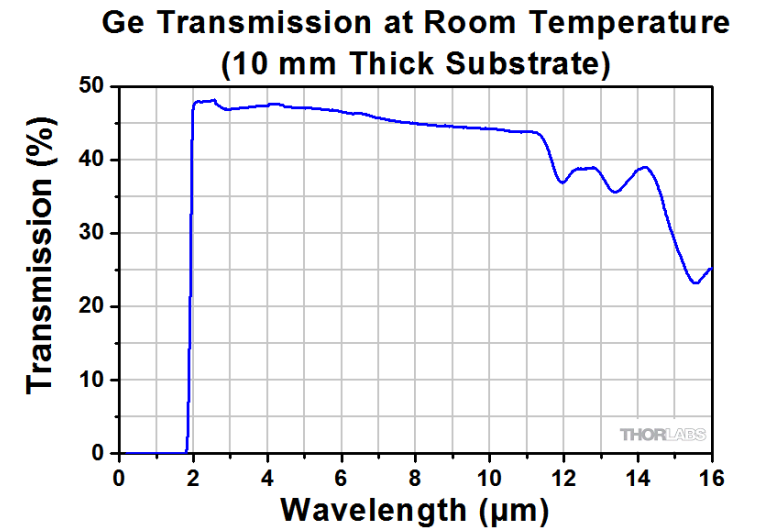
# Materials





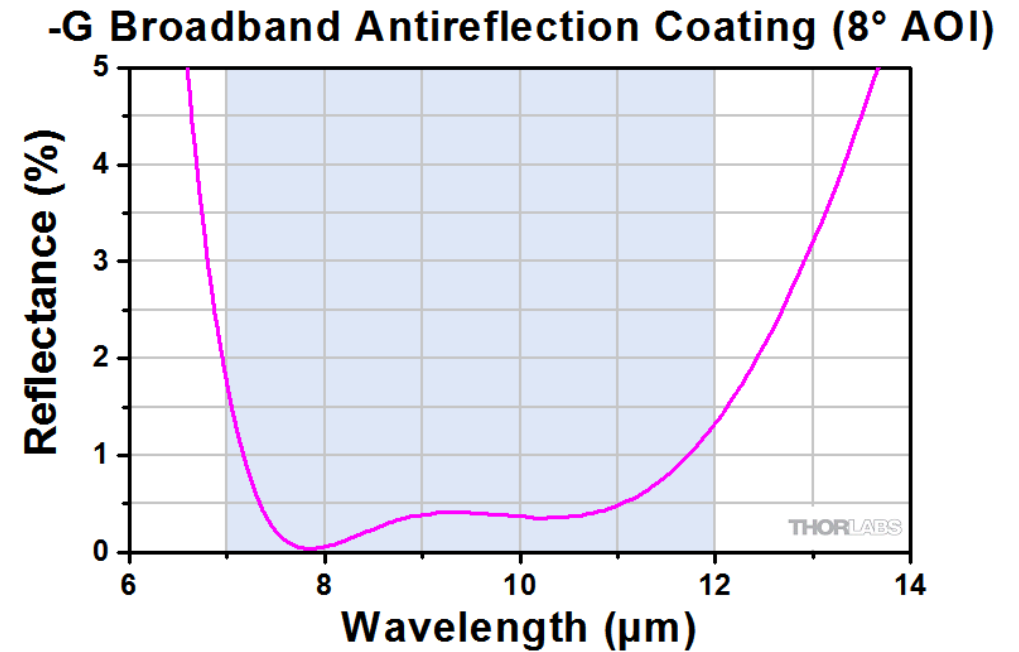
# Lens materials: Germanium

- Good for MWIR and LWIR (with AR coating)
- Durable (KH 780)
- High refractive index (4.0)
- Transmittance drops with temperature!



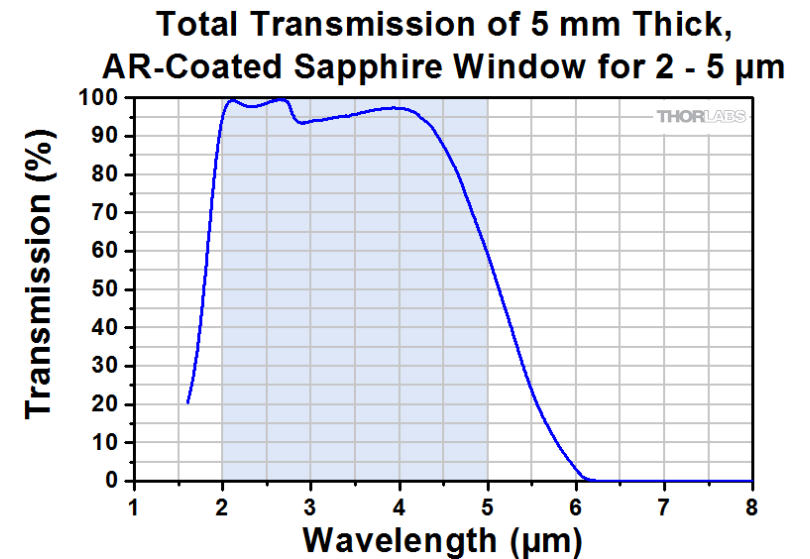
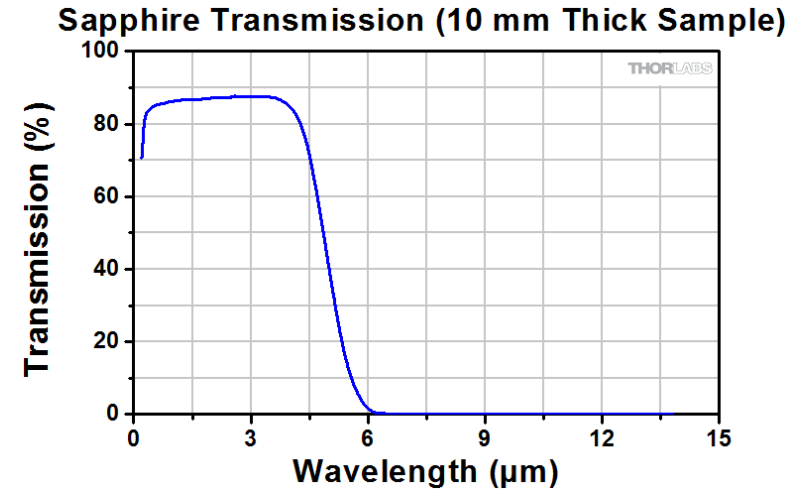
# Lens materials: Zinc Selenide

- Transmits even better than Germanium!
- KH 120 ☹️
- Toxic



# Lens materials: Sapphire

- Durable (KH 2200).
- Good transmittance in VIS-MWIR.



# A note on color



Visual



White hot

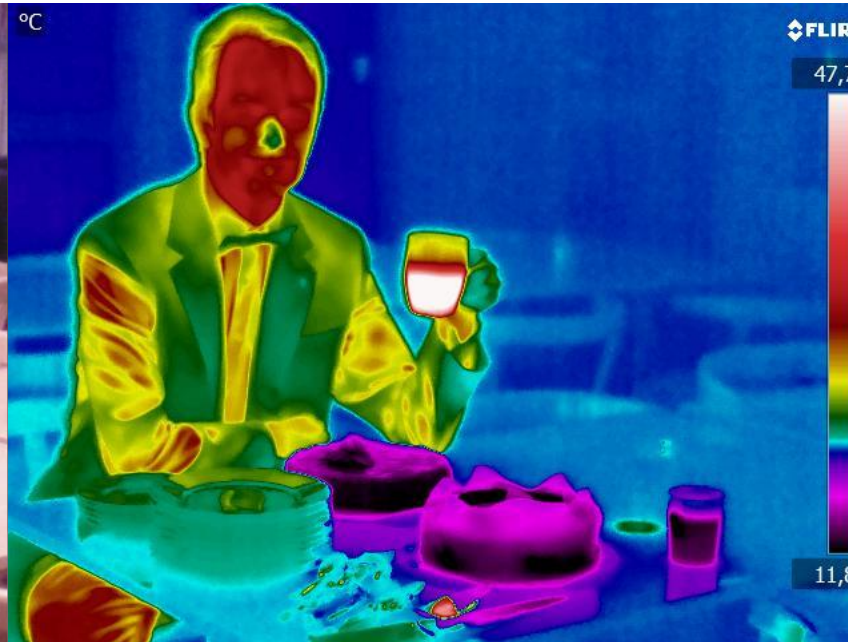


Black hot

# A note on color



Visual



Rainbow



Iron

# Summary: Thermal cameras

- Cooled vs uncooled
  - Cooled: Loud, cumbersome, expensive, fast, sensitive.
- Sensors: Thermal detectors (bolometers) vs photon detectors
- Optics: Transmitting in different bands
- The most common thermal camera: Uncooled bolometer camera for LWIR with Germanium lens.
- Calibrations: Narcissus, NUC, Drift

