Infrared and Multispectral Imaging

TSBB09 Image Sensors

Jörgen Ahlberg

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Termisk Systemteknik

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Contents of today's lecture

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

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Light & Radiation

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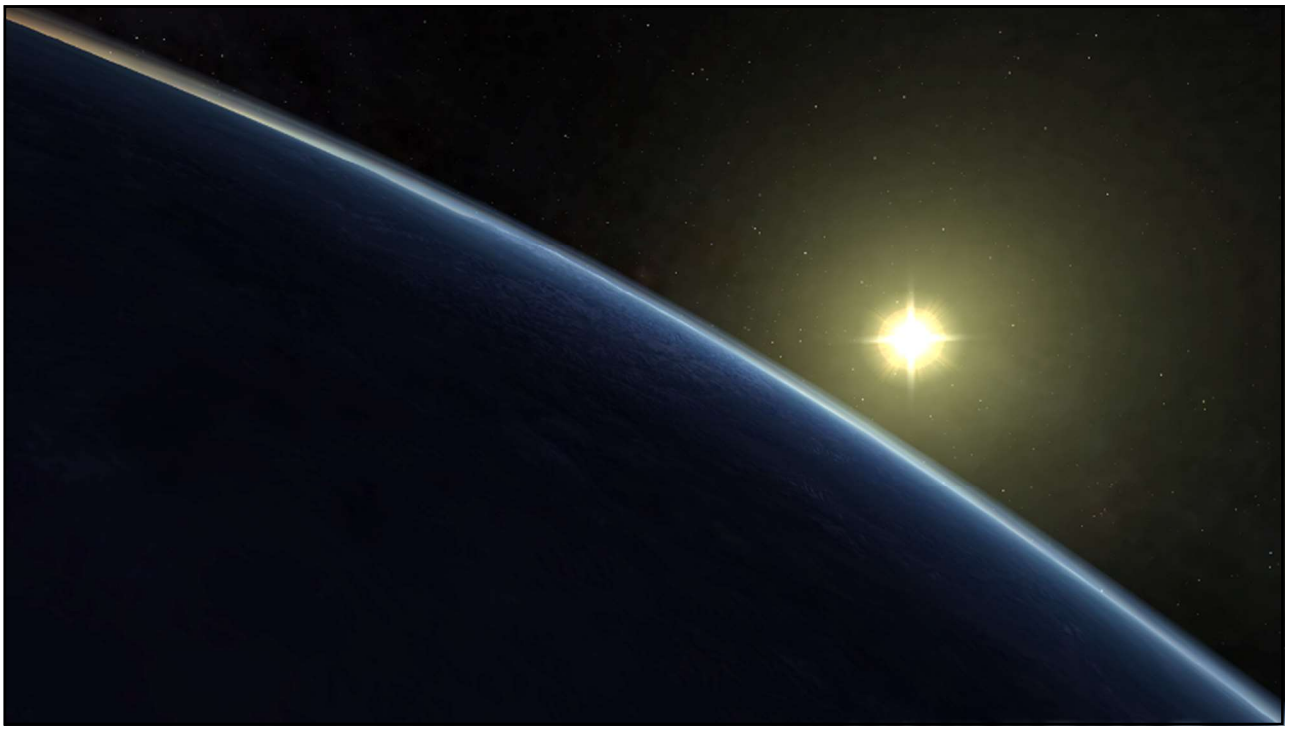

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From where comes the radiation that I see?

- Emitted
- Transmitted
- Reflected
- Absorbed

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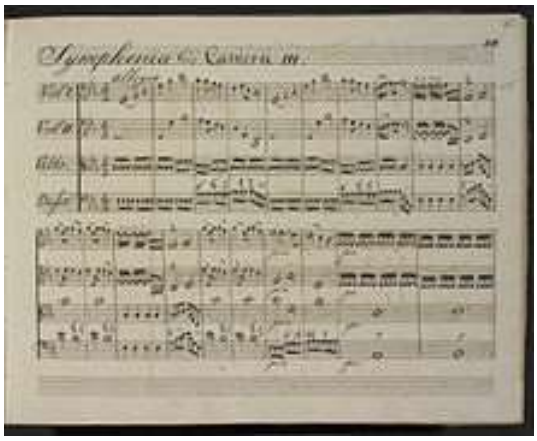
F. W. Herschel



Symphony No. 15 (1762)
https://open.spotify.com/track/0kQcVlkwv2LJQ49KXnklVe

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

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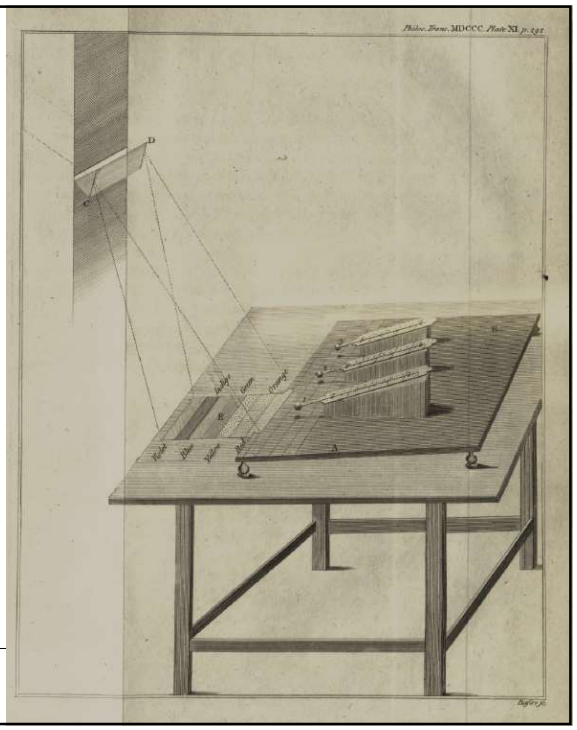

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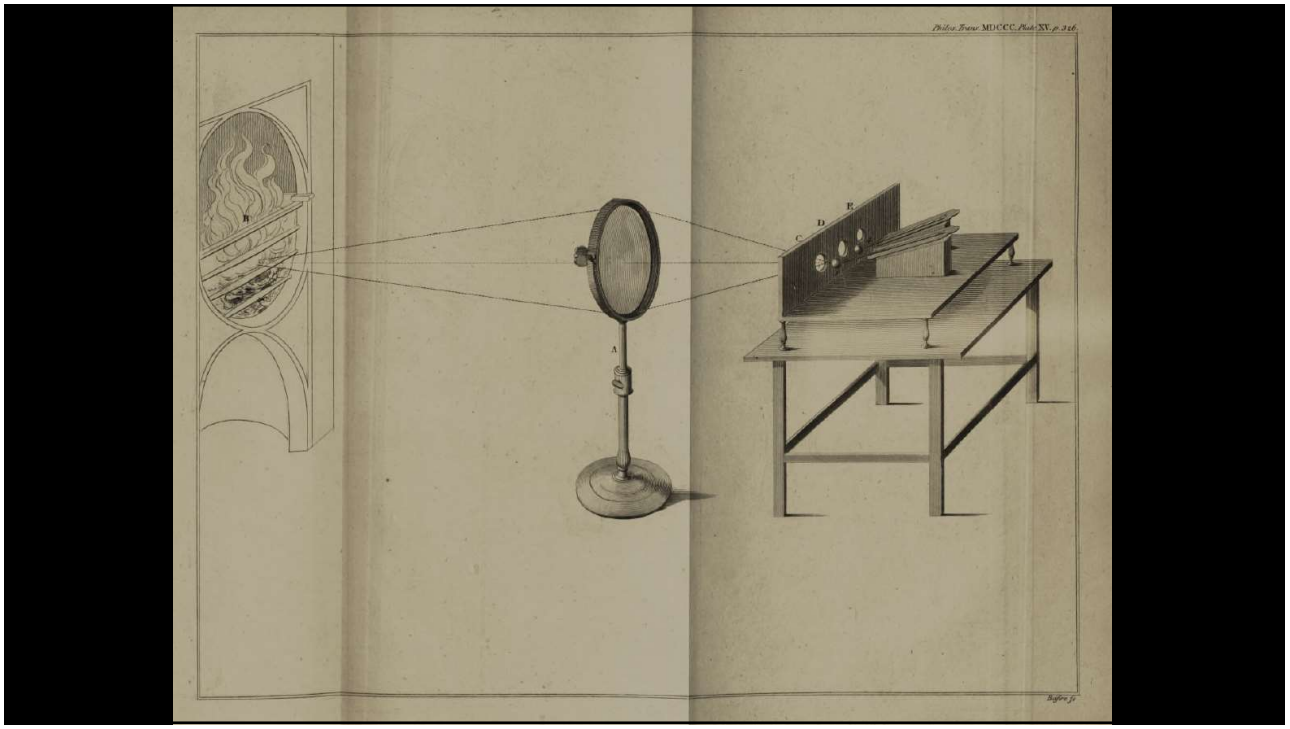

