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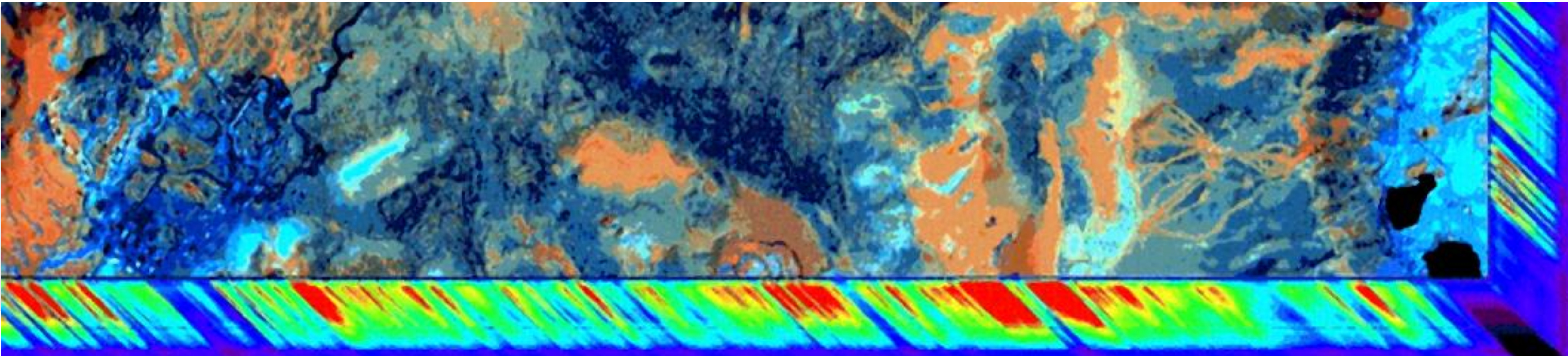

3D and snapshot hyperspectral cameras based on continuously variable filters

Dr.-Ing. Oliver Pust

Delta Optical Thin Film A/S

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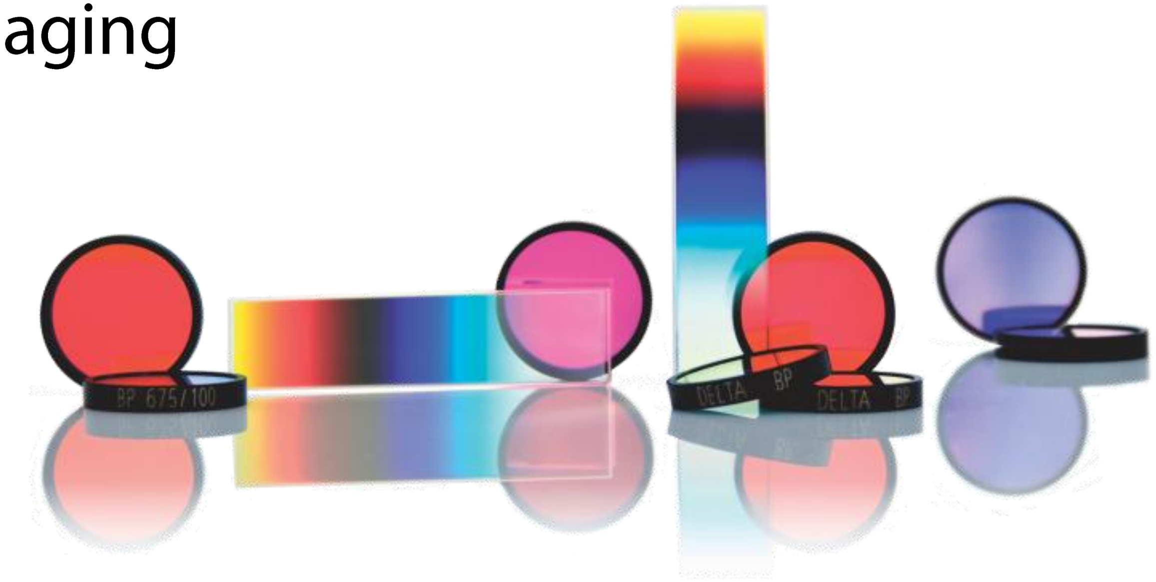
Content

- A few words about Delta Optical Thin Film A/S
- Continuously Variable Bandpass Filters for Hyperspectral Imaging
- Characterization of high-resolution camera
- Measurements compared with reference data
- 3D and snapshot Hyperspectral Imaging
- Discussion



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Delta Optical Thin Film in brief

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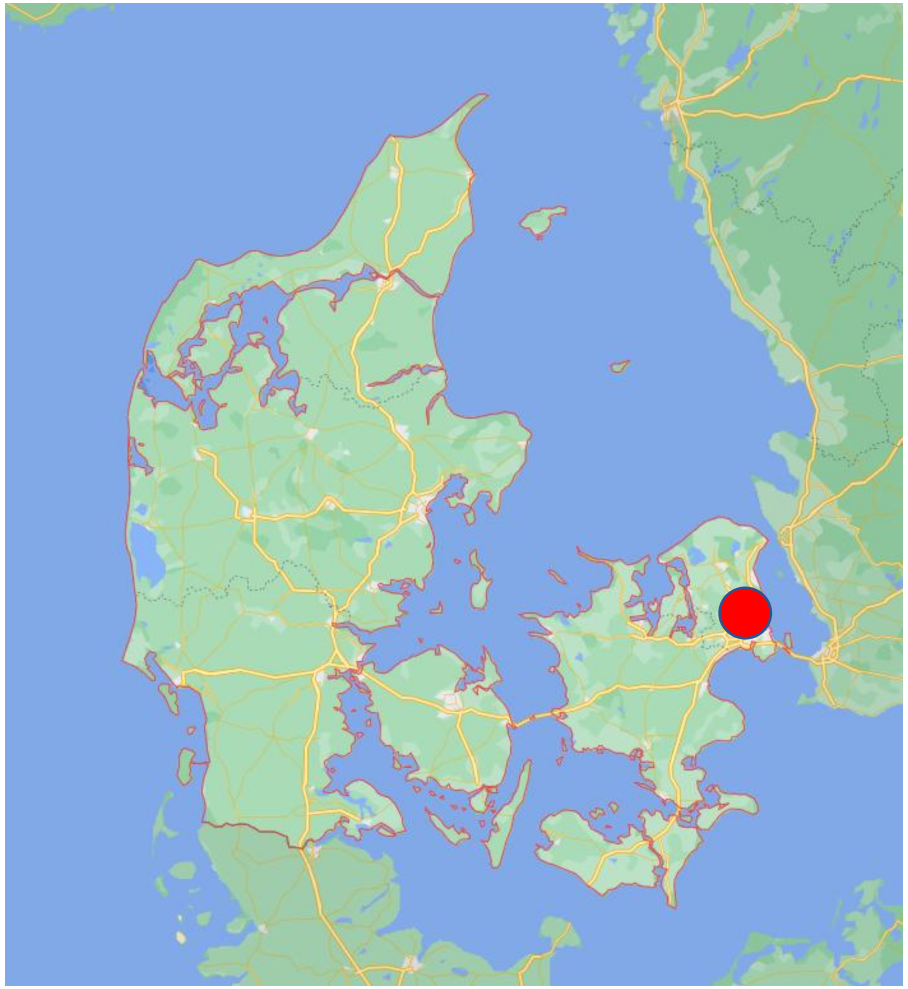
- We focus 100% on design and manufacturing of optical thin film components
- We focus on volume manufacturing for OEM customers
- We are a pioneer in interference filters for fluorescence applications – around since 1970
- Headquarters in Hørsholm, Denmark
- The leading supplier of Continuously Variable Filters
- Highly automated manufacturing 24/5



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Delta Optical Thin Film today

- New global 2,300 m^2 headquarters in August 2020
- Improved clean room with space for further expansion
- Equipped with latest Magnetron Sputter coating technology
- Ultrasonic washing line based on environmentally sustainable chemicals
- 1,000 m^2 solar panels on roof. All other electricity supplied by wind power for minimum carbon footprint

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Tour through our facility

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https://youtu.be/kDf-GkWiwqo

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Optical Thin Film Technology

Delta Optical Thin Film milestones:

- Suggested use of interference filters for use in fluorescence microscopy in the late sixties
- Started volume manufacturing of fluorescence filters in the early seventies
- First computer-controlled deposition implemented in the early nineties
- Own design and deposition control software are tightly integrated and allow us to offer coatings made with magnetron sputter coating or plasma assisted e-beam evaporation technology with the same quality as that offered by IBS and similar technologies
- Obtainable batch sizes and coating speed allows us to offer volume products at very competitive prices

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Applications

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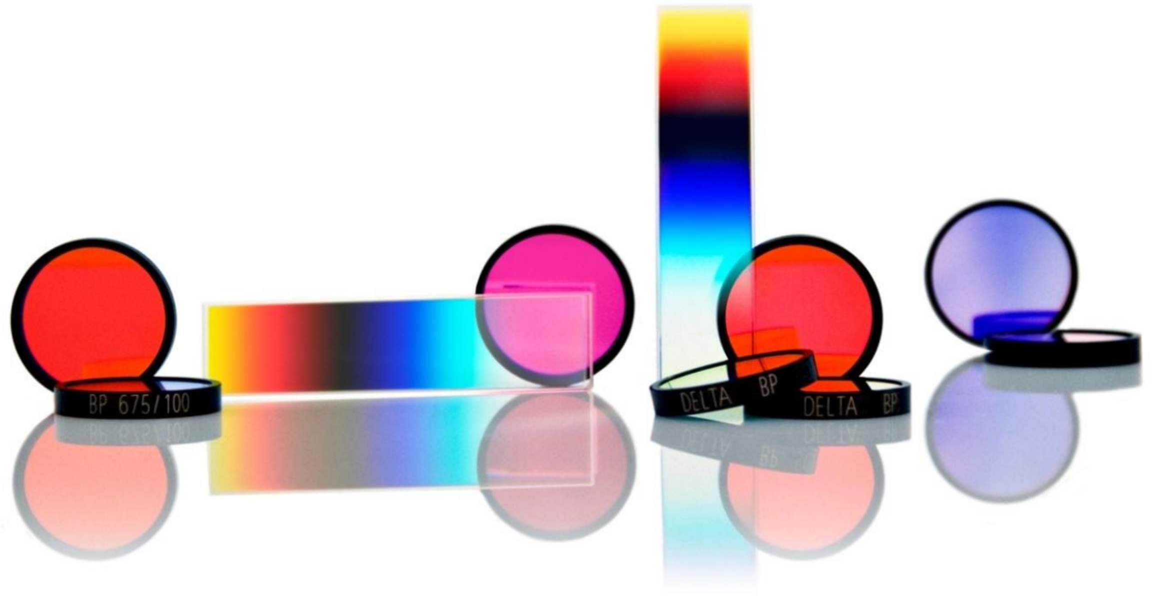
Our products are found in a variety of applications, including:

- Hyperspectral Imaging
- Fluorescence microscopy
- Wavelength selectors
- High-performance monochromators
- Biomedical laser systems
- Point of Care (PoC) instruments
- Image transferring systems
- Colour separation systems
- Optical Coherence Tomography