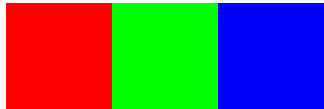
# Multi- and hyperspectral imaging



# What is multi/hyperspectral imaging?



Greyscale image – one band



Color image – three bands



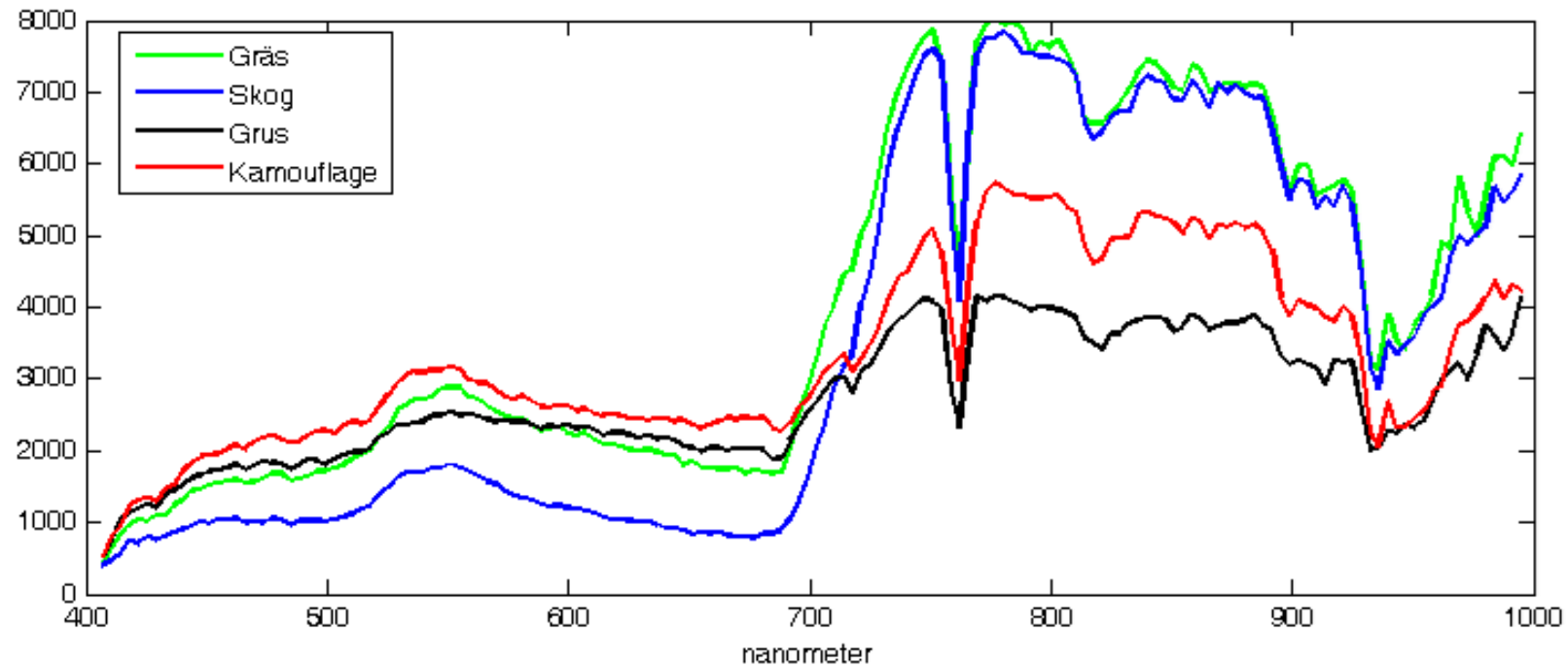
Multispectral image – several bands



...

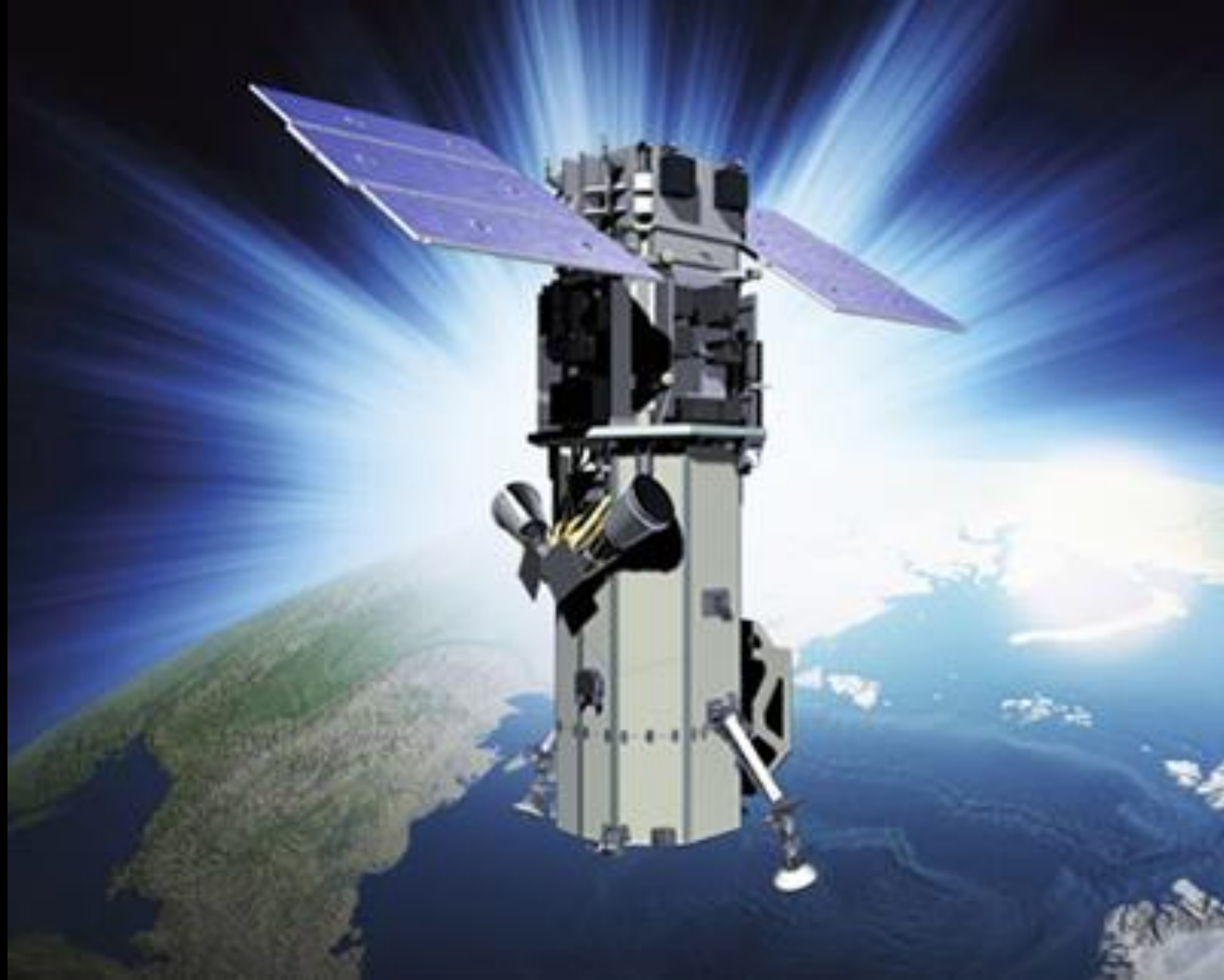
Hyperspectral image –  
many contiguous bands