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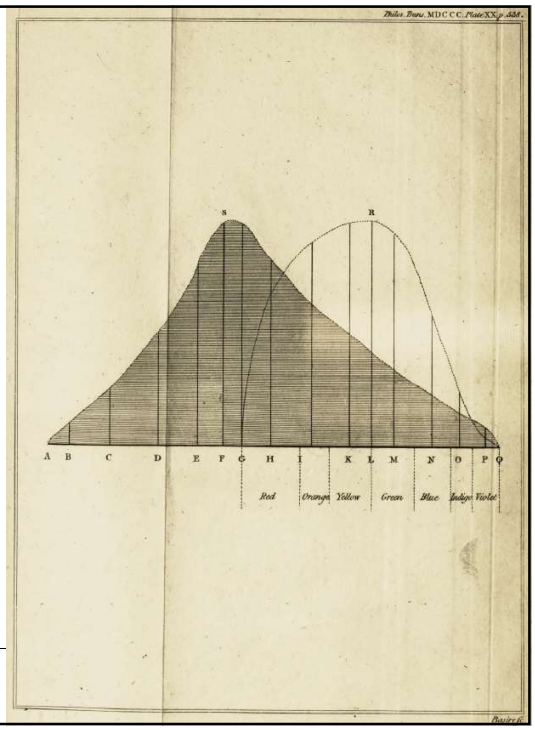
Herschel 1800b, c

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.
doi: 10.1098/rstl.1800.0020



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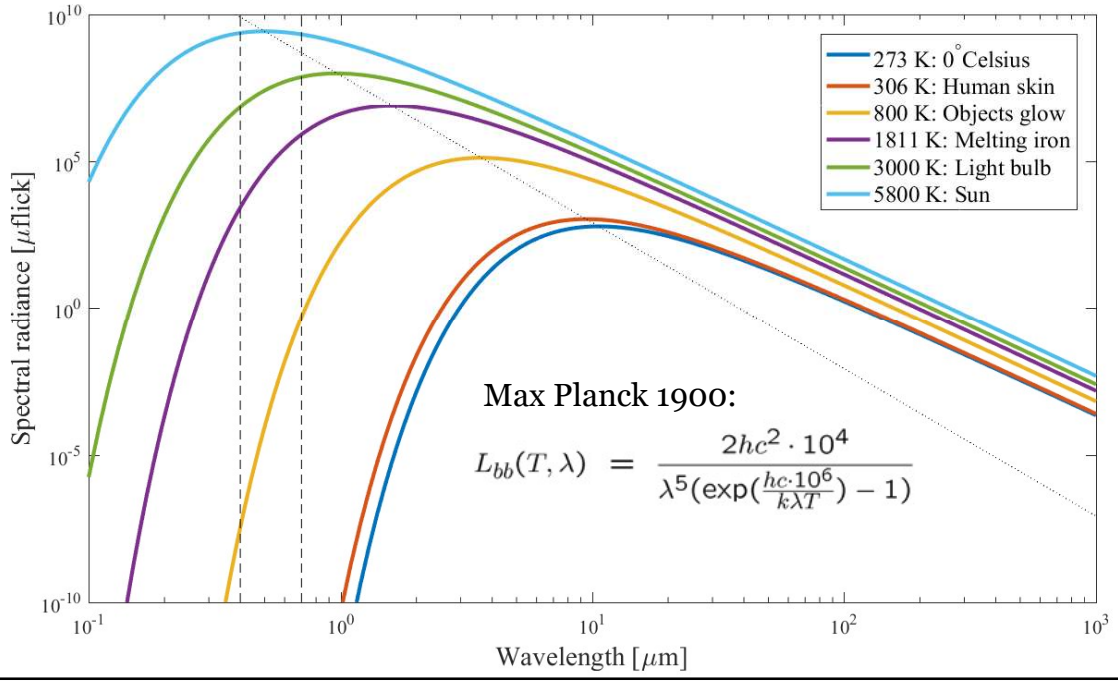

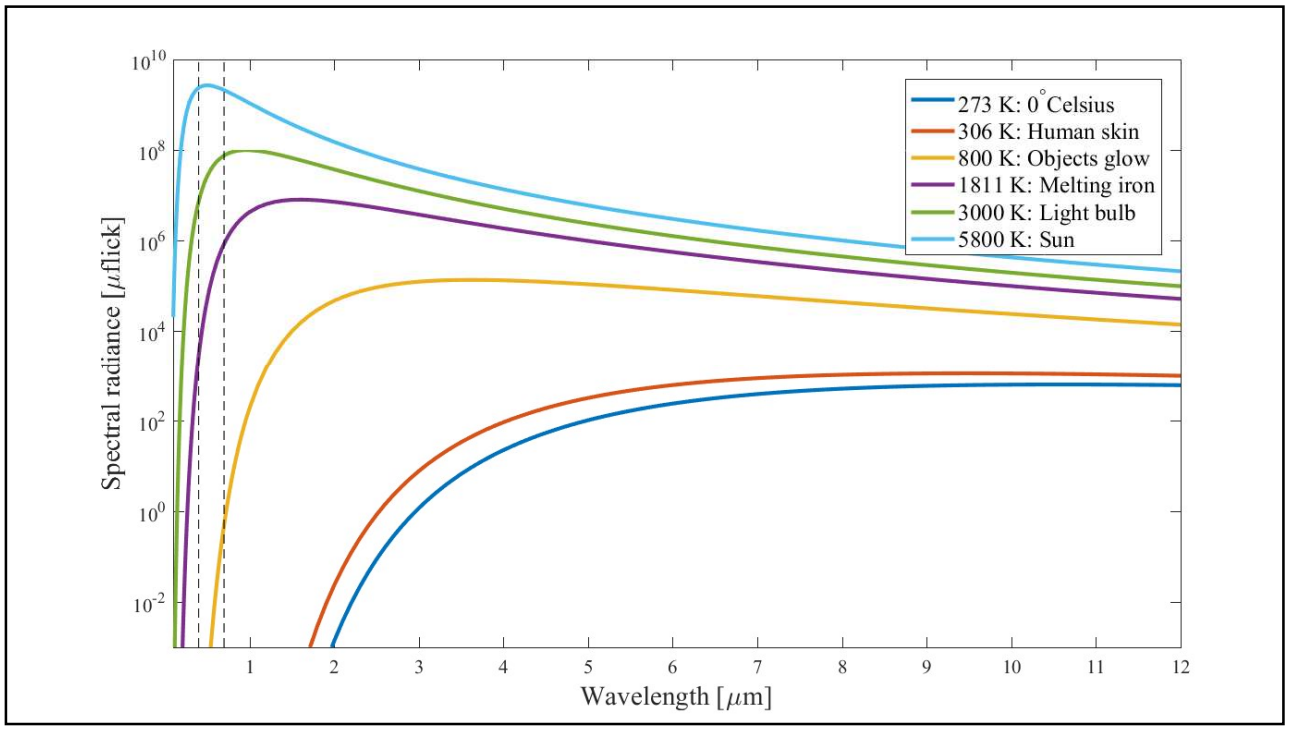
Spectral radiance [μflick]
Wavelength [μm]
273 K: 0 °Celsius
306 K: Human skin
800 K: Objects glow
1811 K: Melting iron
3000 K: Light bulb
5800 K: Sun