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Product Range

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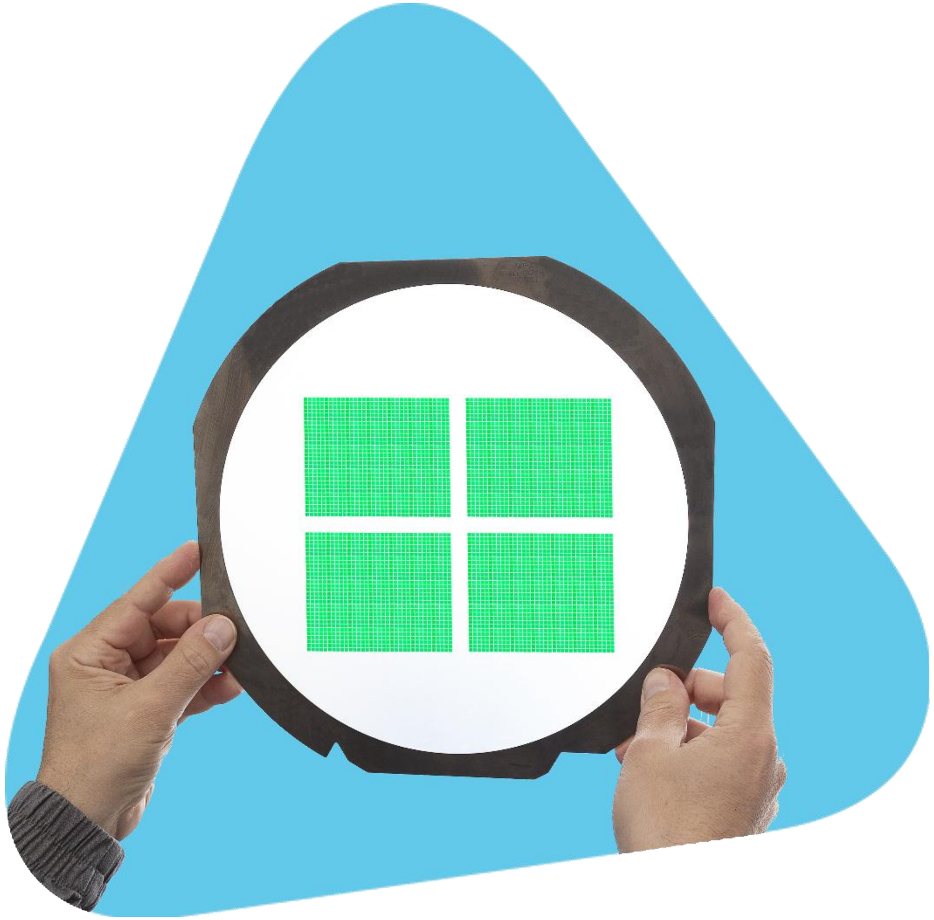
Choose from our product range:

- Continuously Variable Filters
- Bandpass filters: Single or Multiband, Laser line, Broadband
- Beamsplitters (flats and cubes): Dichroic, Polarization
- Edge filters: Long Wave Pass or Short Wave Pass
- SMART coatings: Multifunctional filters

- All filters can be diced to fit modern PoC instruments



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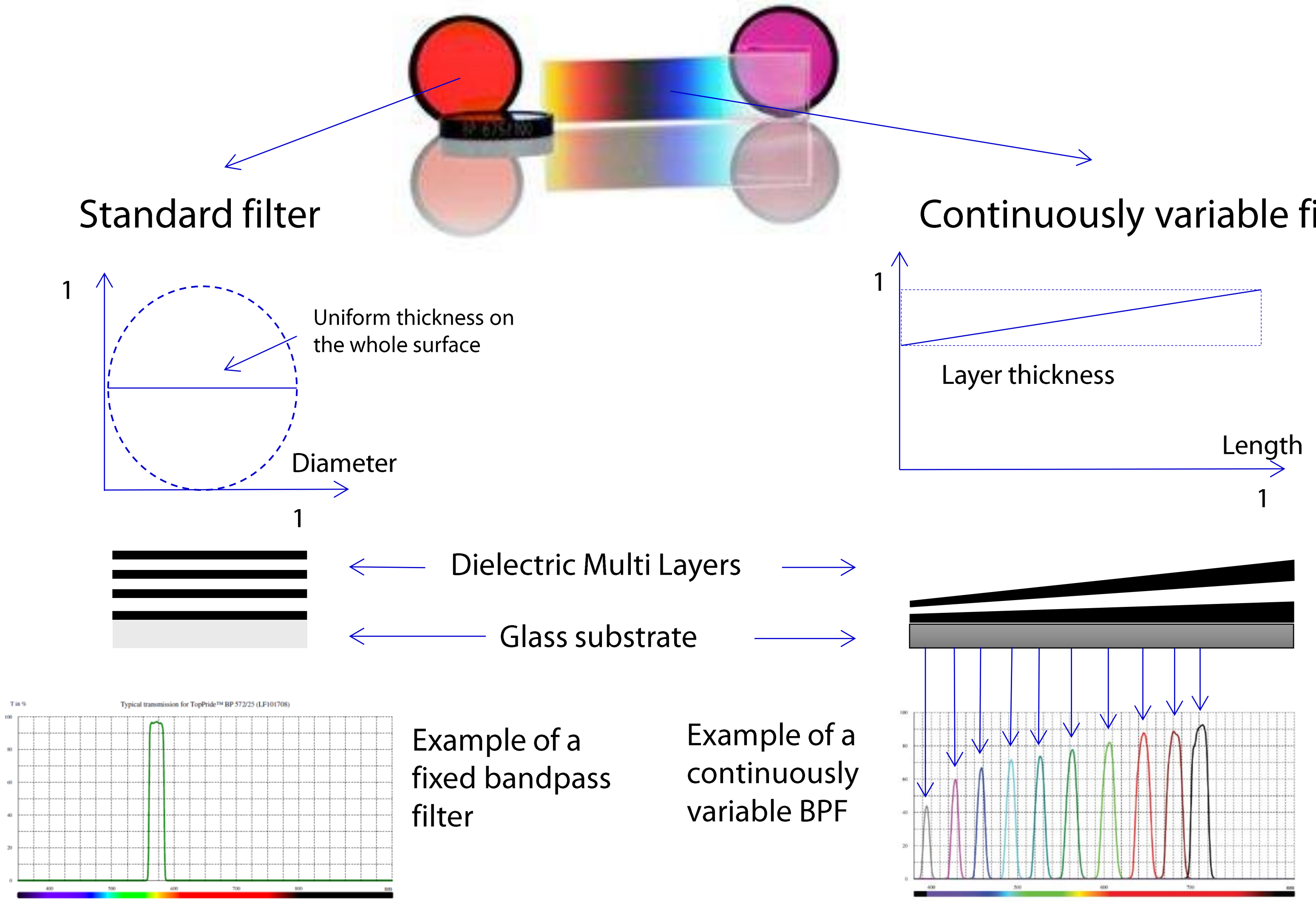
Construction of Continuously Variable Filters



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Advantages of Continuously Variable Filters

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- Robust and shift free surface coatings on unglued fused silica substrates for minimal auto fluorescence and high Laser Damage Threshold
- The filters work well with Supercontinuum Light Sources
- Transmission is mostly higher than 92%
- Blocking is better than OD3 (3G filters) or OD4 (4G filters)
- Blocking to beyond OD7 by adding another Continuously Variable Filter
- Several SWP: Edge to be tuned from 320 nm – 895 nm
- Several LWP: Edge to be tuned from 310 nm – 895 nm
- Several Dichroics: Edge to be tuned from 320 nm – 860 nm
- UVVISBP: Centre wavelength from 320 nm to 560 nm
- VISBPs: Centre wavelength from 400 nm to 700 nm
- NIRBP: Centre wavelength from 550 nm to 1000 nm
- VISNIRBPs for HSI: Centre wavelength from 450 nm to 850/950 nm
- NIRBP for HSI: Centre wavelength from 800 nm to 1000/1100 nm
- Helpful application notes available

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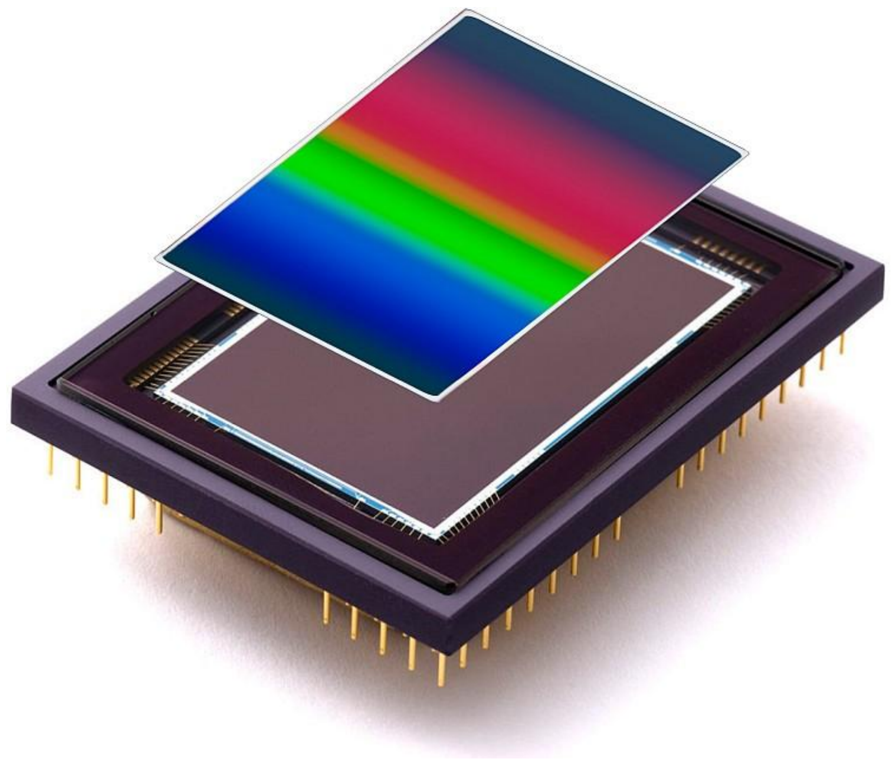
CVBPFs for Hyperspectral Imaging

- For mid-size and full-frame CCD/CMOS sensors (e.g. 25 mm x 25 mm or 24 mm x 36 mm)
- Very high transmission
- Fully blocked in the wavelength sensitive range of silicon-based detectors (200 nm to 1150 nm)
- Centre wavelength range 450 nm to 880/950 nm, FWHM ≈ 2% * CWL, length 36 mm
- Centre wavelength range 450 nm to 850 nm, FWHM ≈ 4% * CWL, length 25 mm
- Centre wavelength range 800 nm to 1000 nm, FWHM ≈ 1% * CWL, length 8.4 mm
- Centre wavelength range 800 nm to 1088 nm, FWHM ≈ 1% * CWL, length 18 mm