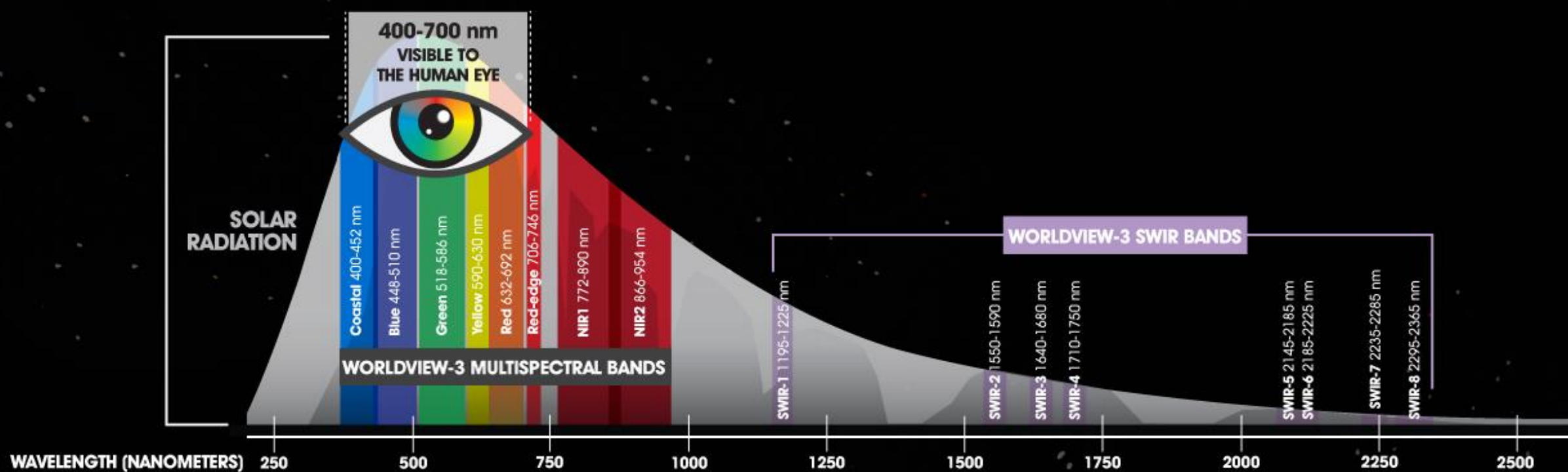
# Why multi/hyperspectral images?



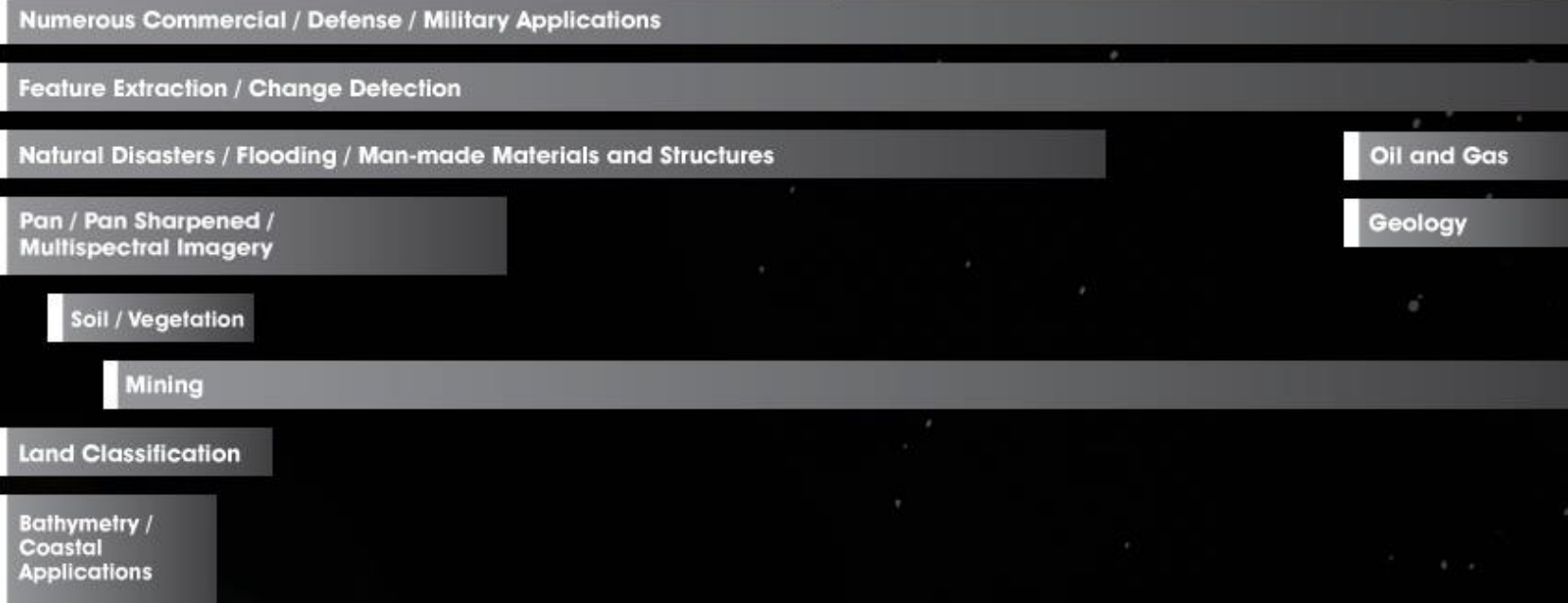
# Applications

- Defence
- Mineralogy
- Land-use classification
- Precision farming
- Food inspection
- Environmental monitoring
- ...