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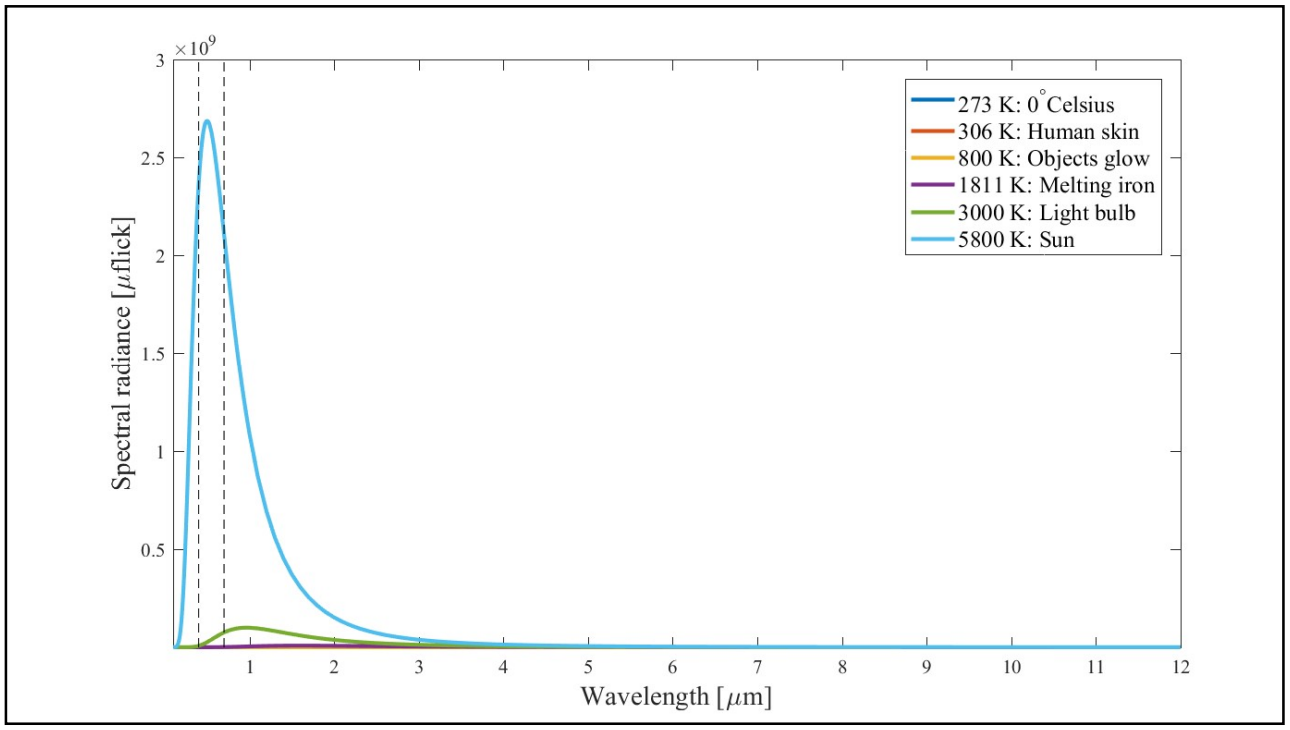
×10^9
Spectral radiance [μflick]
Wavelength [μm]
273 K: 0 °Celsius
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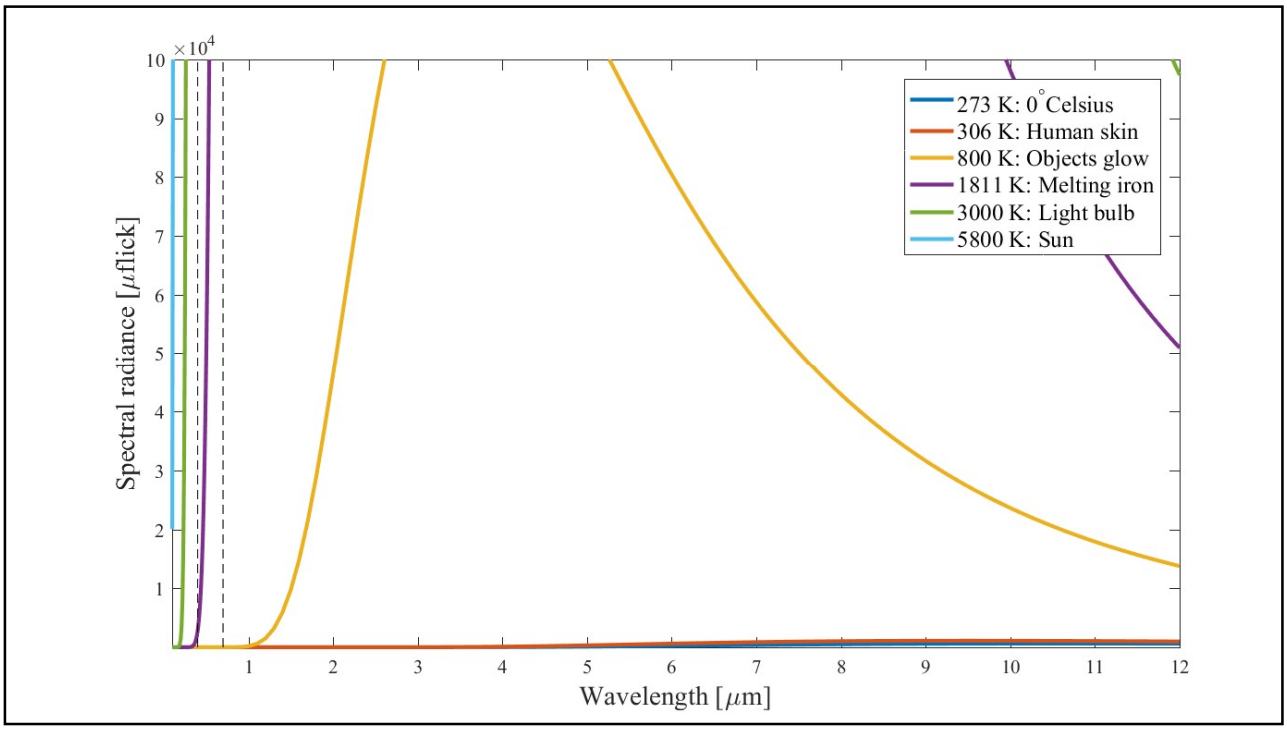

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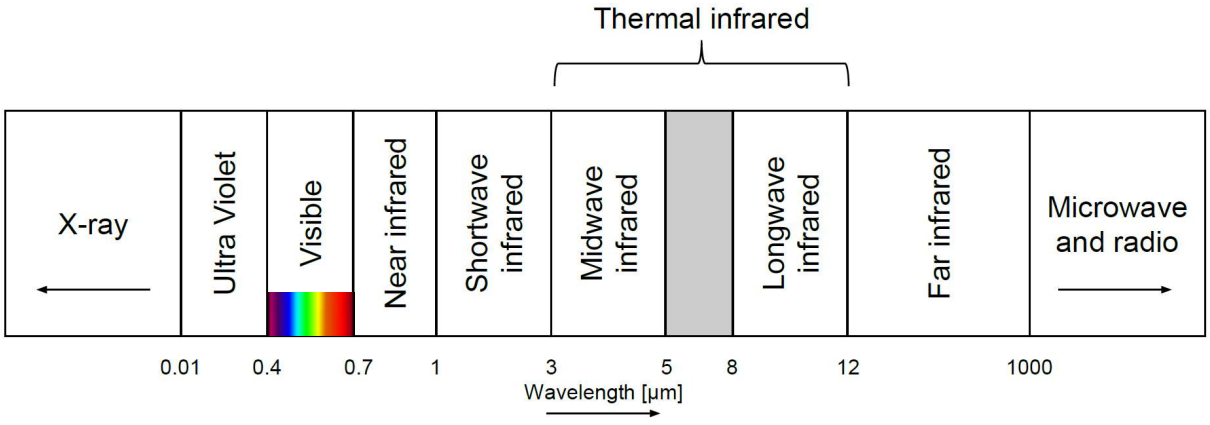
Domains and wavelengths and bands

Why this particular division?



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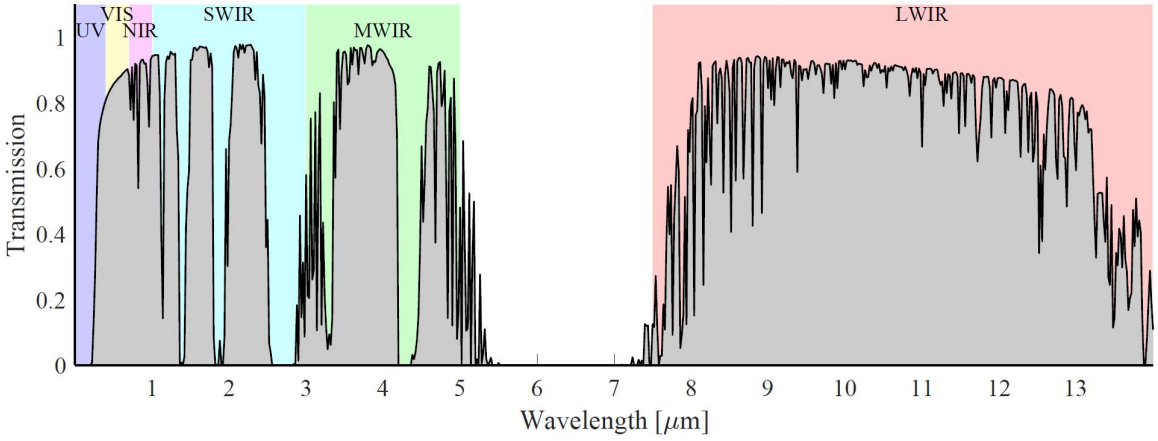
Reason 1: Atmospheric transmission



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Reason 2: Behaviour

- Reflective domain
- Emissive domain

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Reason 3: Sensors

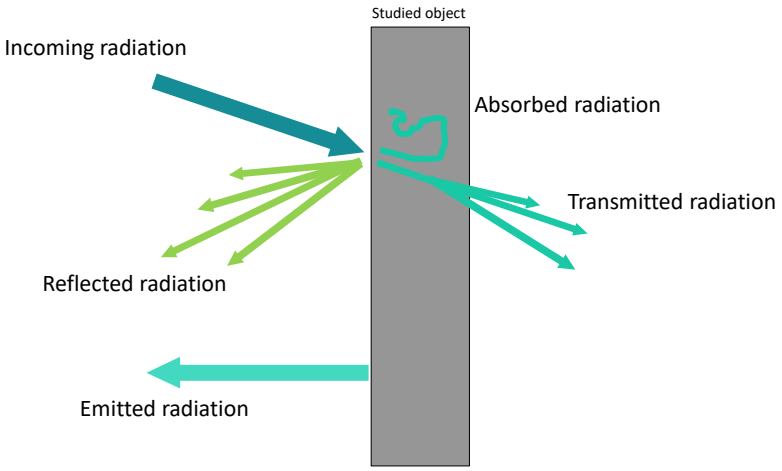
- VNIR: Silicon (CCD, CMOS)
- SWIR: InGaAs sensors
- MWIR: InSb and MCT sensors
- LWIR: MCT and bolometer sensors

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



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

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

$$\alpha = \varepsilon$$

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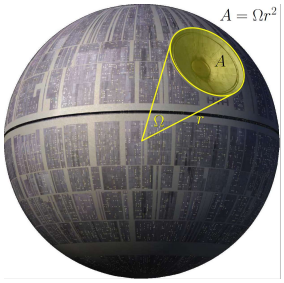
- Absorptivity α
- Emissivity ε
- Transmittance τ
- Reflectance r

- α + τ + r = 1
- Dependent on wavelength and angle!
- Commonly: τ or r close to zero.