CVF based Hyperspectral Imaging detector

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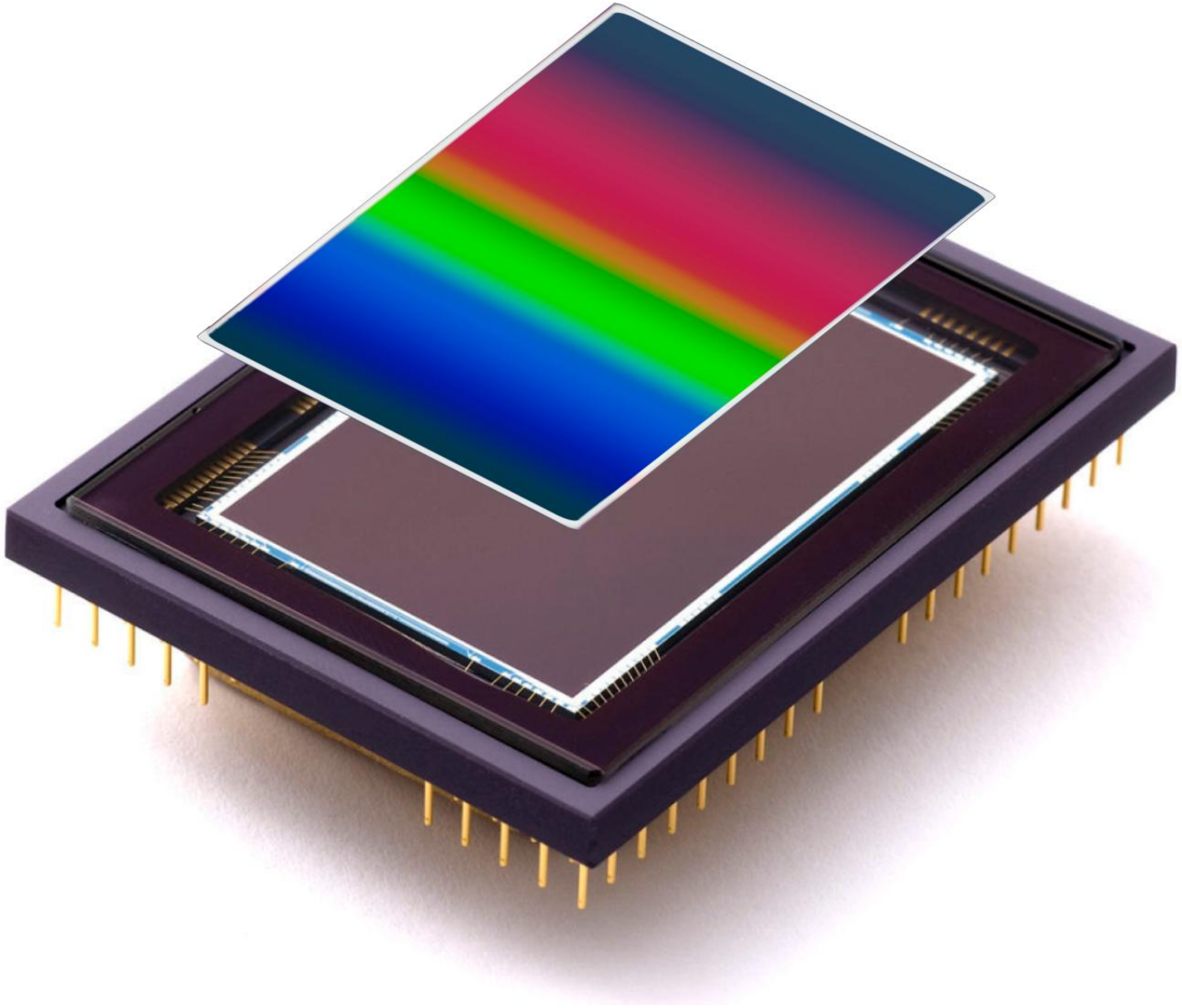

- Compact
- Robust
- Light efficient
- High signal to background ratio
- Inexpensive
- Simultaneous 3D measurements
- Snapshot possible

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Size comparison dispersive vs. filter-based camera

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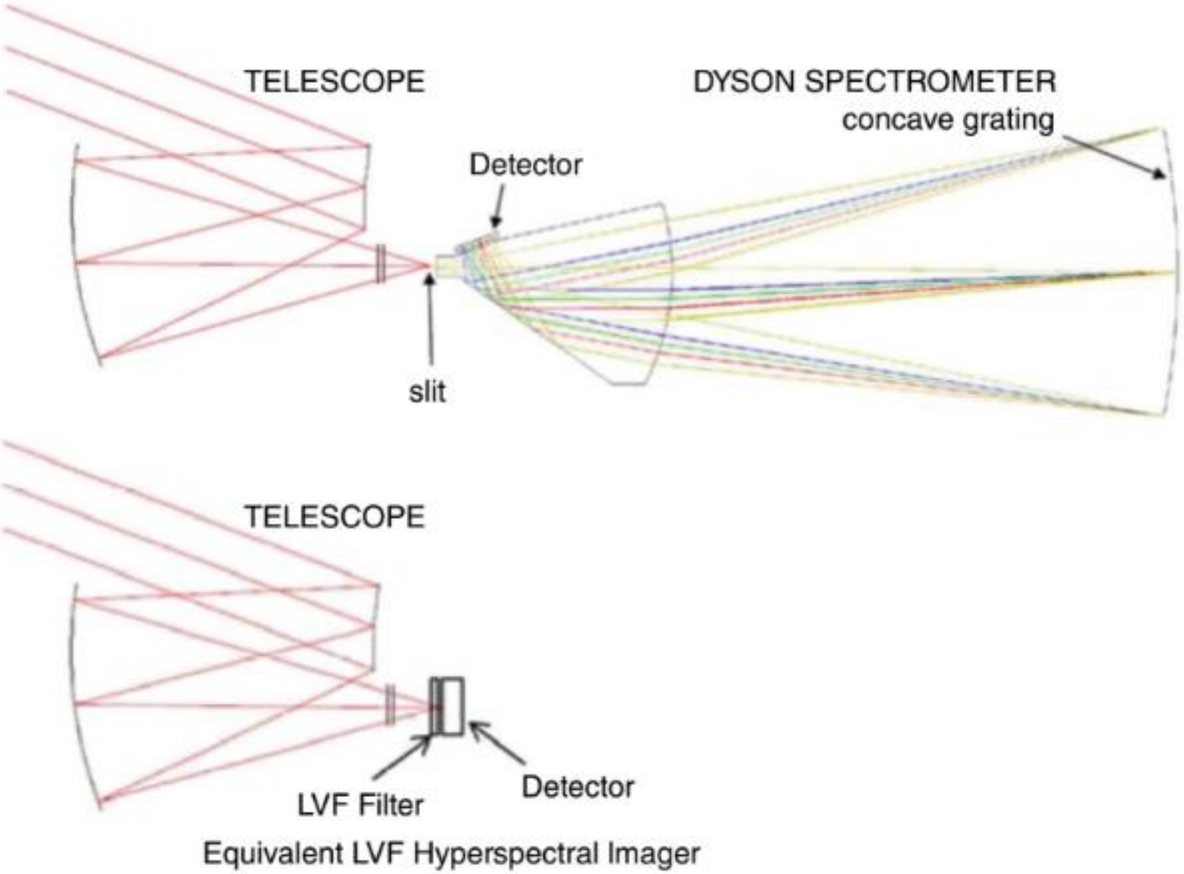
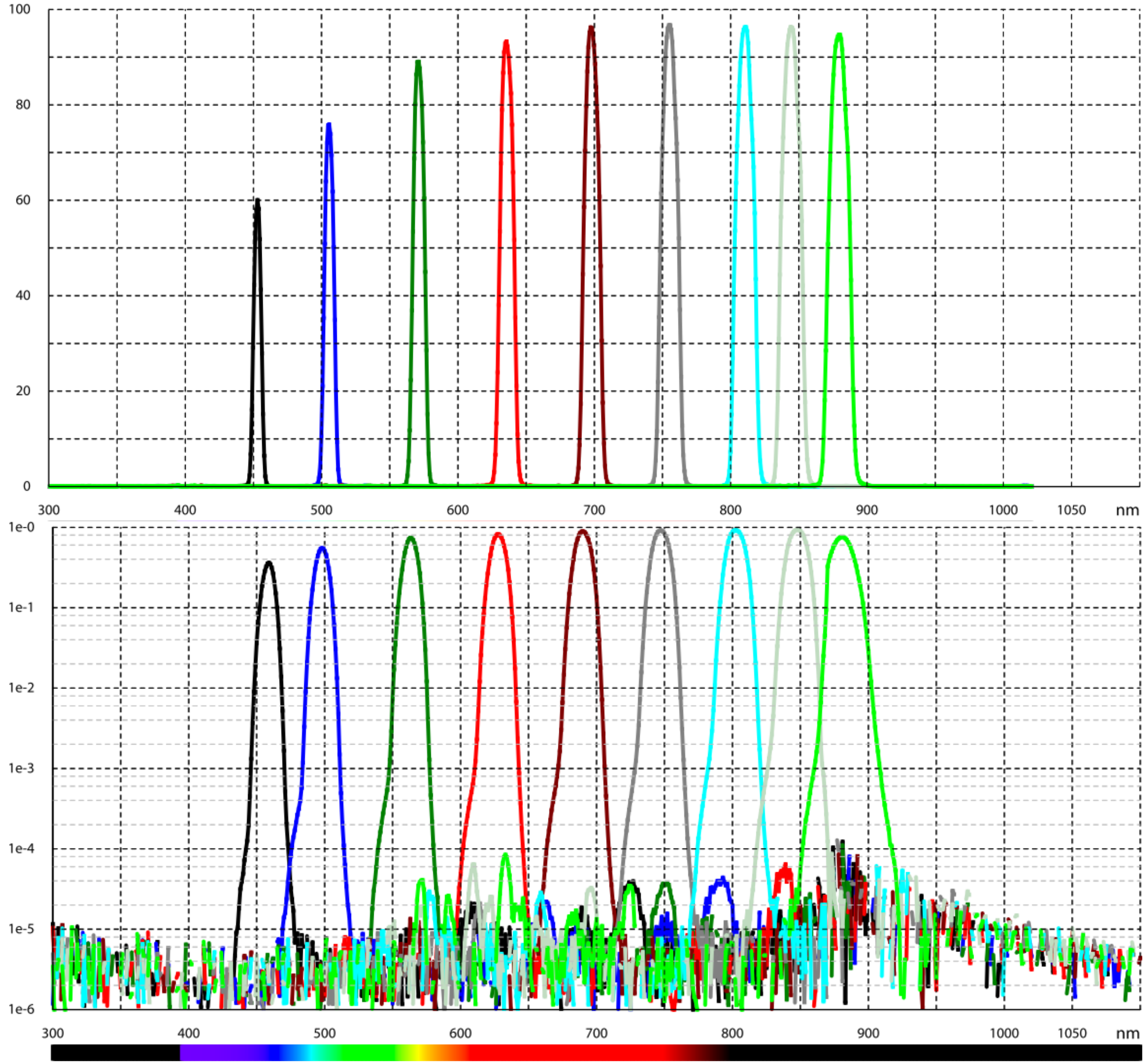


FIGURE 1.5 An example of how the volume and mass of a filter-based hyperspectral sensor is reduced compared to a traditional dispersive element based approach.