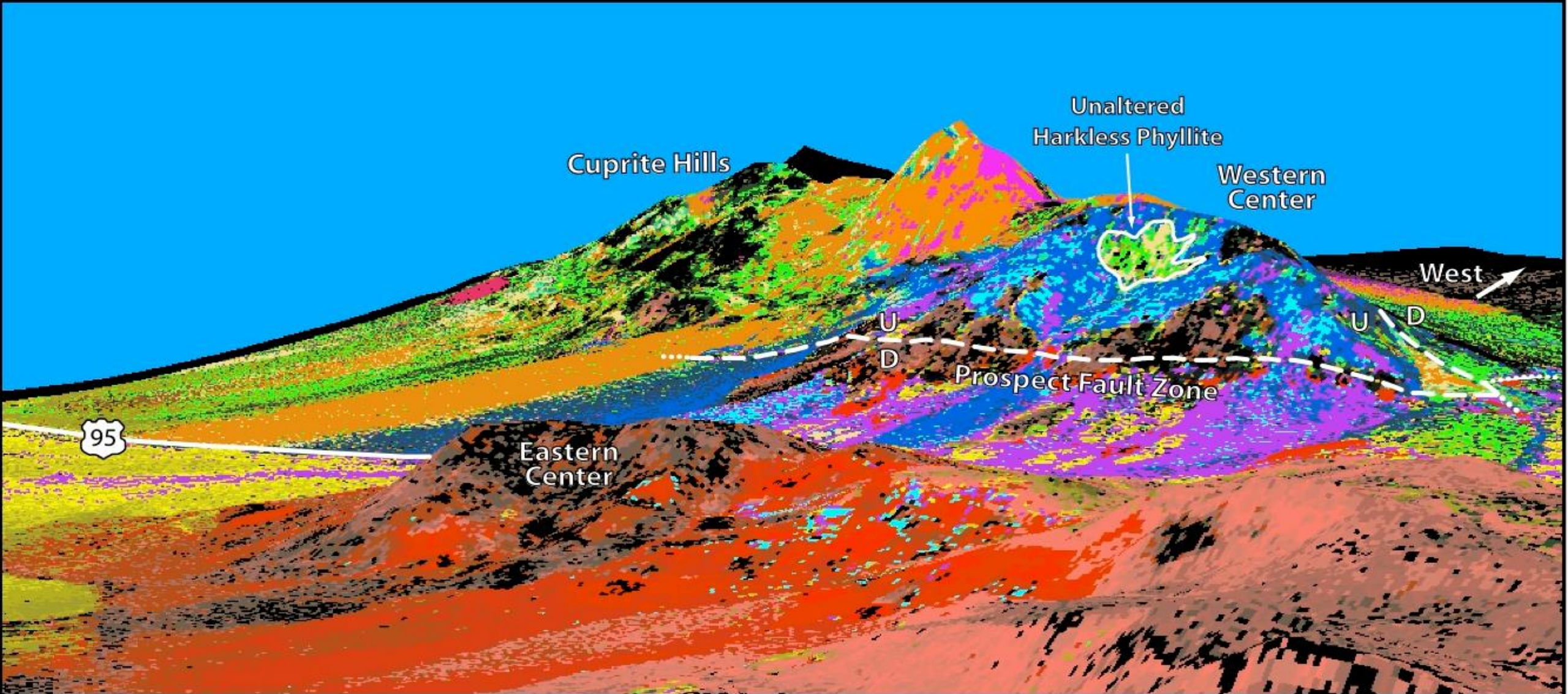




### CUSTOMER APPLICATIONS

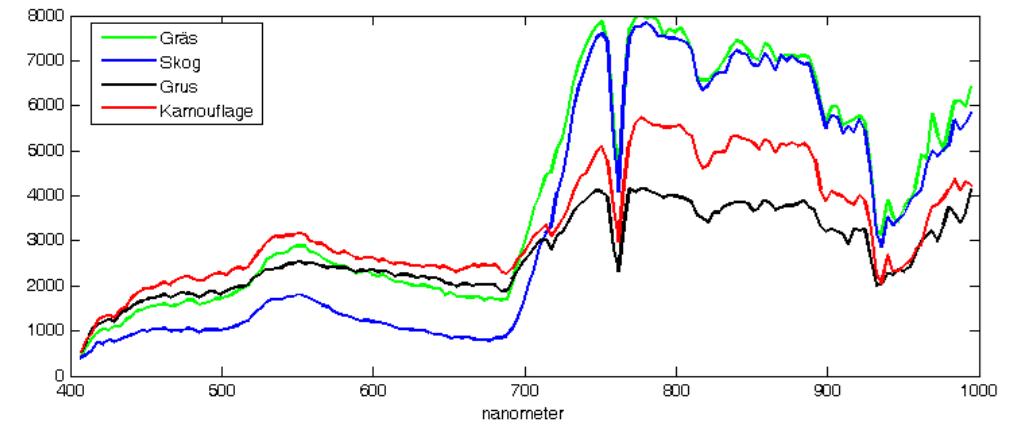
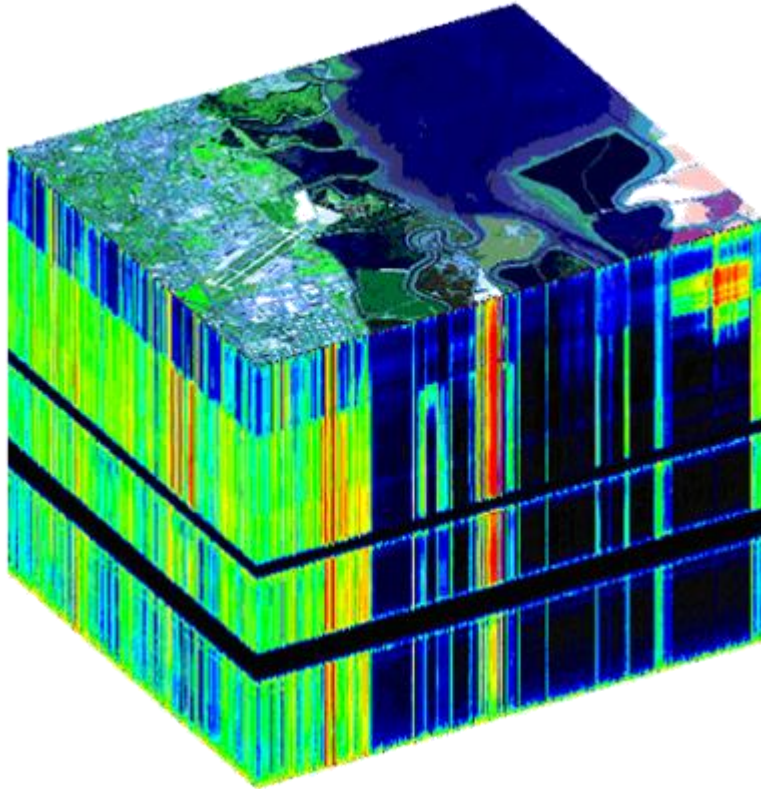


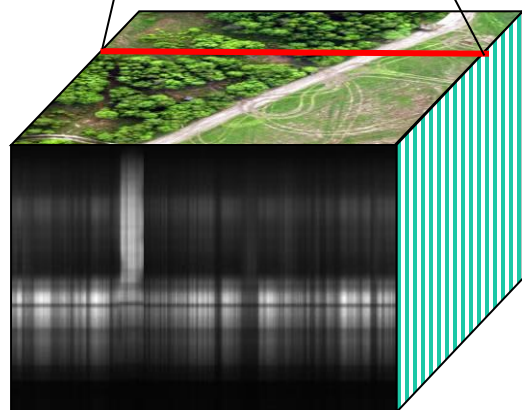




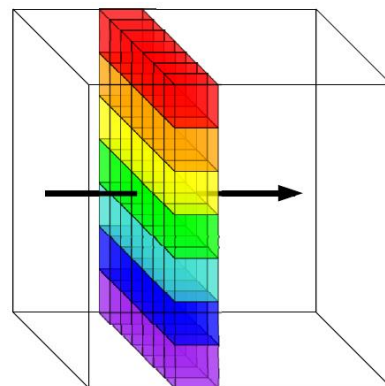


# The data cube

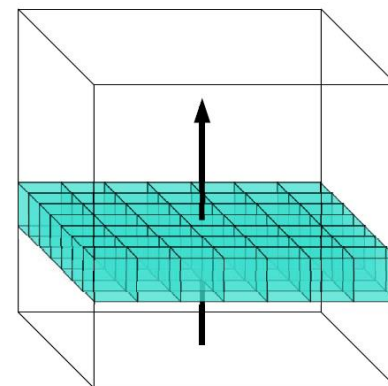




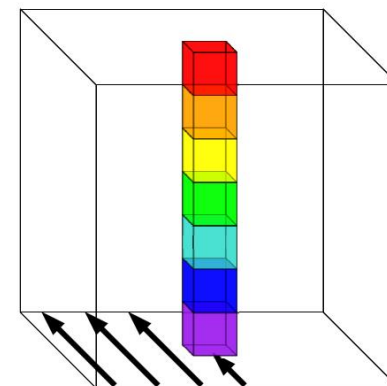
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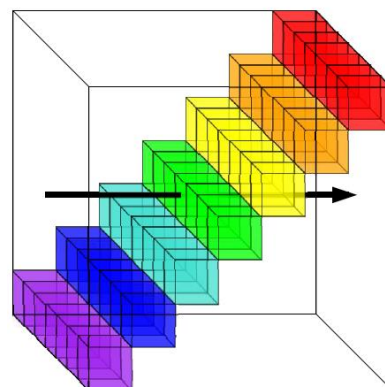
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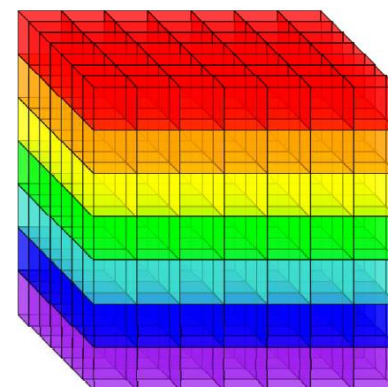
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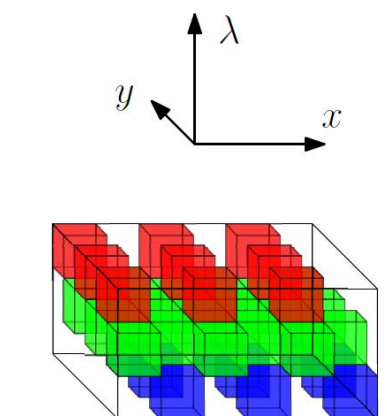
c