- (Radiant) Flux Φ [W]
- Radiance L [W / m² sr]
- Irradiance E [W / m²]



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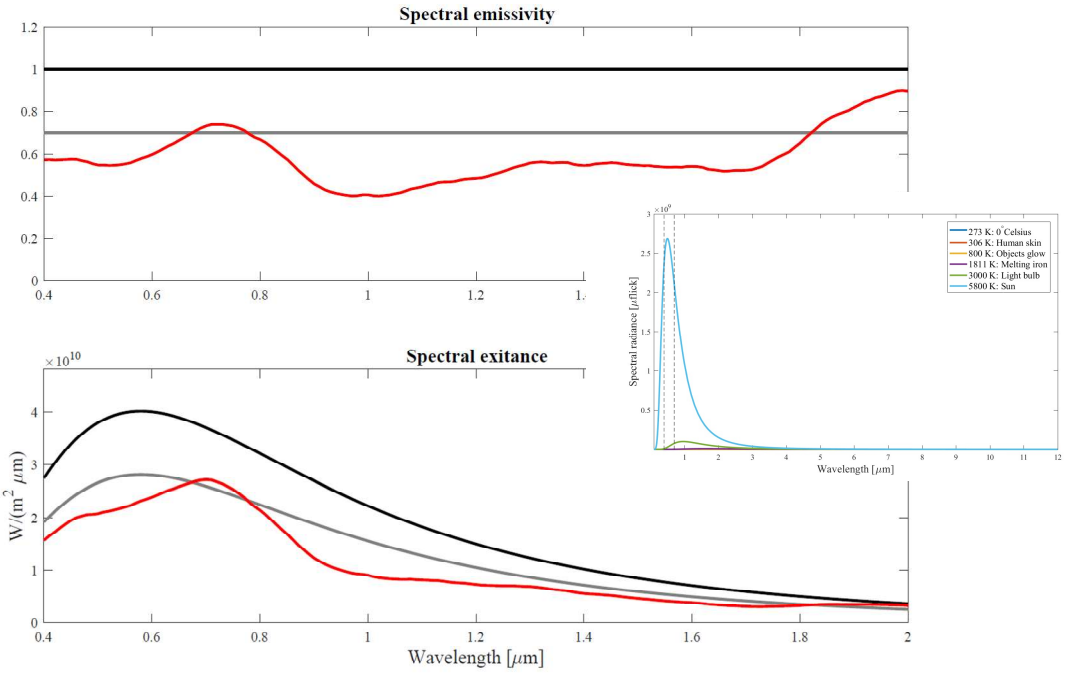

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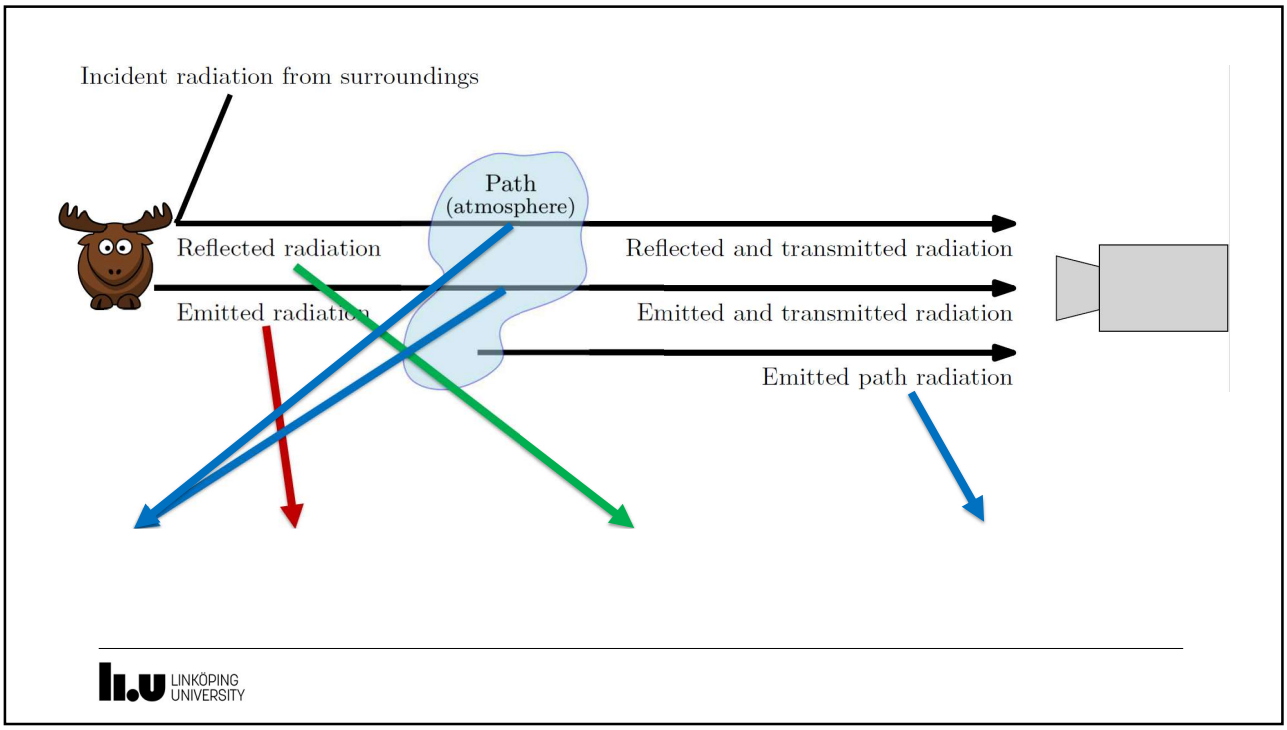
Incident radiation from surroundings
Path
(atmosphere)
Reflected radiation
Reflected and transmitted radiation
Emitted radiation
Emitted and transmitted radiation
Emitted path radiation
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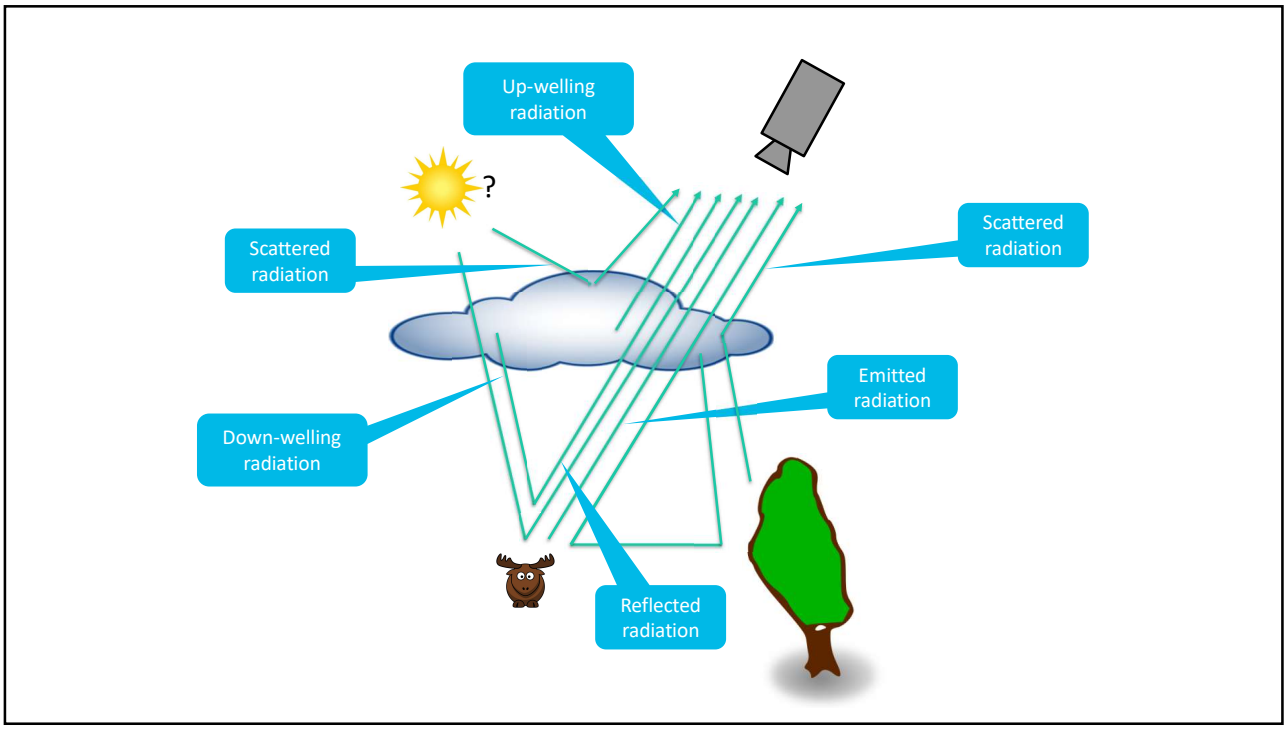
Up-welling
radiation
?
Scattered
radiation
Scattered
radiation
Emitted
radiation
Down-welling
radiation
Reflected
radiation