(Source: Hyperspectral Satellites and System Design, Shen-En Qian, CRC Press)

HSI filter 450 nm to 880 nm, 24 mm x 36 mm



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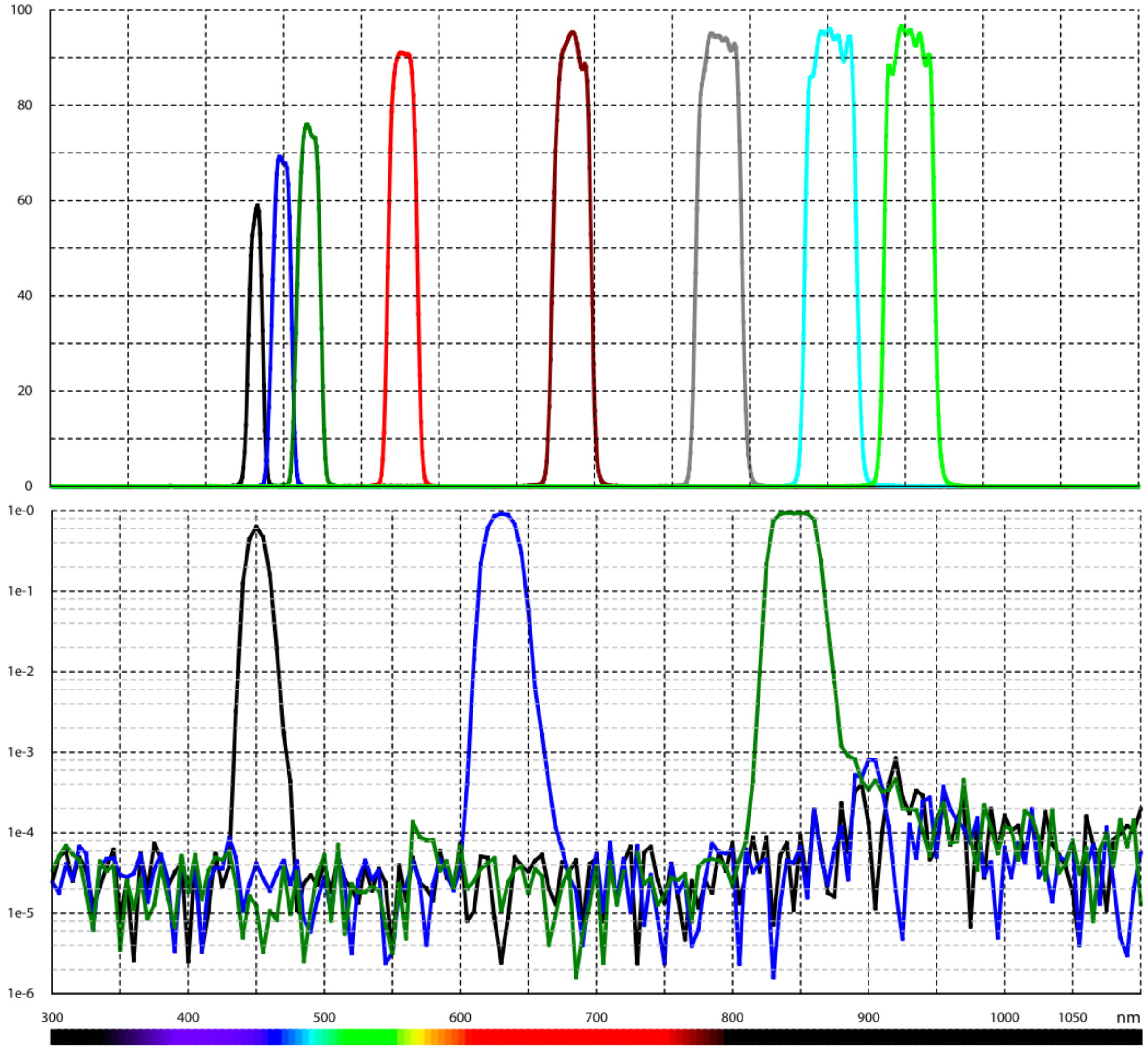
HSI filter 450 nm to 850 nm, 25 mm x 25 mm



The apparent drop in blocking from 860 nm and upwards is due to low detector sensitivity.

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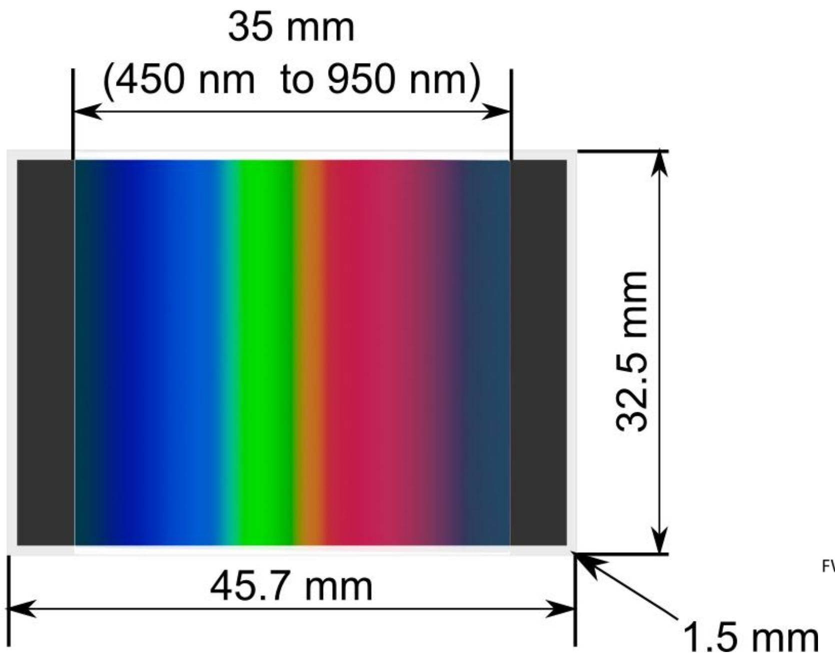
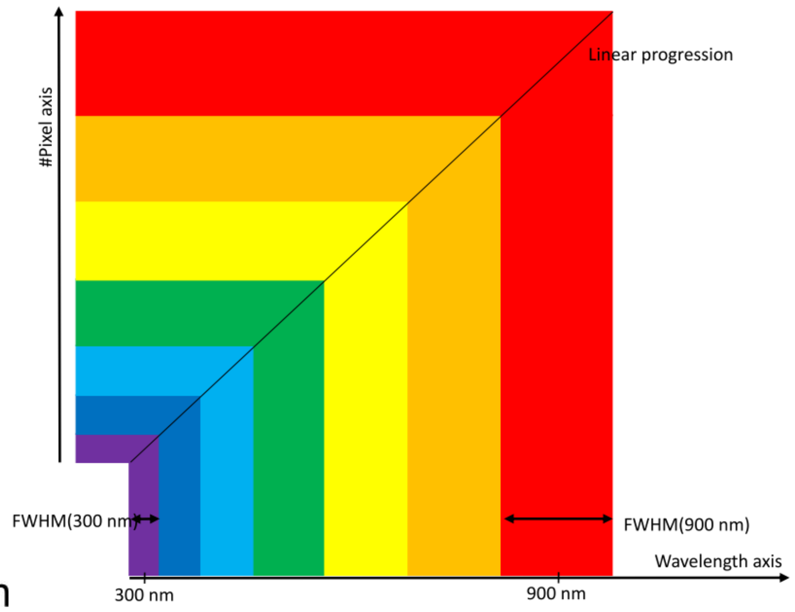
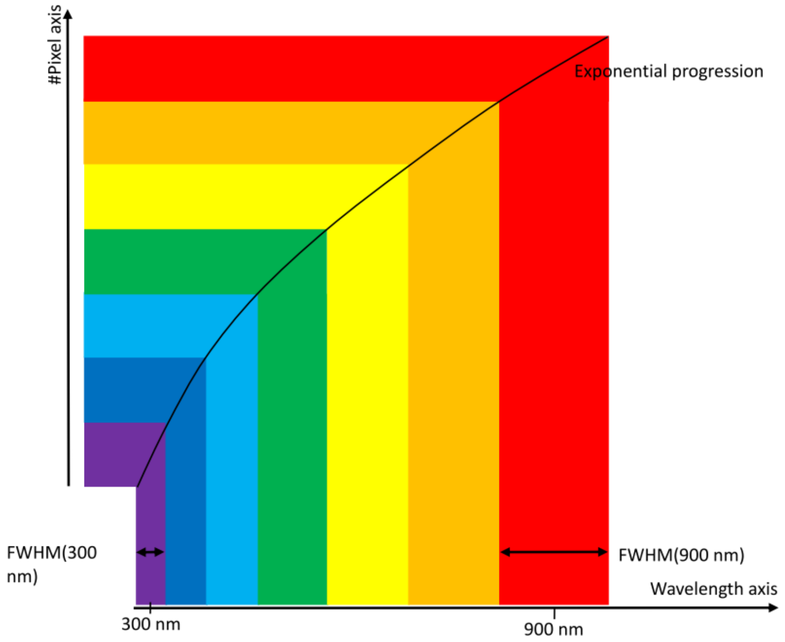
Linear or exponential dispersion?

2nd generation Hyperspectral Imaging filter

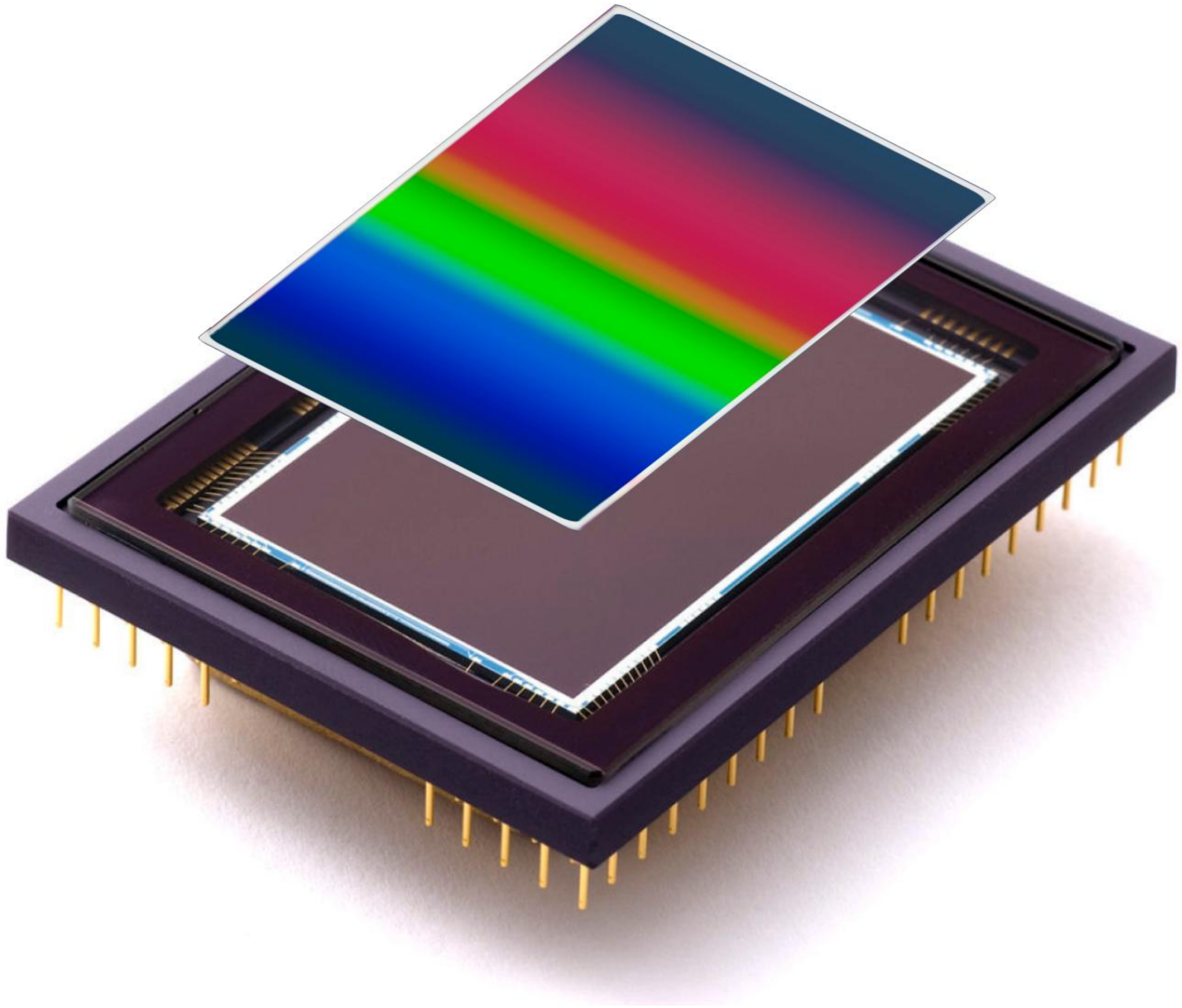
- Wavelength range 450 nm to 950 nm
- FWHM = 2% * CWL
- Blocking range 200 nm to 1200 nm
- Exponential dispersion