d



e

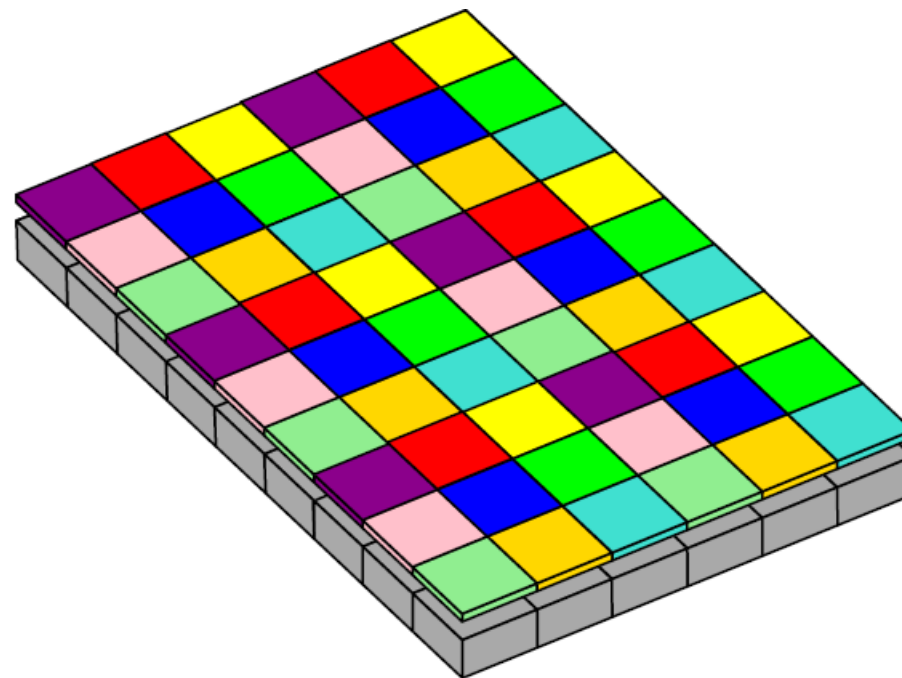
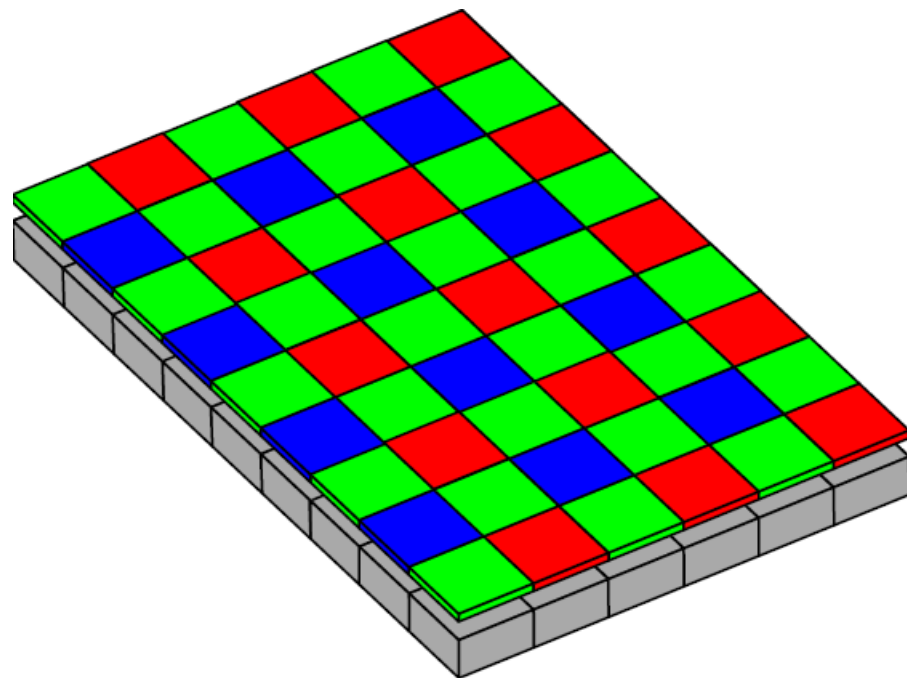
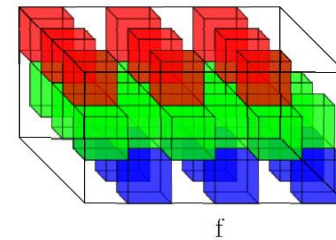


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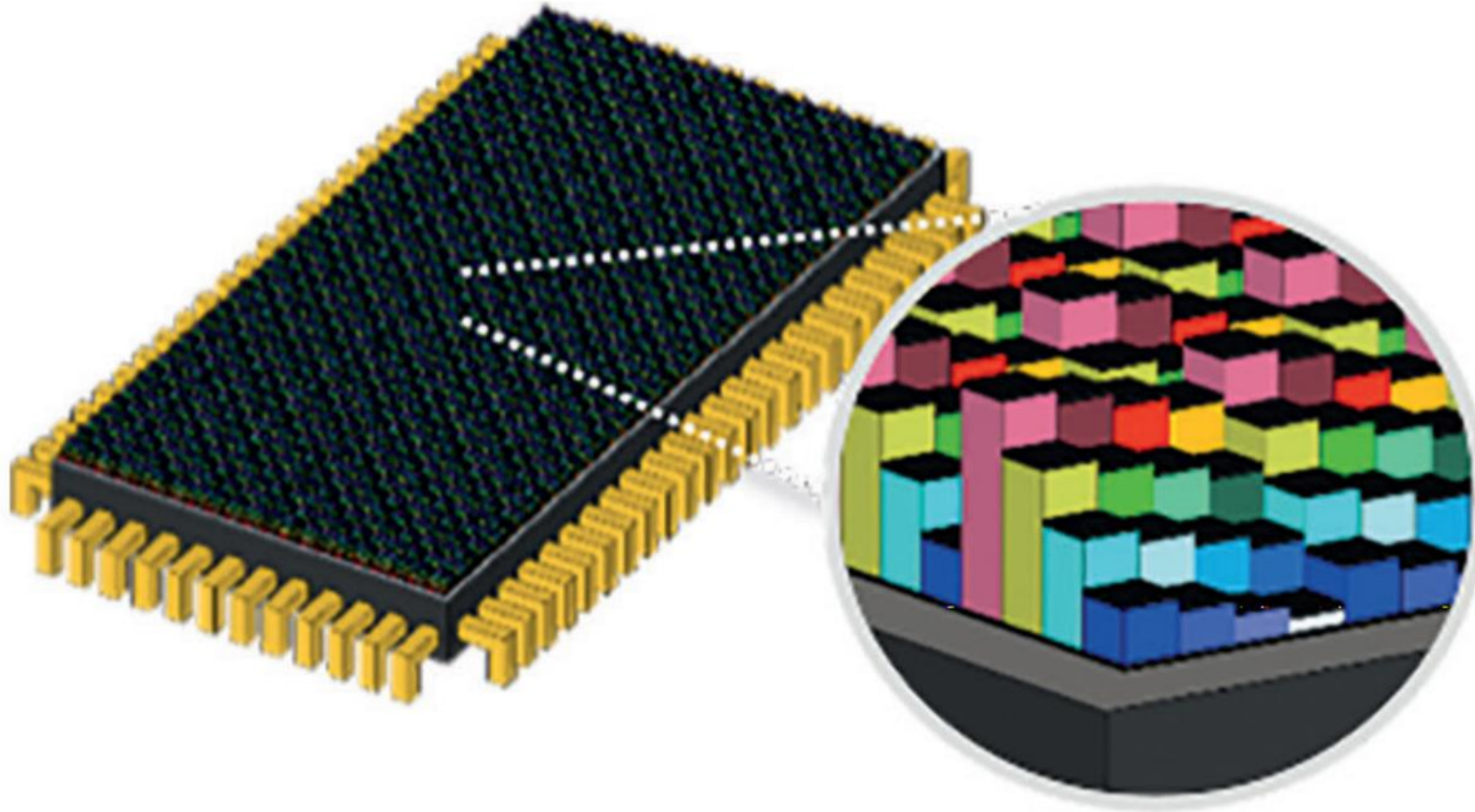
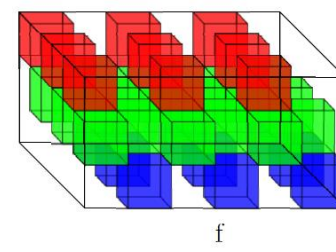


# Multispectral cameras

# Filter mosaics



# 16-band sensor from IMEC

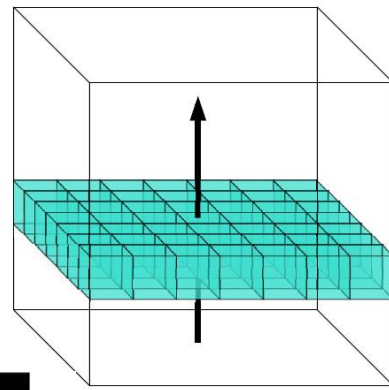
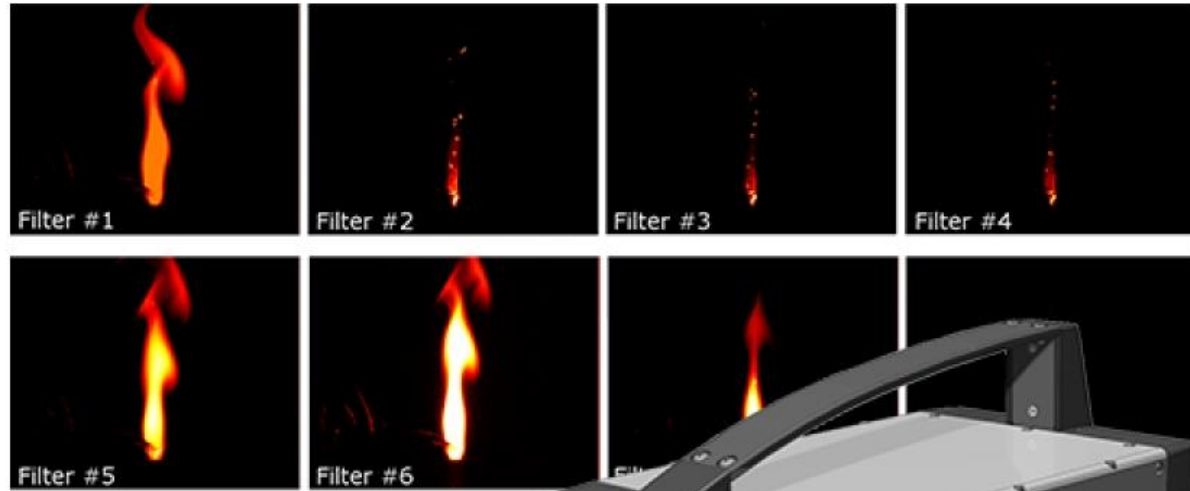