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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

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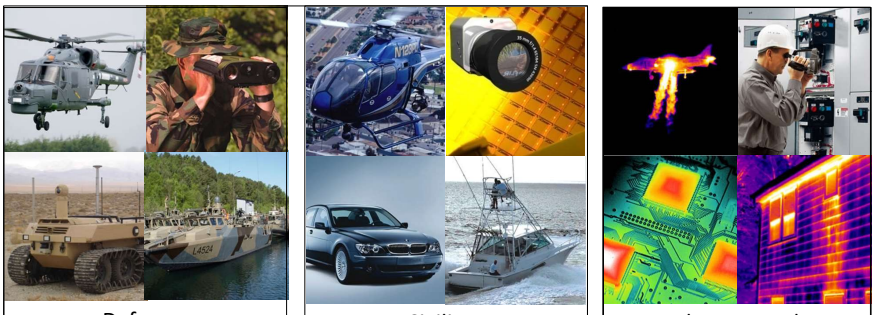
Thermal cameras



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

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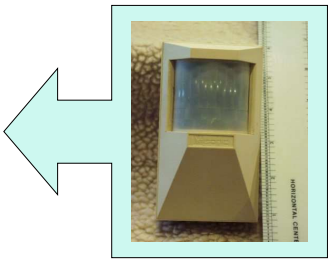
Low-end 	Medium 	Advanced 	Automation, monitoring, R&D 
SWIR 	High performance for R&D 	High resolution for R&D 	Gas finder cameras 

Cooled and uncooled cameras

Sensor type / material		Used for
Cooled		
Mercury cadmium telluride	MCT	SWIR – LWIR
Indium antimonide	InSb	NIR – LWIR
Strained Layer Superlattice	SLS	MWIR, LWIR
Un-cooled		
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

3 thermometers in this one!

Cooled cameras

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

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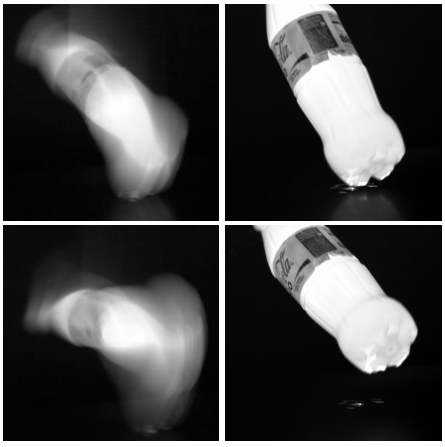
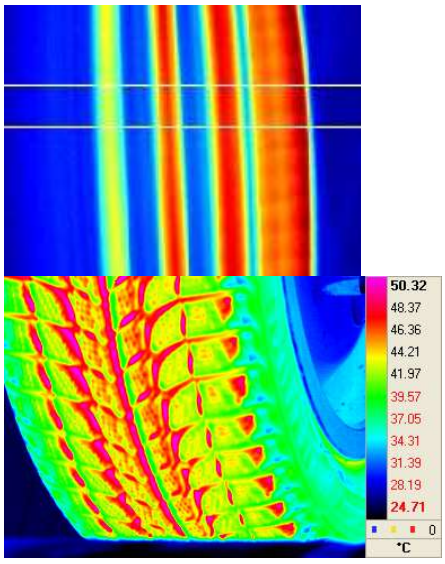
Cooled vs uncooled





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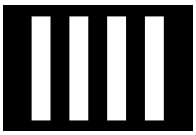
Performance measures

- NETD: Noise Equivalent Temperature Difference
- MRTD: Minimum Resolveable Temperature Difference



- NEP: Noise Equivalent Power

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

- Normalized Detectivity D*
  - Indepedent of detector size and speed

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

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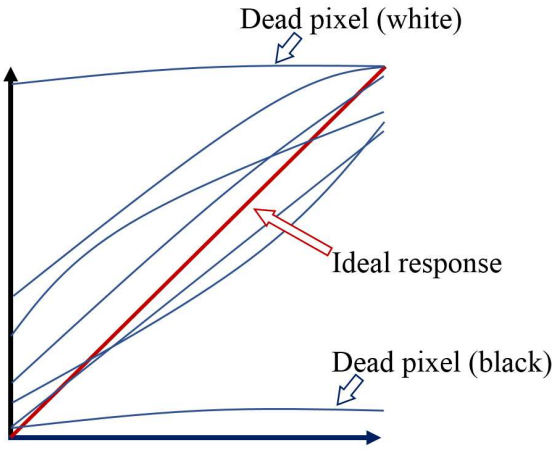
Calibration and NUC



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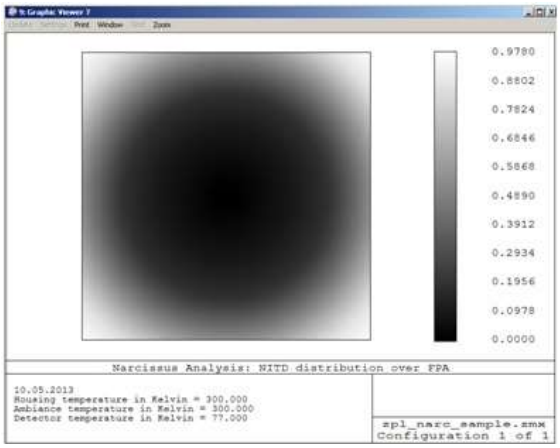
Narcissus

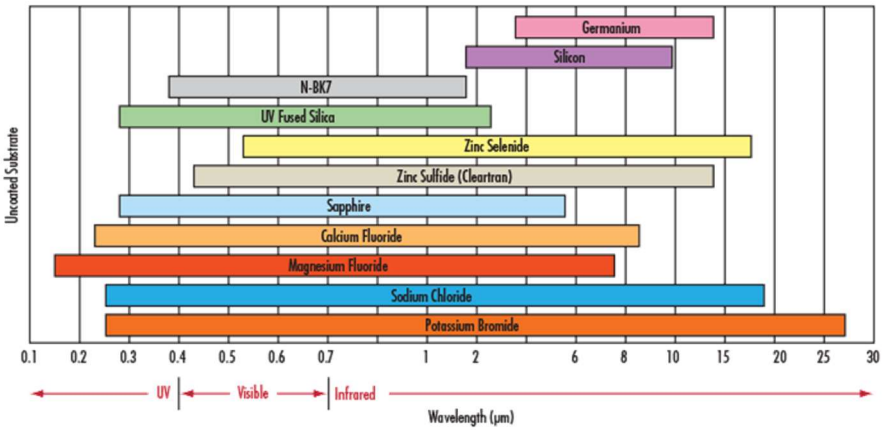


Optics for thermal cameras

Parameters

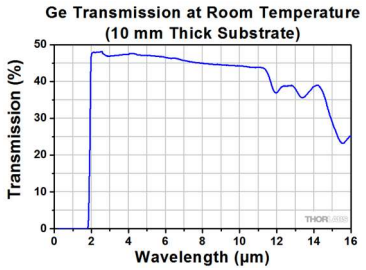
- Durability
- Refractive index
- Variability due to heat
- Cost
- Transmittance

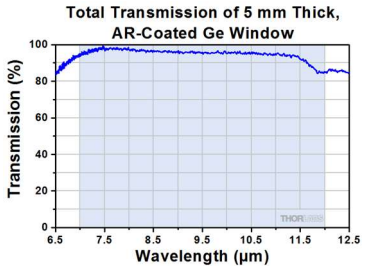
Materials



Lens materials: Germanium

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





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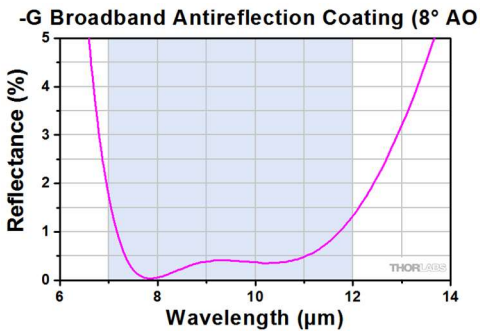
Lens materials: Zinc Selenide