CVF based Hyperspectral Imaging detector



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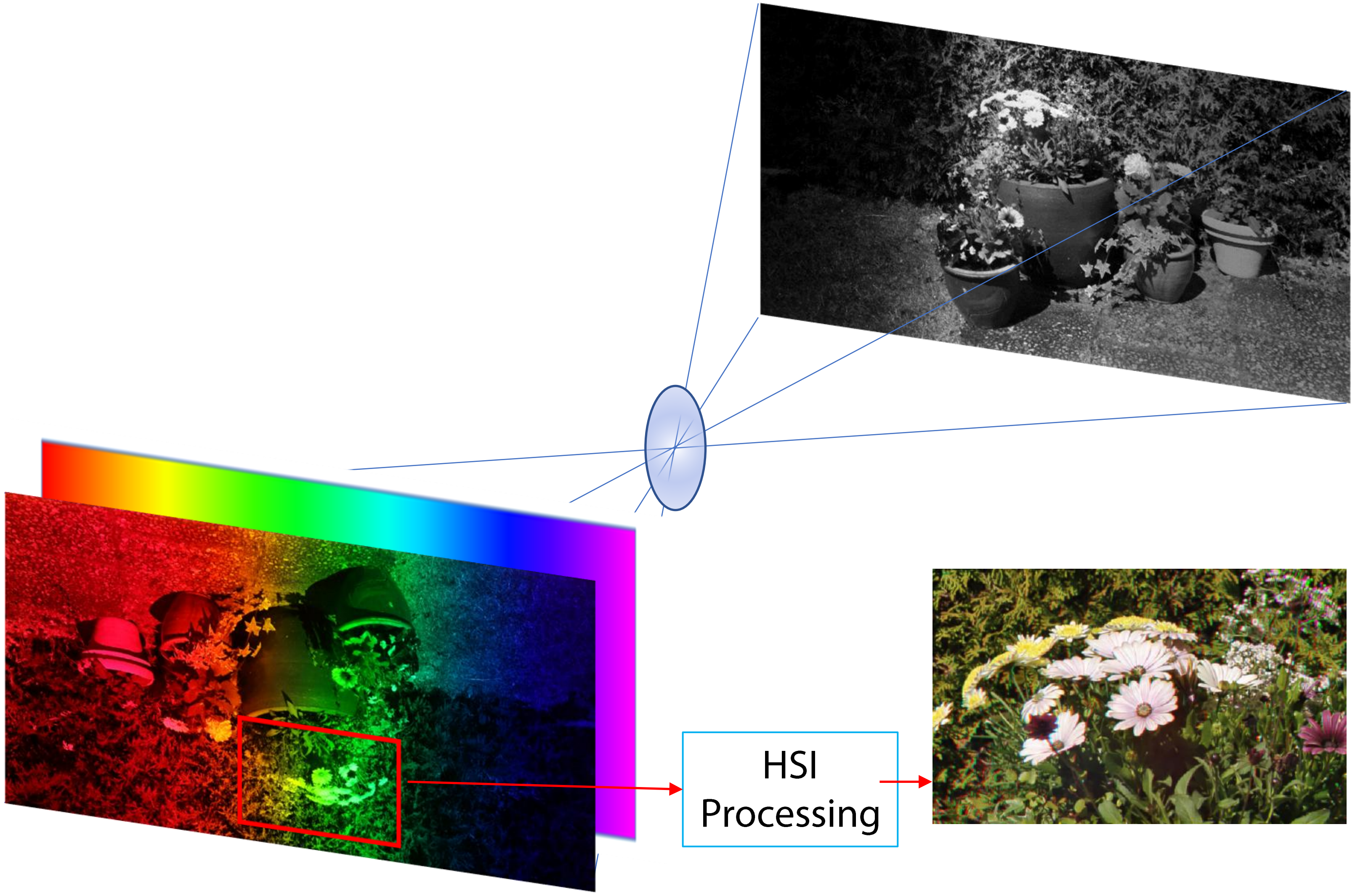
Working principle



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Building the Hyperspectral Imaging data cube

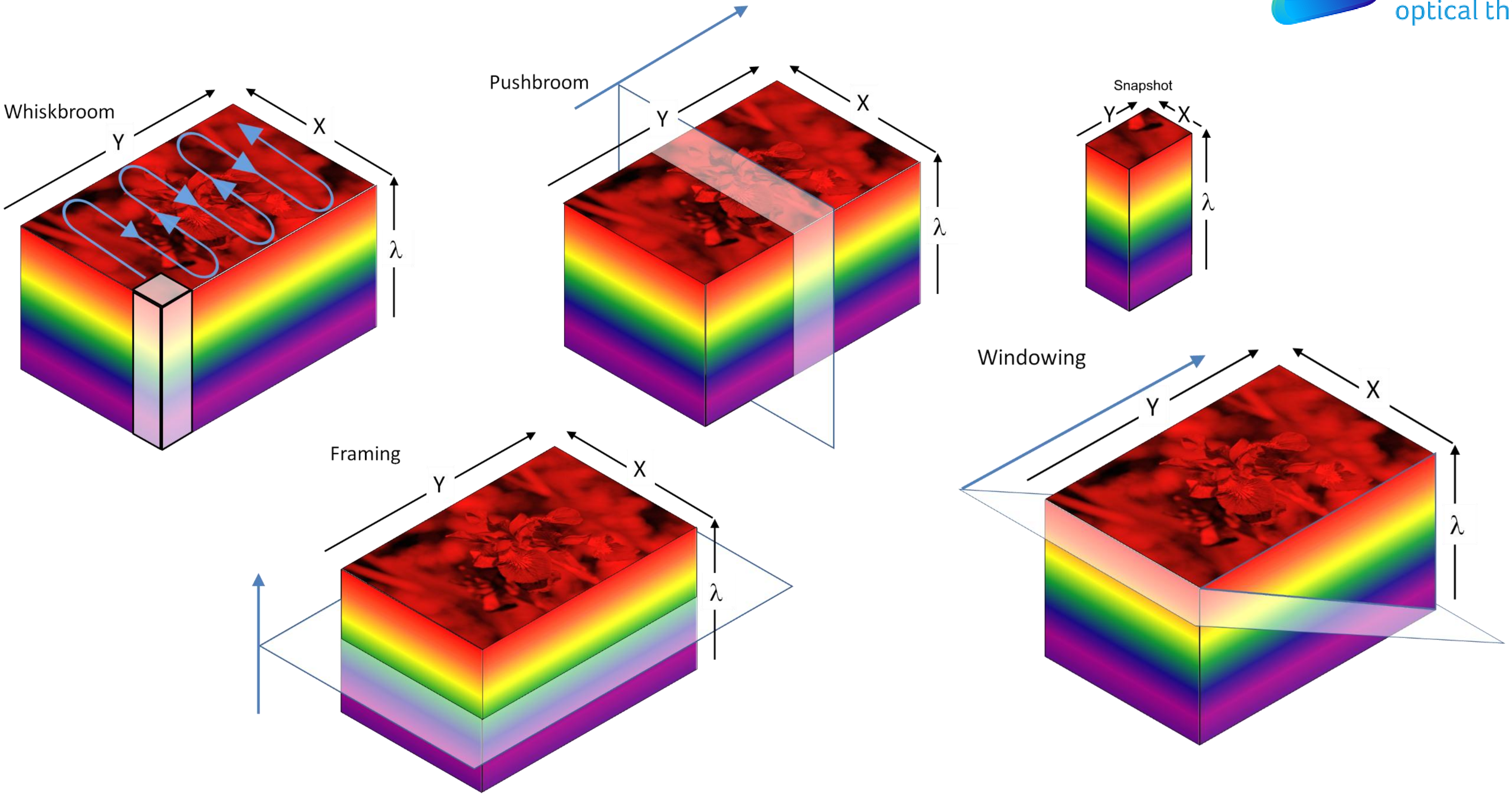

Image credit Matt Gunn, Aberystwyth University

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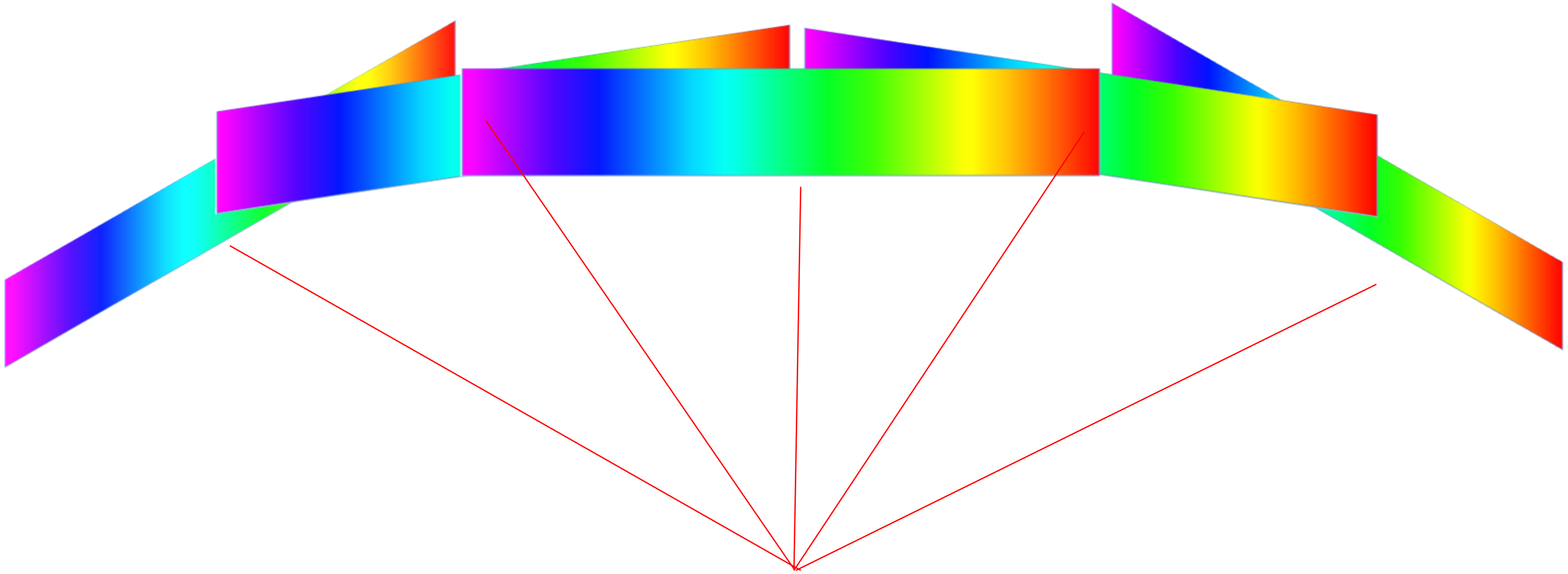
Building the Hyperspectral Imaging data cube