# Filter wheels

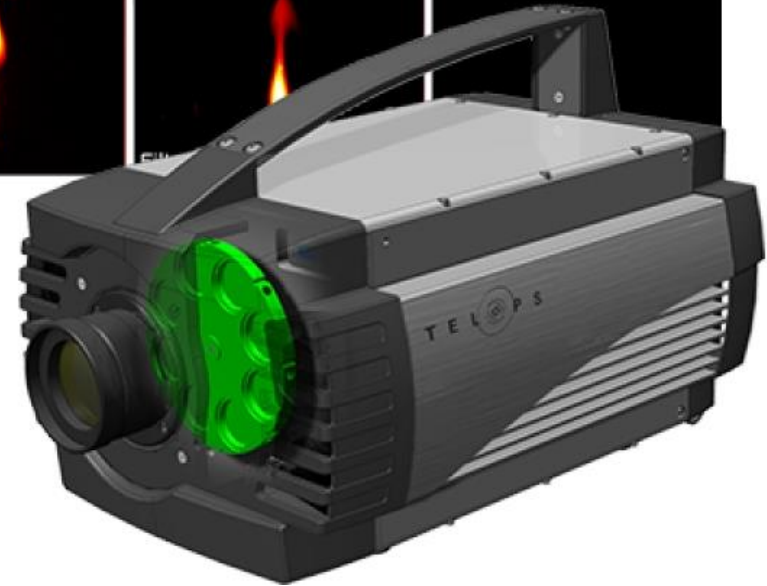
FW212CWNEB



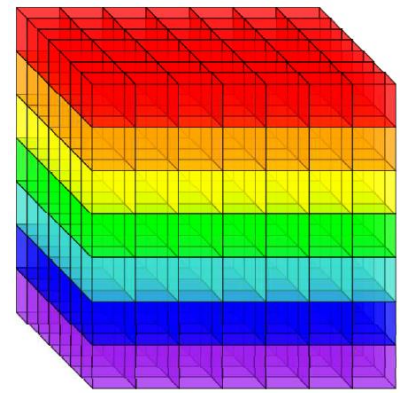
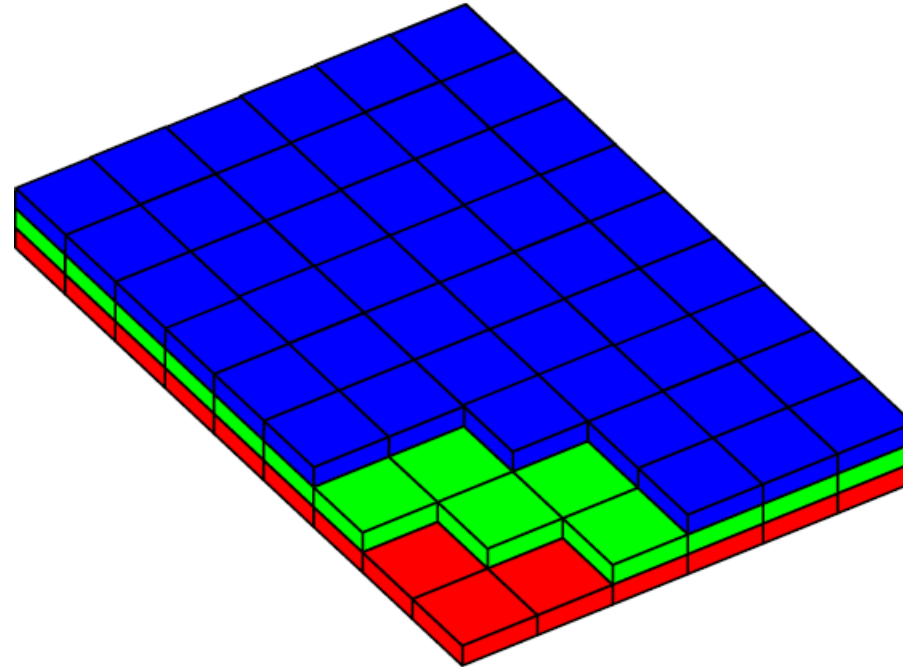
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b



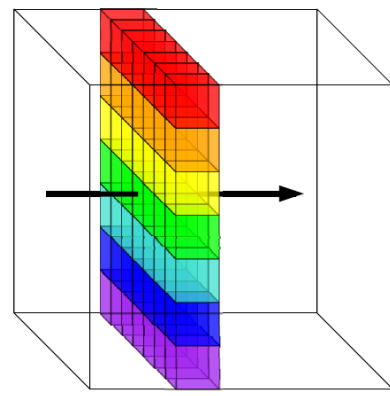
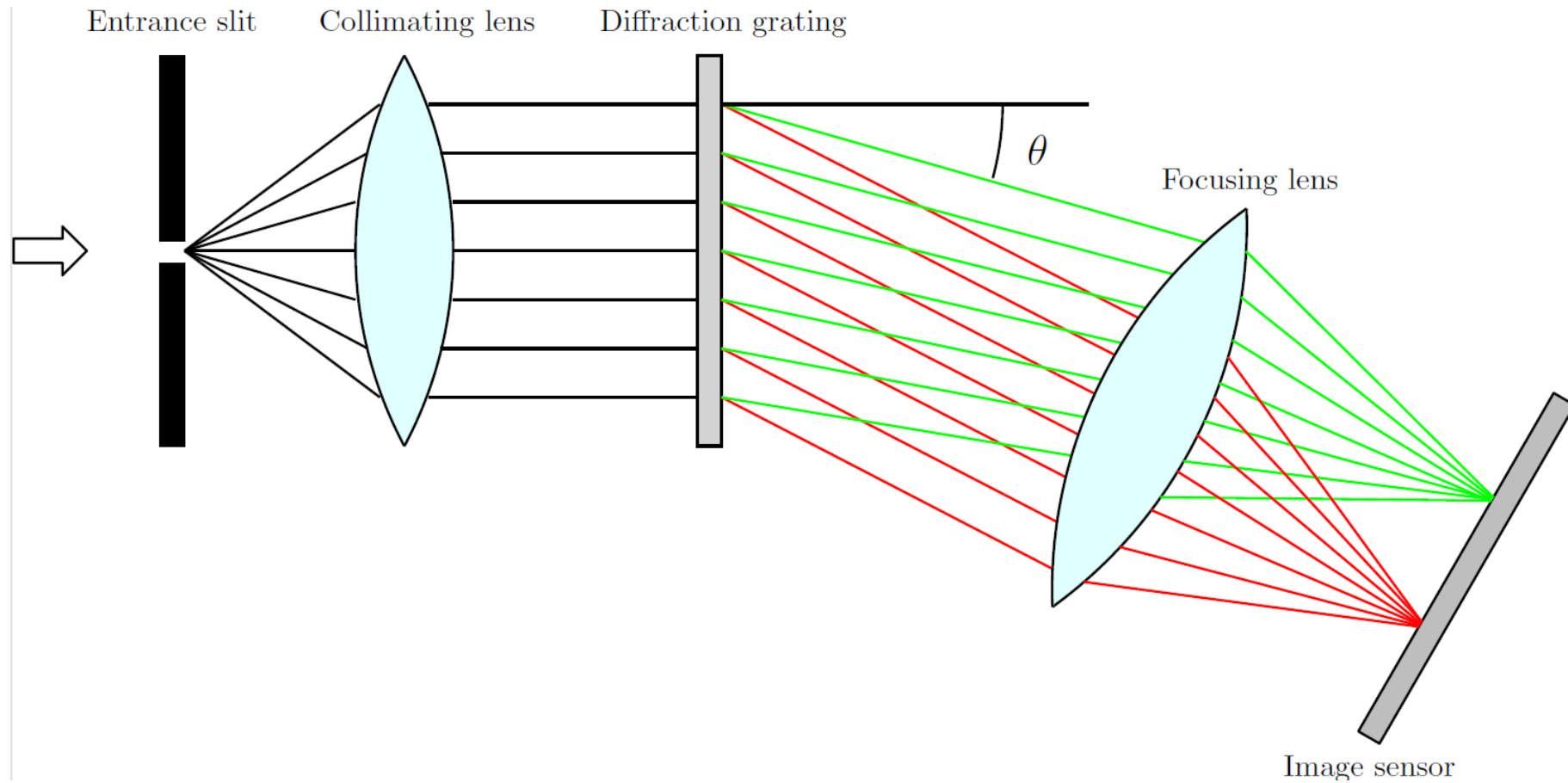
# Multi-layer sensors