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



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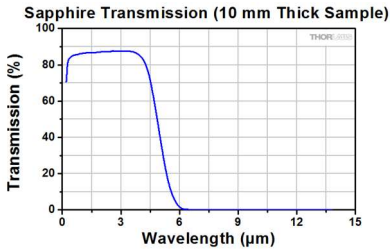
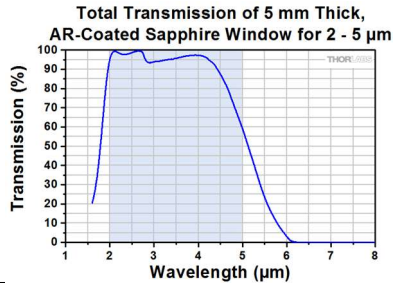
Lens materials: Sapphire

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





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A note on color

Visual White hot Black hot

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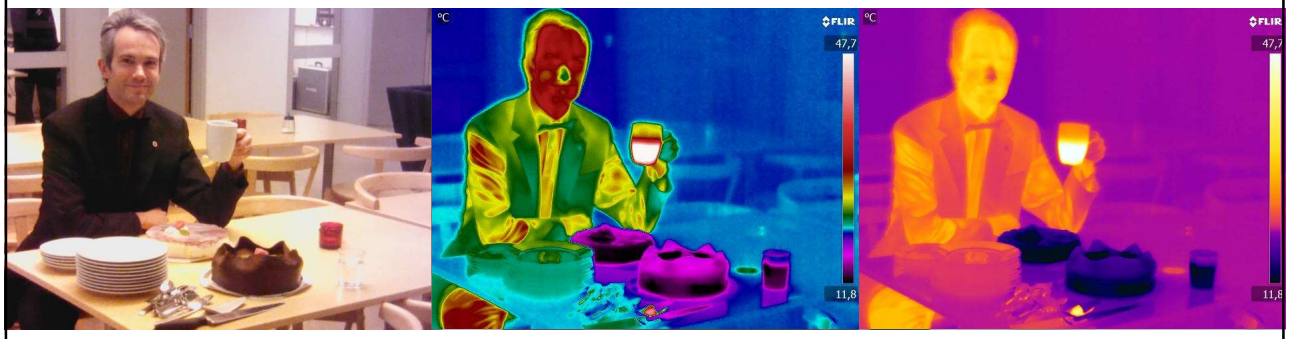
A note on color



Visual Rainbow Iron

Summary: Thermal cameras

- Cooled vs uncooled
  - Cooled: Loud, cumbersome, expensive, fast, sensitive.
- Sensors: Thermal detectors 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

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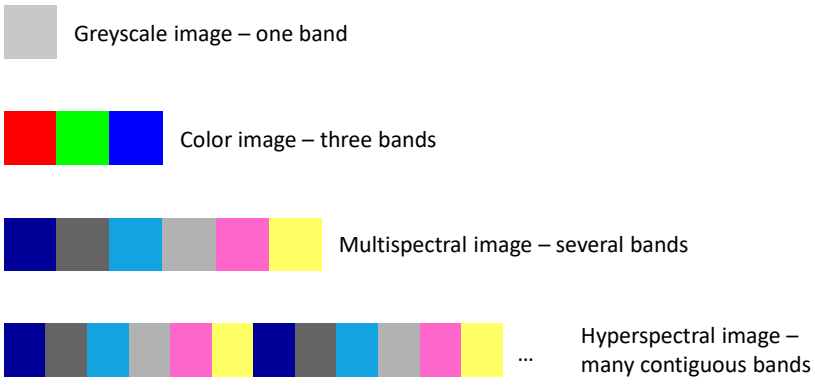
What is multi/hyperspectral imaging?



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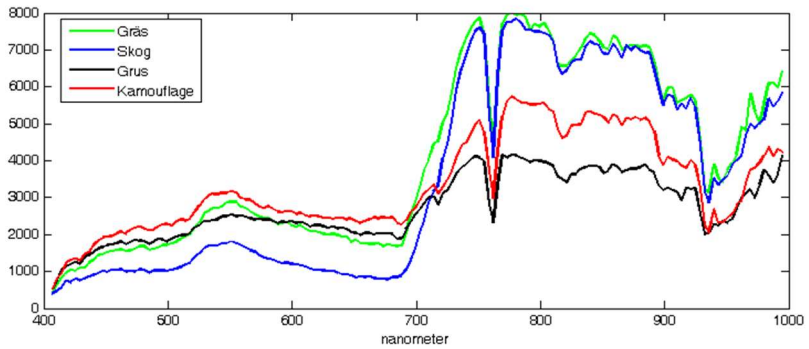
Why multi/hyperspectral images?



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Applications

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

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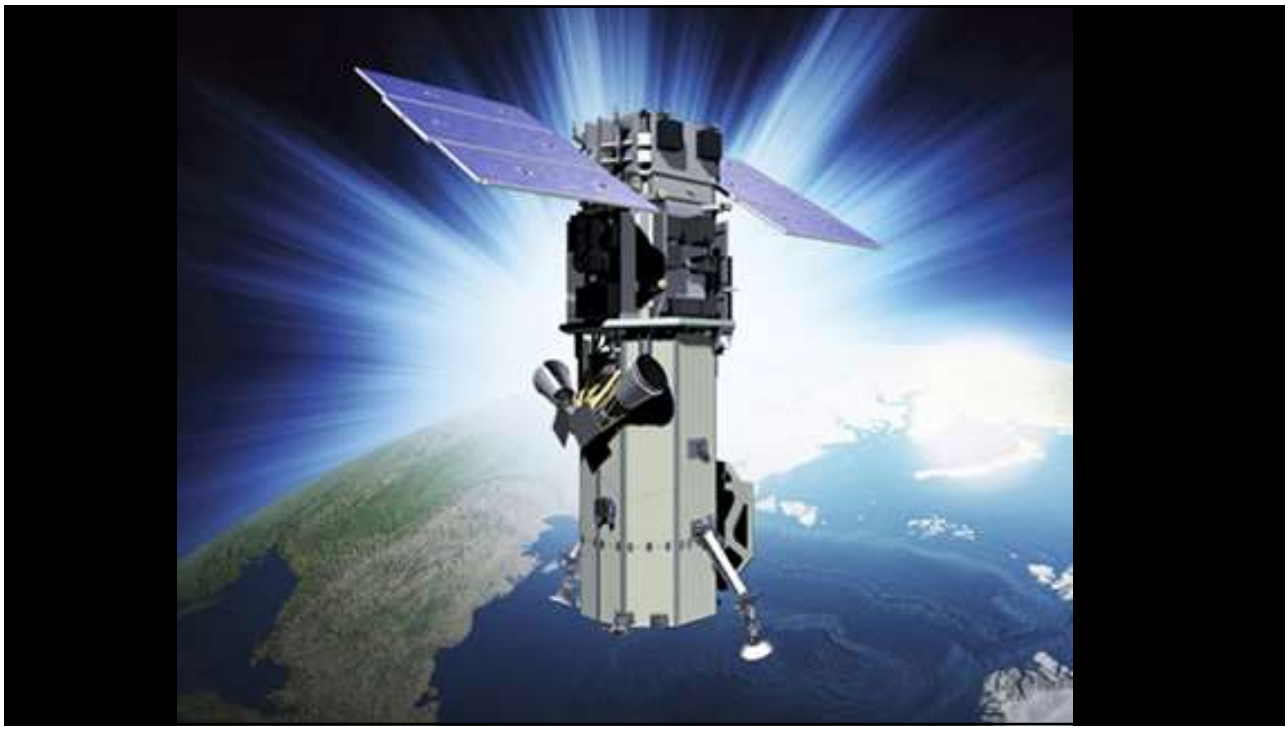