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3D Hyperspectral Imaging

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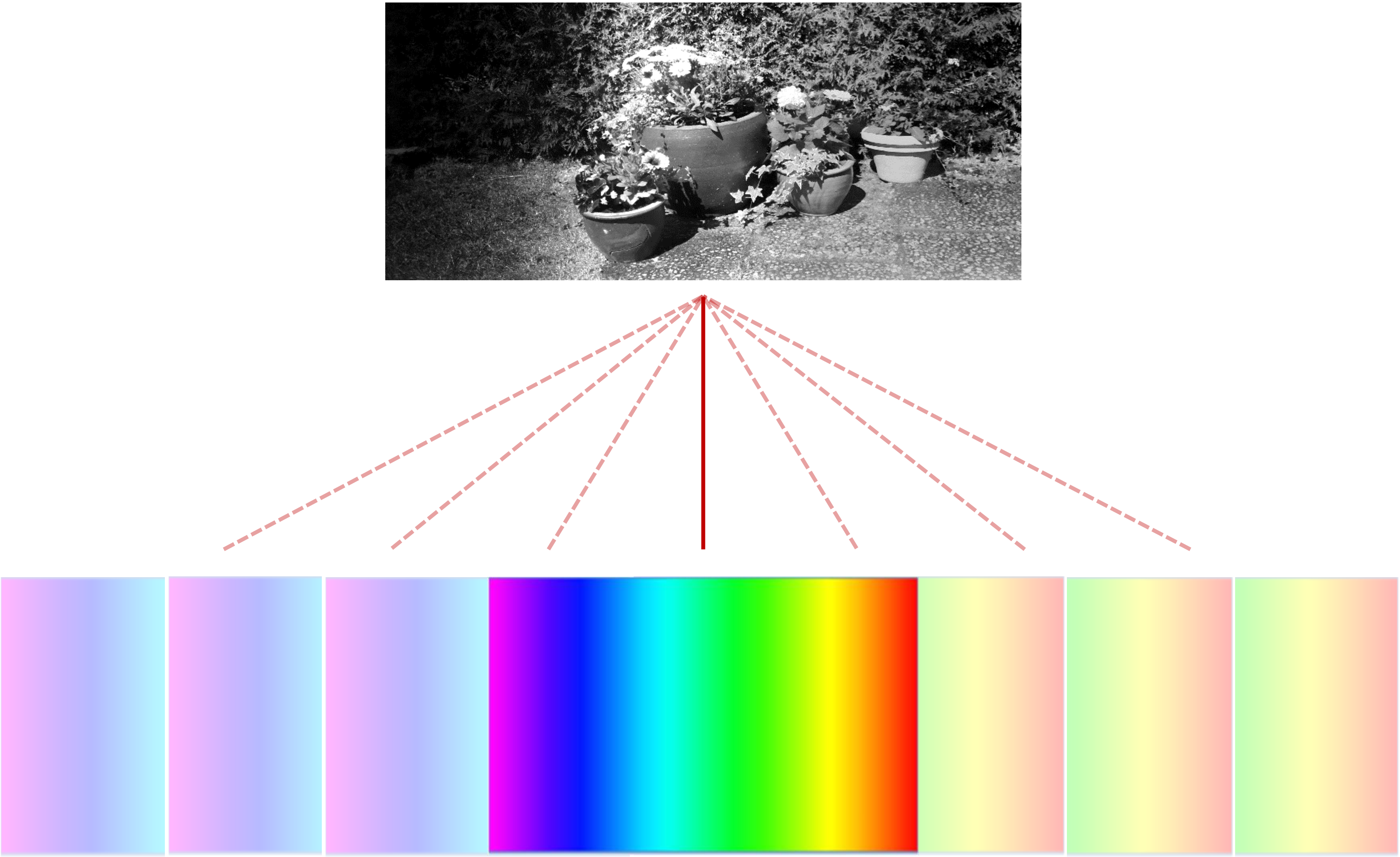

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Hyperspectral Imaging Demo

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Hyperspectral Satellite Imaging

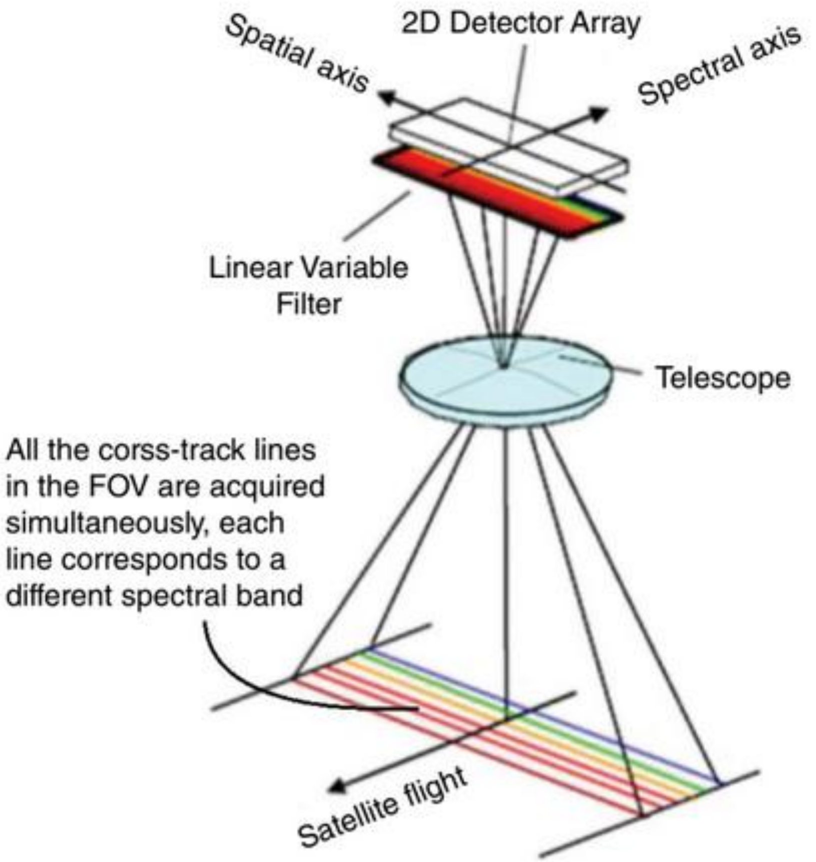

FIGURE 1.8 An illustration of the concept of a linear variable filter based hyperspectral sensor.

(Source: Hyperspectral Satellites and System Design, Shen-En Qian, CRC Press)

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Hyperspectral Satellite Imaging

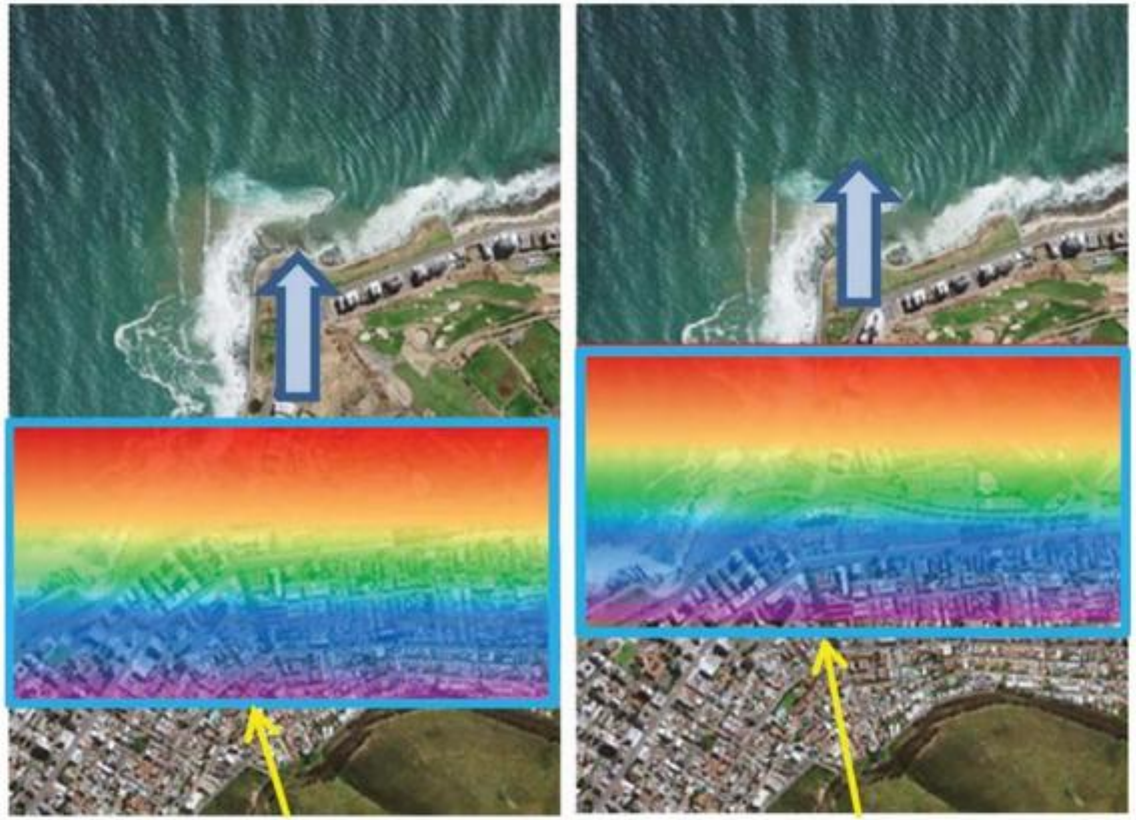
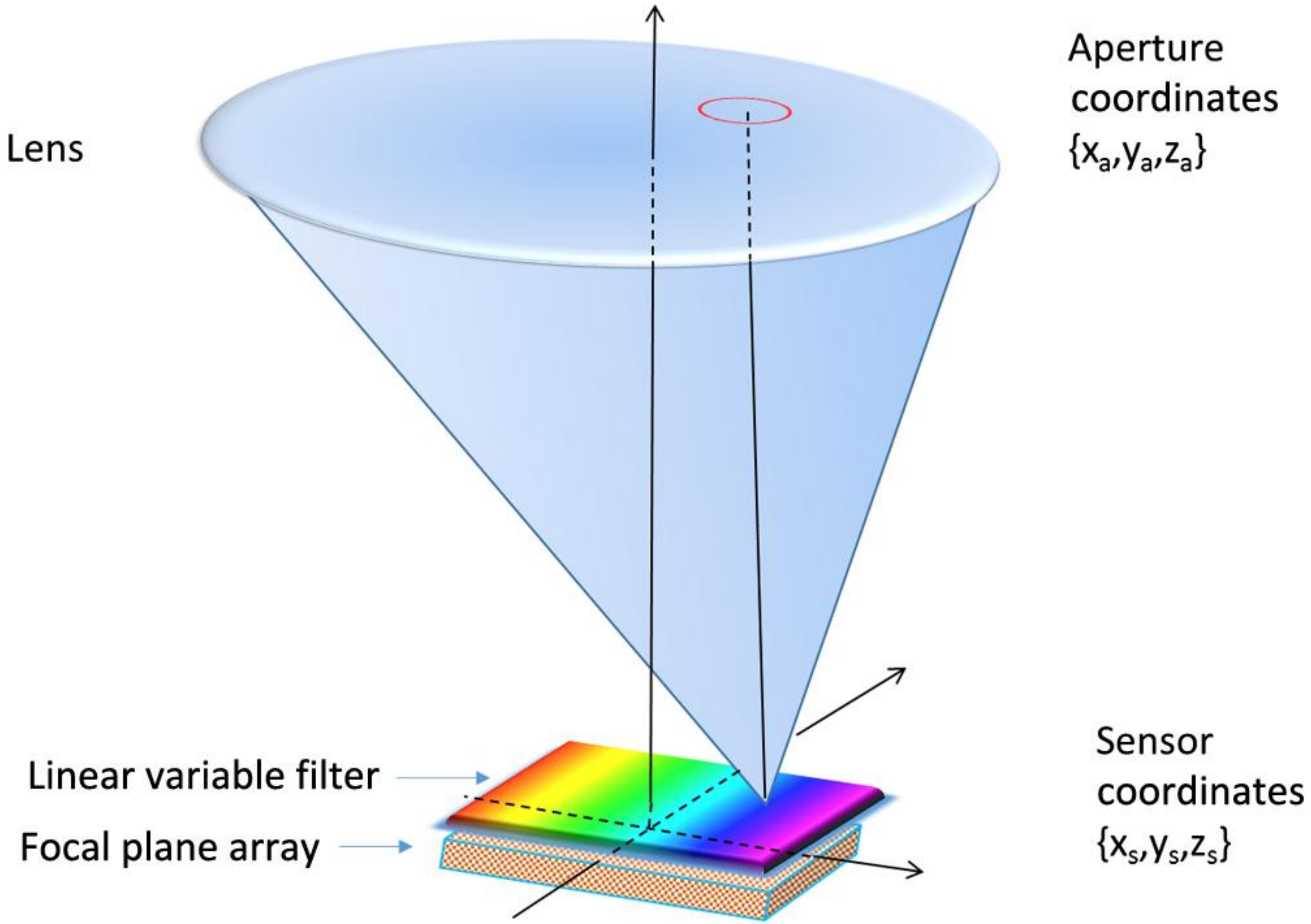