e

# Hyperspectral cameras

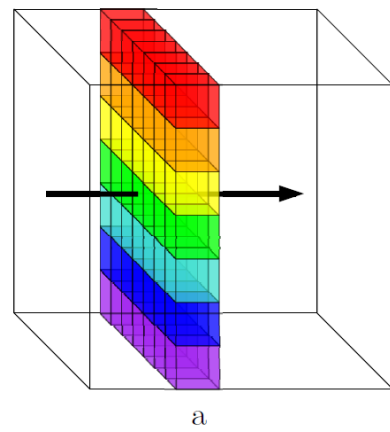
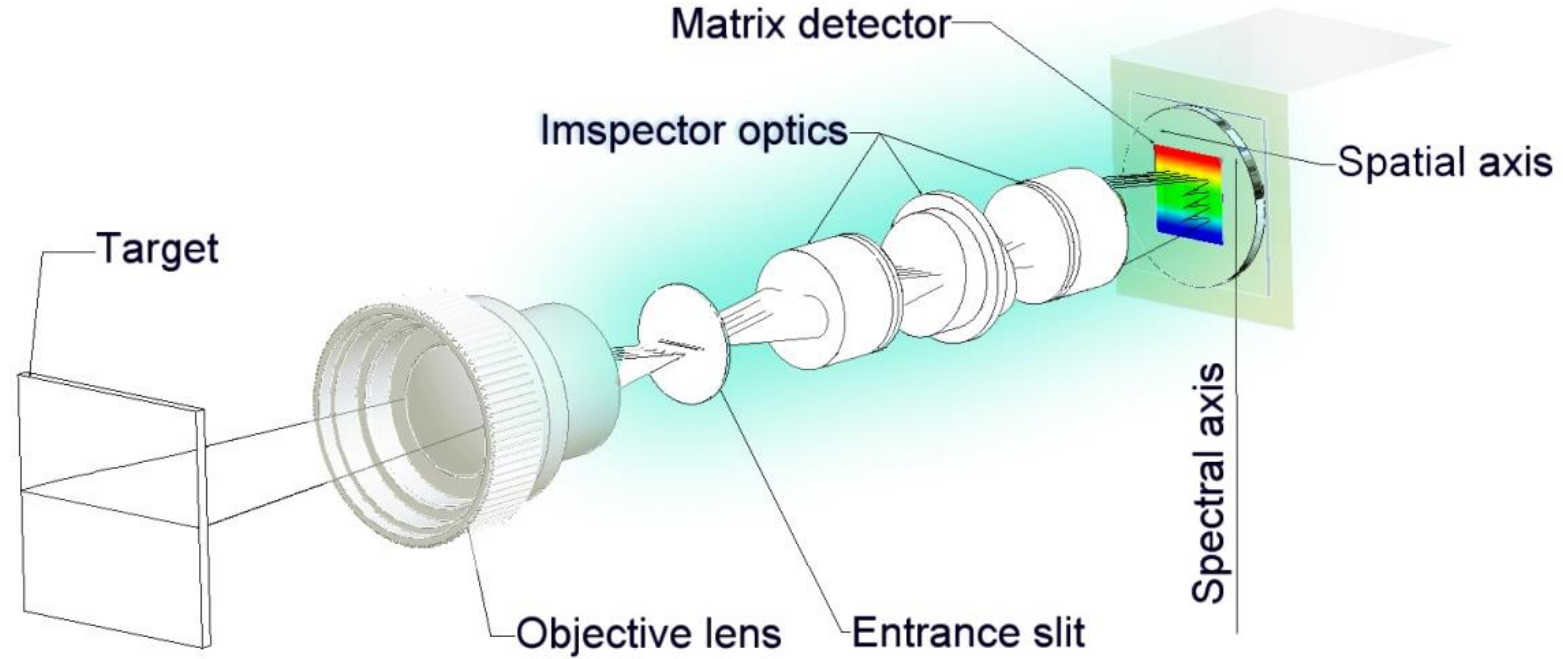
# Diffraction grating



a

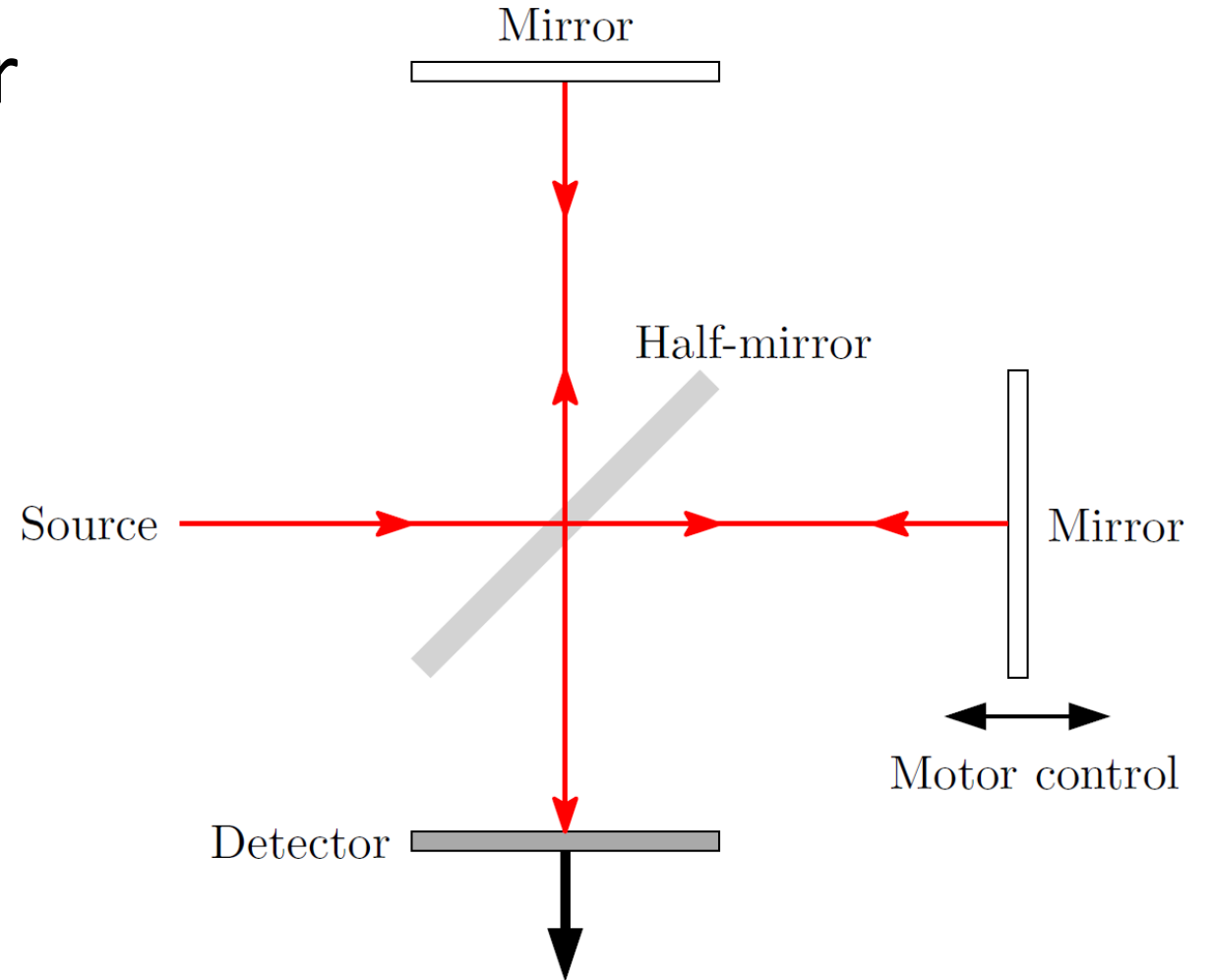
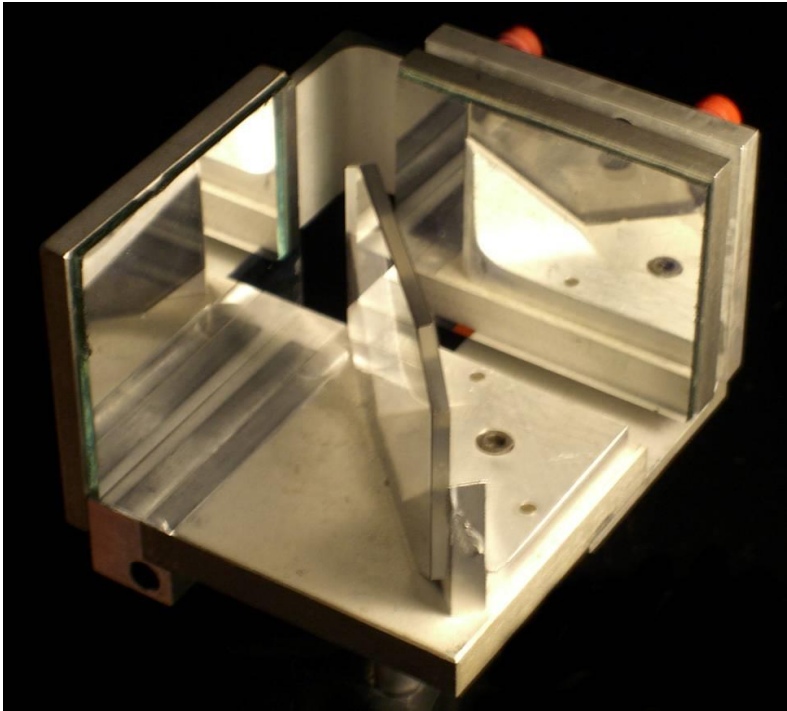