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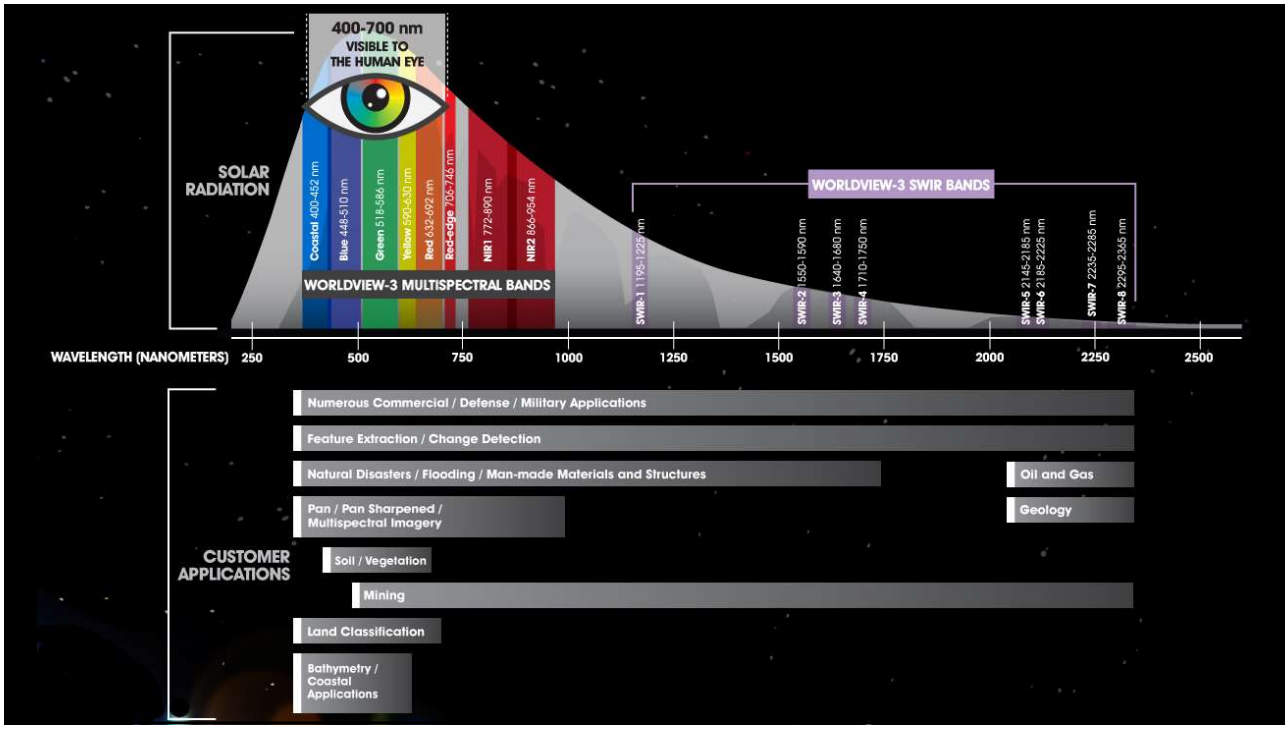
400-700 nm
VISIBLE TO THE HUMAN EYE
SOLAR RADIATION
Coastal 400-452 nm
Blue 448-510 nm
Green 518-586 nm
Yellow 590-630 nm
Red 632-692 nm
Red-edge 706-746 nm
NIR1 772-890 nm
NIR2 866-954 nm
WORLDVIEW-3 MULTISPECTRAL BANDS
WORLDVIEW-3 SWIR BANDS
SWIR-1 1195-1225 nm
SWIR-2 1550-1590 nm
SWIR-3 1640-1680 nm
SWIR-4 1710-1750 nm
SWIR-5 2145-2185 nm
SWIR-6 2185-2225 nm
SWIR-7 2235-2285 nm
SWIR-8 2295-2365 nm
WAVELENGTH (NANOMETERS)
250
500
750
1000
1250
1500
1750
2000
2250
2500
CUSTOMER APPLICATIONS
Numerous Commercial / Defense / Military Applications
Feature Extraction / Change Detection
Natural Disasters / Flooding / Man-made Materials and Structures
Oil and Gas
Geology
Pan / Pan Sharpened / Multispectral Imagery
Soil / Vegetation
Mining
Land Classification
Bathymetry / Coastal Applications

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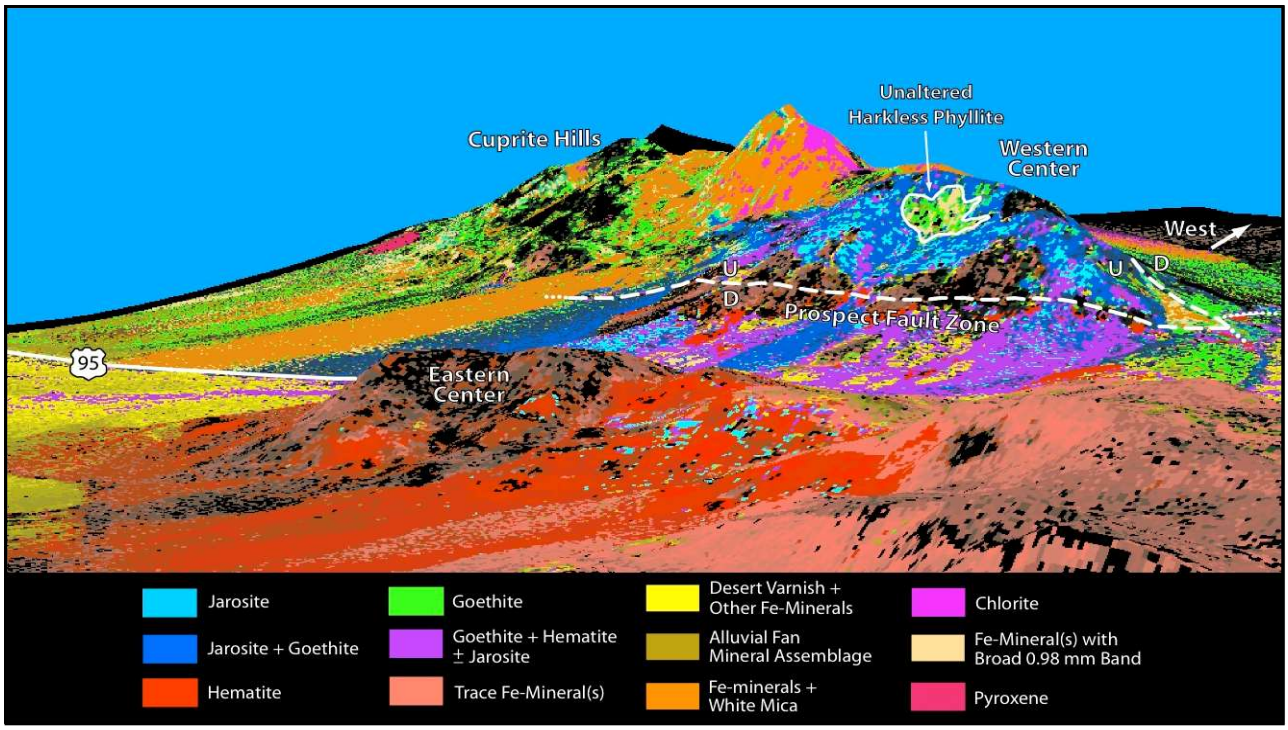

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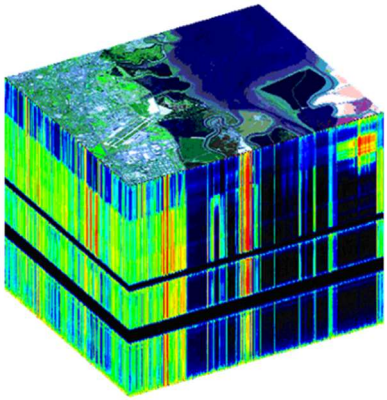
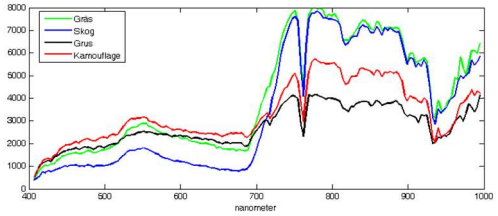
The data cube





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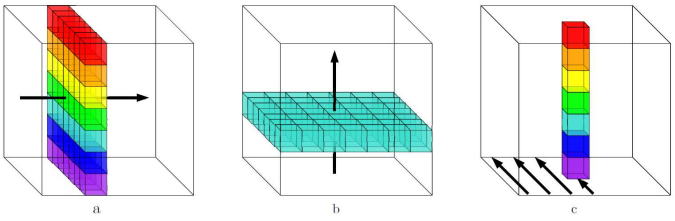