FIGURE 1.9 Two field of views of a linear variable filter based hyperspectral sensor passing over a ground track when a satellite flies at the moment $T = 0$ and $T = t$.

(Source: Hyperspectral Satellites and System Design, Shen-En Qian, CRC Press)



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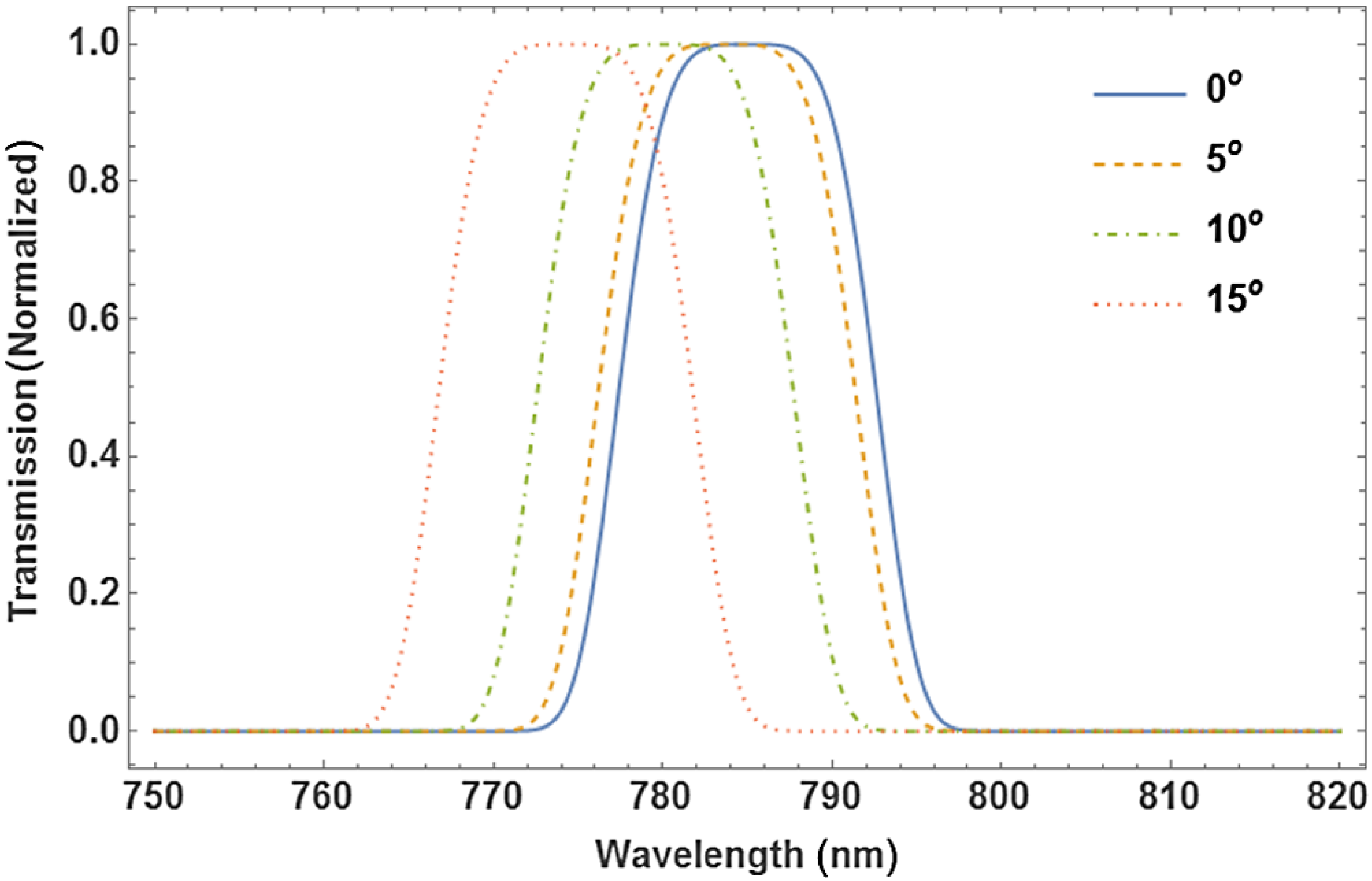
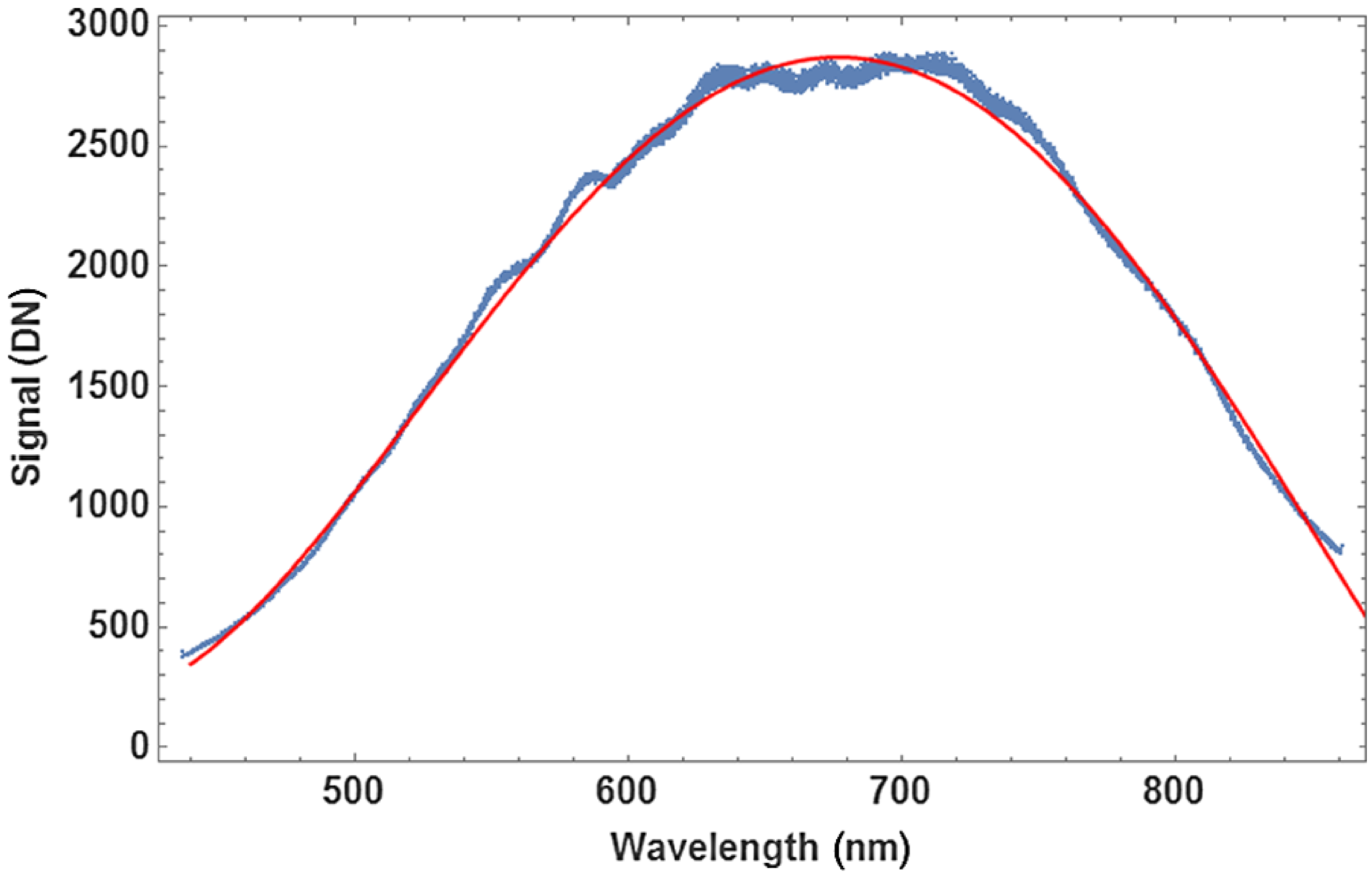
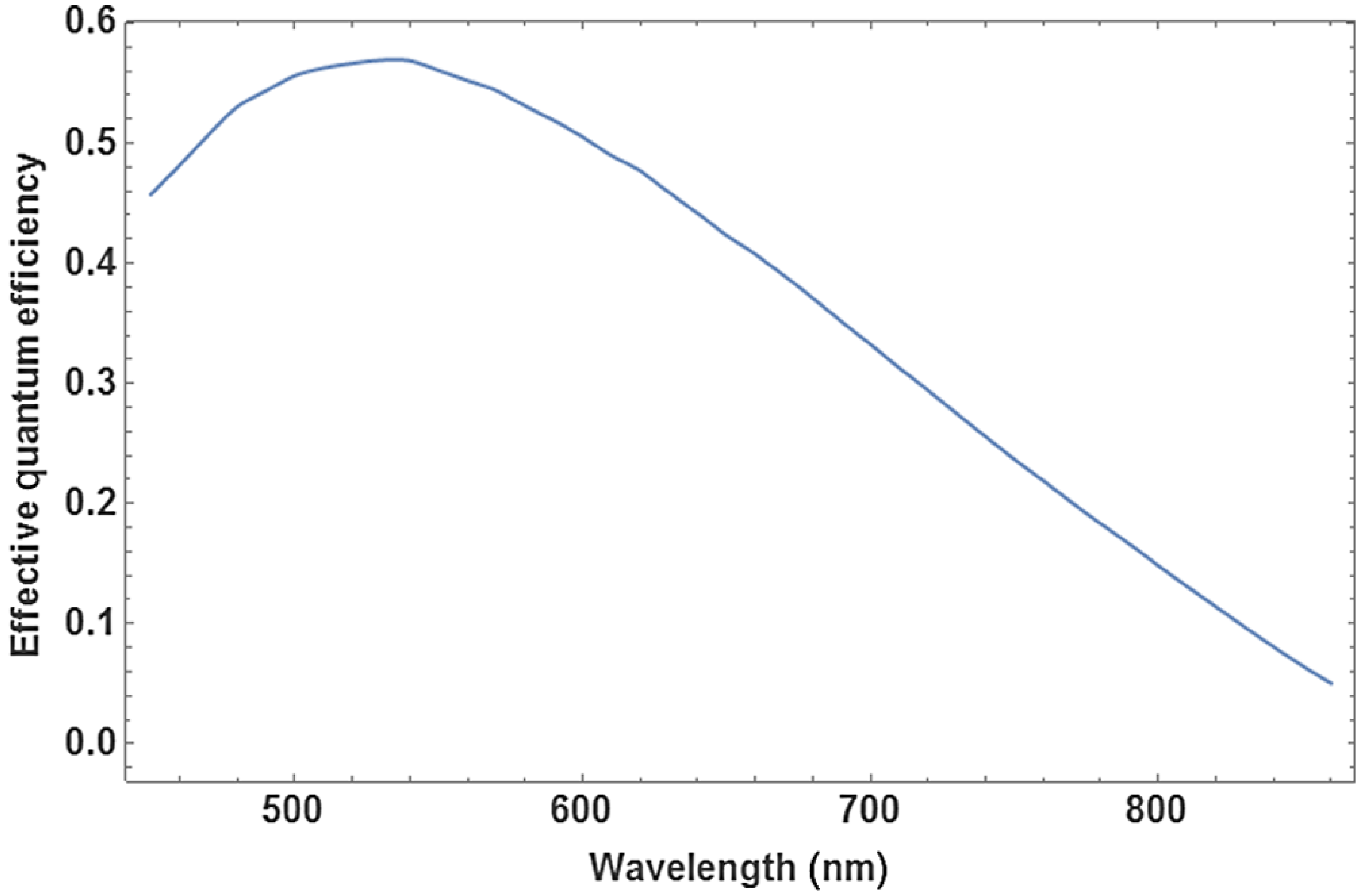