# Specim

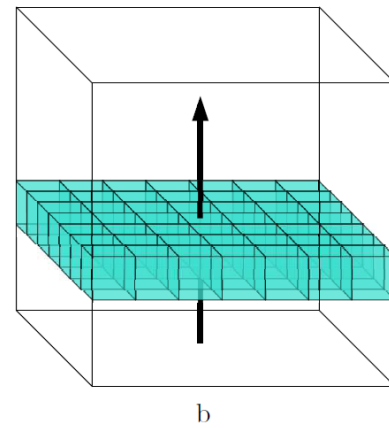
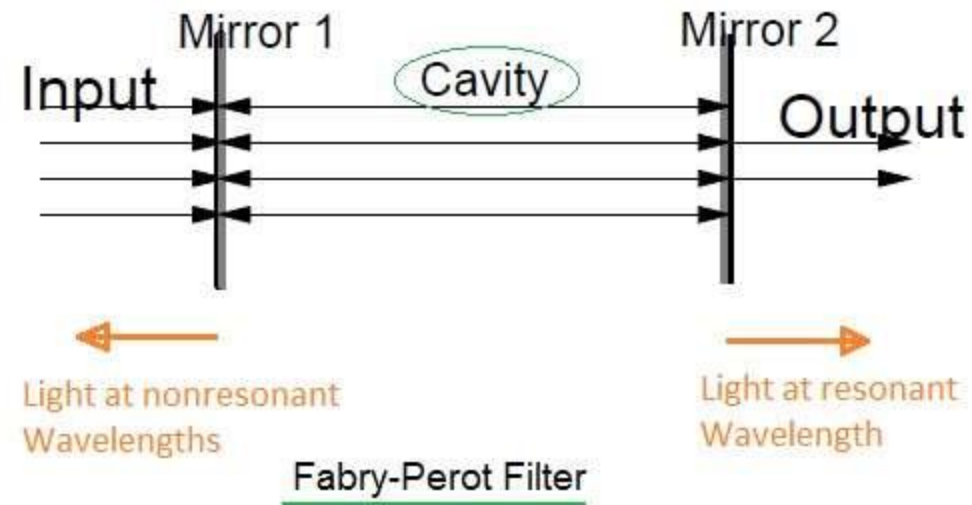




# Michelson interferometer

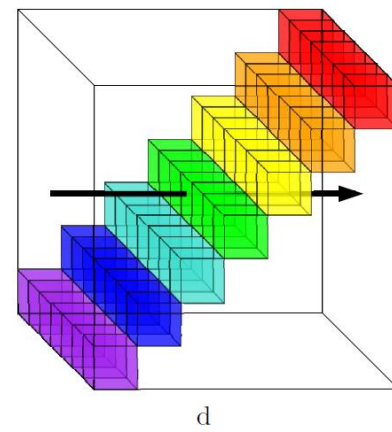
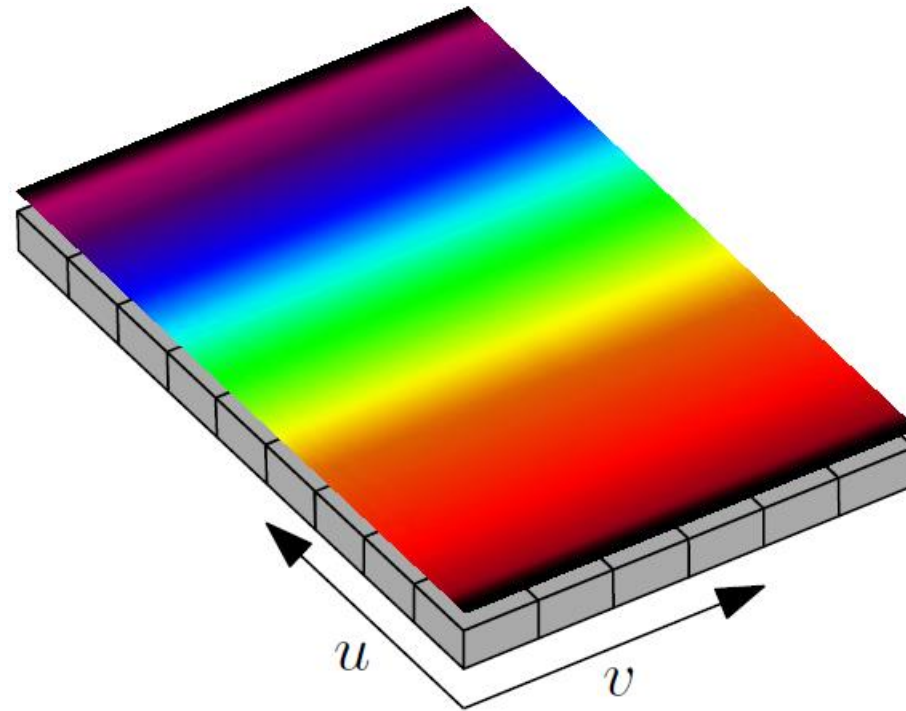


# Fabry-Perot interferometer



<https://www.rfwireless-world.com/Terminology/Fabry-Perot-Filter-vs-Fabry-Perot-Interferometer-vs-Fabry-Perot-Cavity.html>

# Continuously variable optical band-pass filter



# Summary: Multi/hyperspectral

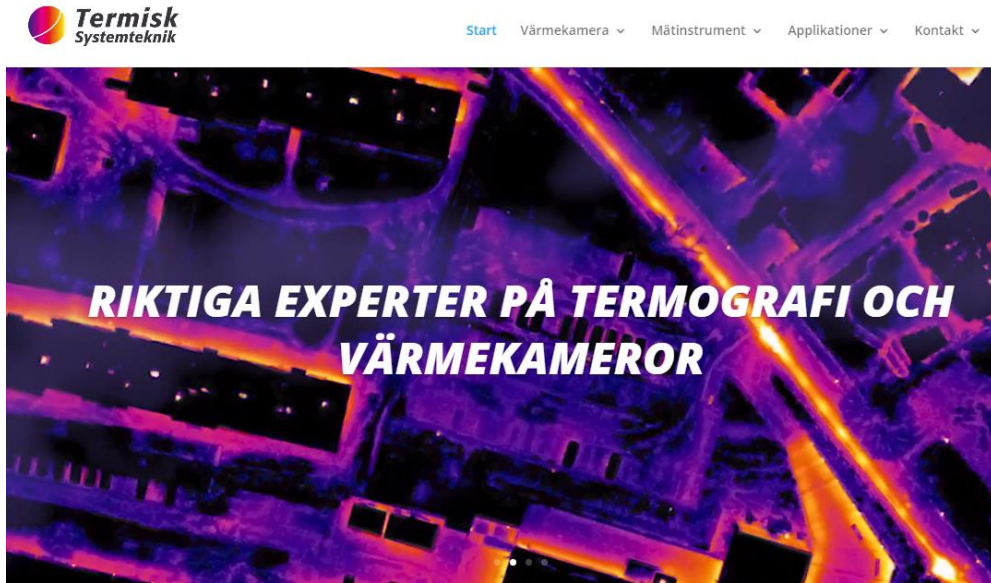
- Use multiple wavebands to see better!
- Recognize materials in one pixel!
- Many ways of making M/HS cameras.
- Applications: Mostly remote sensing and military, others upcoming, especially life sciences and agriculture.

Misc

# ”The Ultimate Handbook...” + ”5 factors...”

- ”The Ultimate Handbook...” (Ch 1-3)
- ”5 factors...”
- These slides.
- Pdfs on course website.

# MSc thesis project



Contact:  
[jorgen.ahlberg@termisk.se](mailto:jorgen.ahlberg@termisk.se)  
[mathias.kindstedt@termisk.se](mailto:mathias.kindstedt@termisk.se)

A thermal image of a cat's face, showing the eyes as bright, glowing yellow-orange shapes. The rest of the face is rendered in various shades of orange, red, and yellow, indicating different temperatures. The background is dark blue. The word "Demo!" is overlaid in the center in a large, bold, black font.

**Demo!**