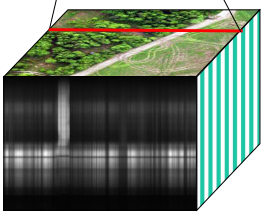

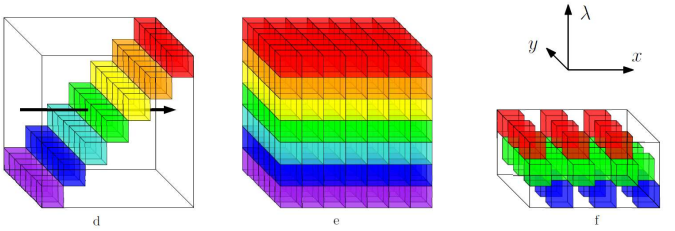

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Multispectral cameras

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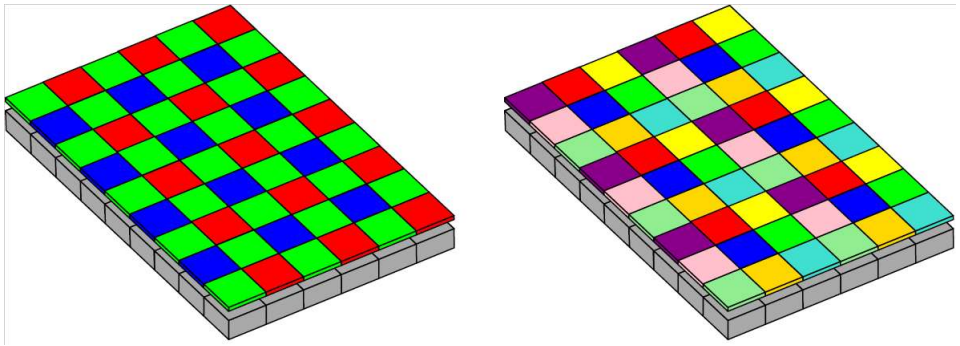
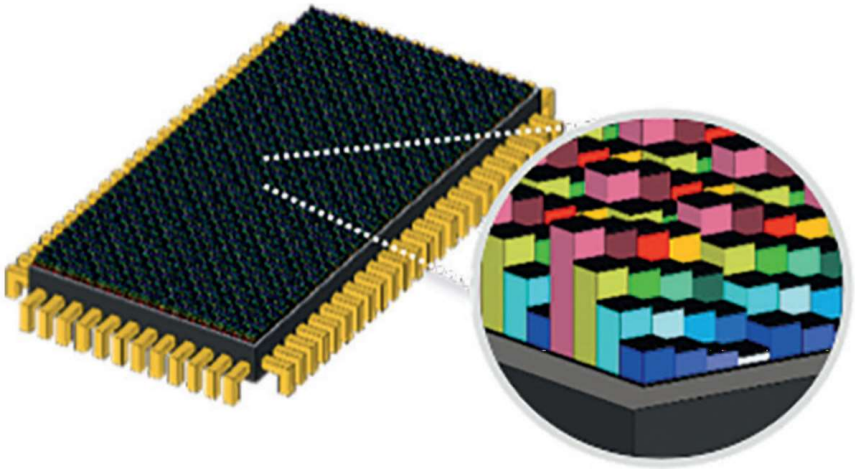
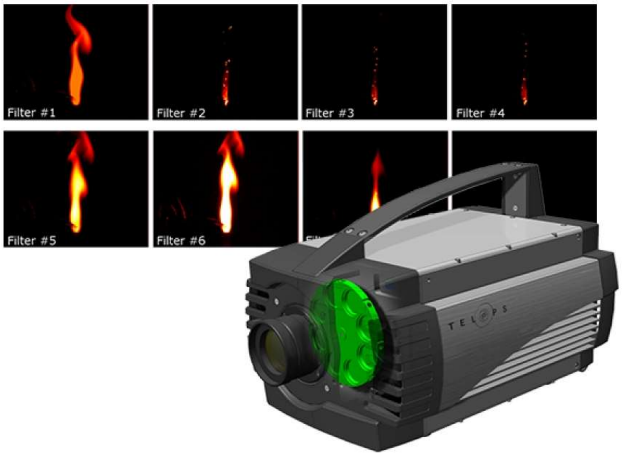
Filter mosaics



16-band sensor from IMEC



Filter wheels



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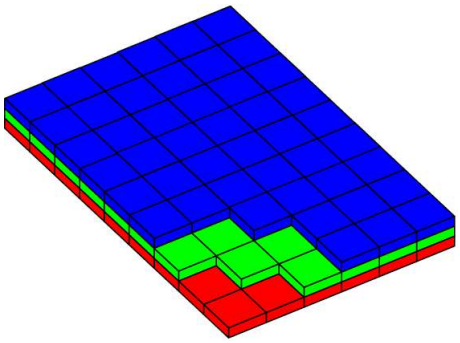
Multi-layer sensors



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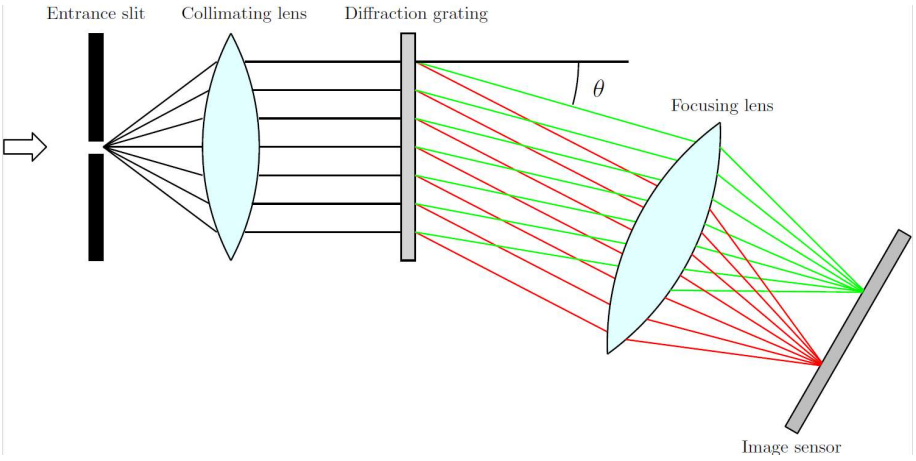
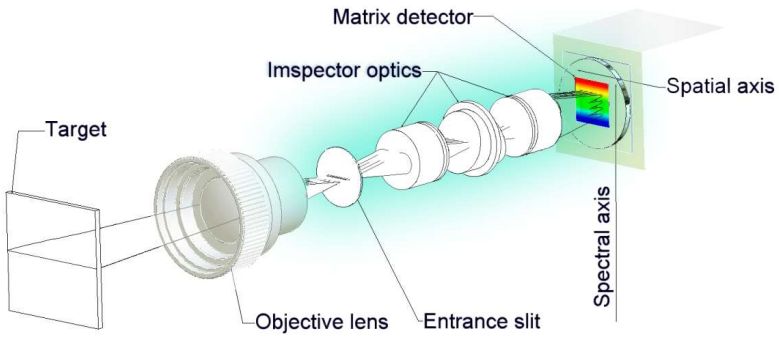
Hyperspectral cameras

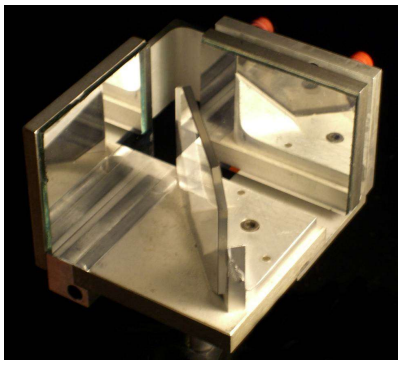
Diffraction grating

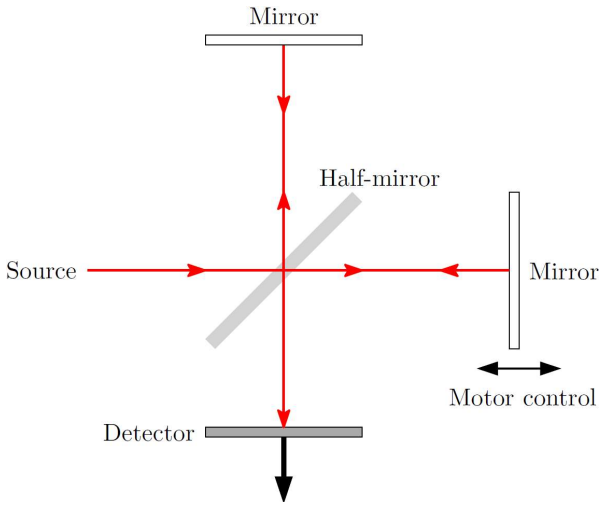


Specim

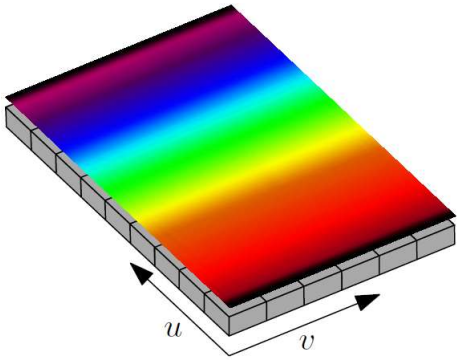


Interferometer





Continuously variable optical band-pass filter



Summary: Multi/hyperspectral

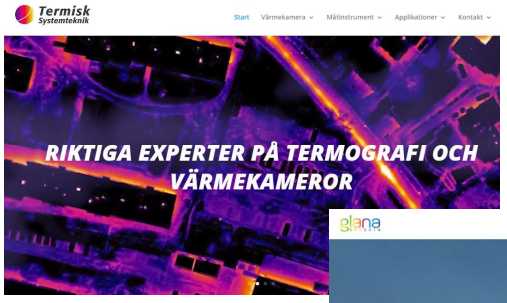
- Use multiple wavebands to see better!
- Recognize materials in one pixel!
- Many ways of making M/HS cameras.
- Applications: Mostly remote sensing and military, others upcoming, especially life sciences and agriculture.

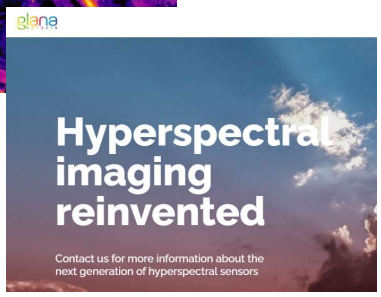
Misc

”The Ultimate Handbook…”

- Read Ch 1-3.
- Pdf on course website.

MSc thesis project





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