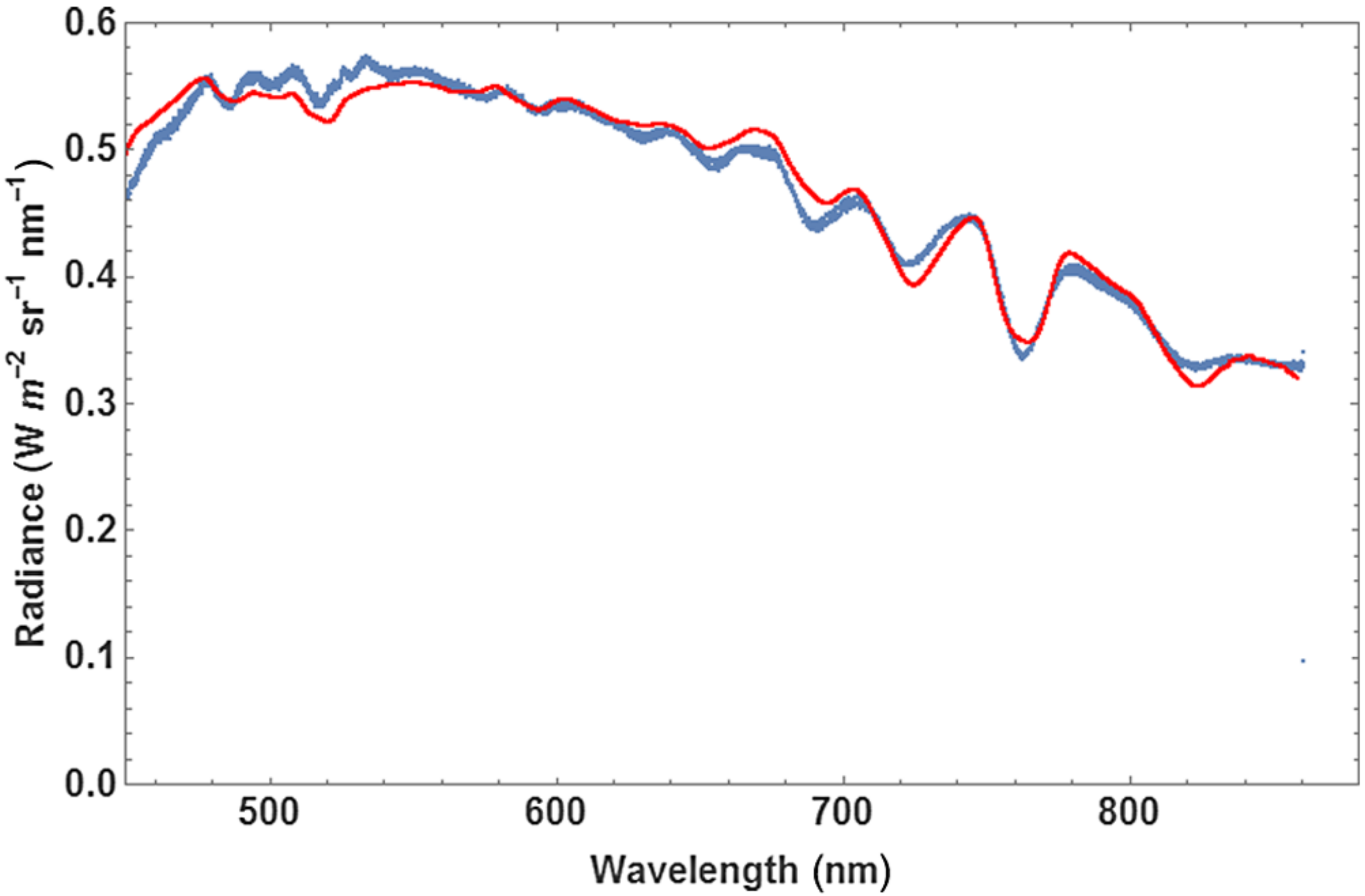
Wavelength shift due to changes in angle of incidence. Transmission of the filter at normal incidence for the center wavelength 785 nm is shown as a solid blue line, in which a relative bandwidth of 2% was used. Transmission profiles are shown for the angles of incidence 0°, 5°, 10°, and 15°.



Signal obtained at ISO 400 from the calibrated integrating sphere, where the red smooth curve is a polynomial fit to image data obtained by using the integrating sphere.

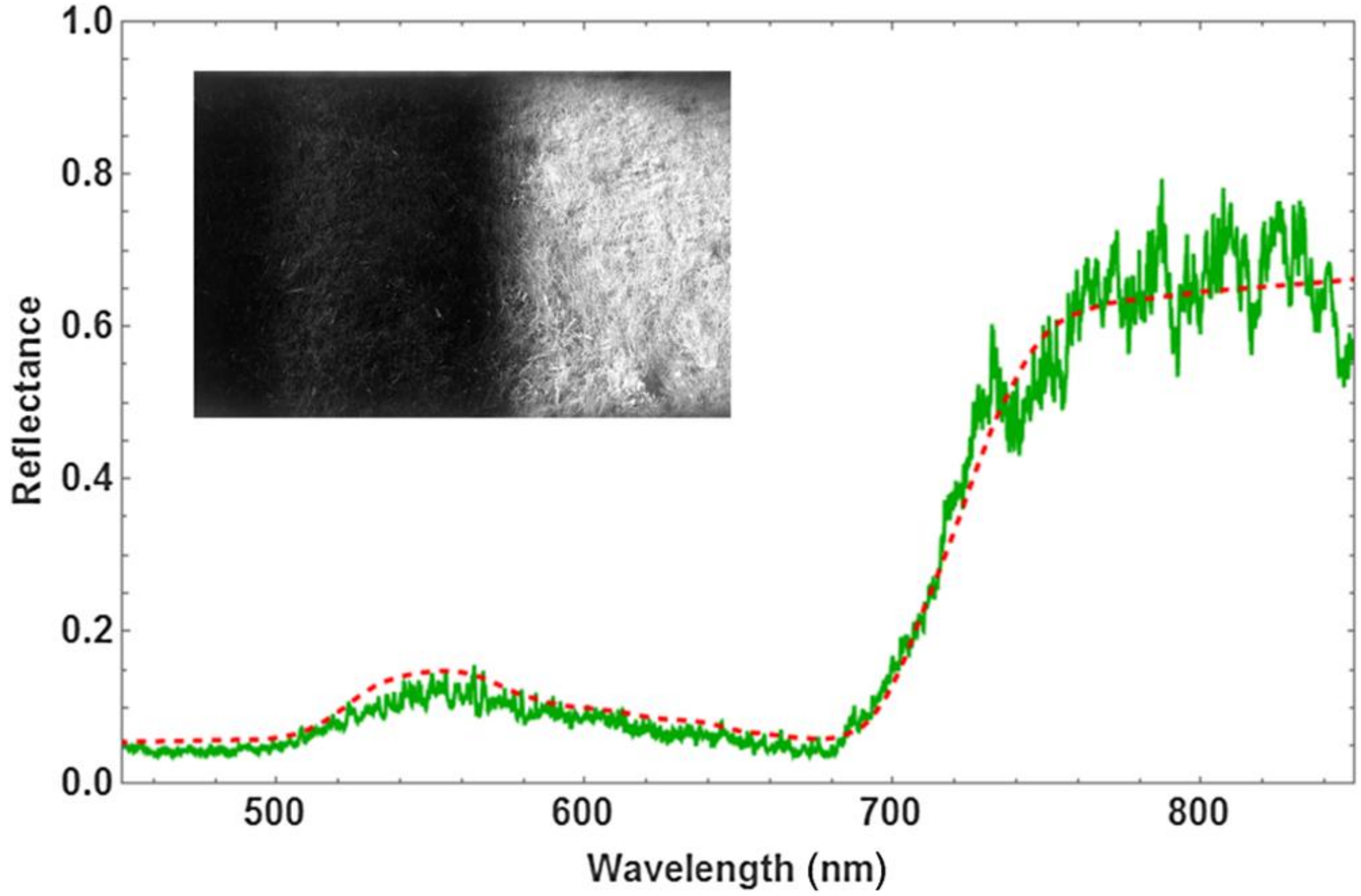


Effective quantum efficiency q_λ including filter losses and other optical losses.



Solar irradiance reflected from a white panel close to normal used as reflectance reference. The red thin curve is solar radiance calculated using MODTRAN. The blue curve is the measured reflected solar radiance.

Hyperspectral scene shown in false colors, red→800 nm, green→650 nm, and blue→510 nm.



Grass spectrum obtained from newly cut field (see inset) using a white panel as a reference. The spectral median value has been obtained using several rows in the image. Dashed red line is a reference spectrum from the ASTER database.

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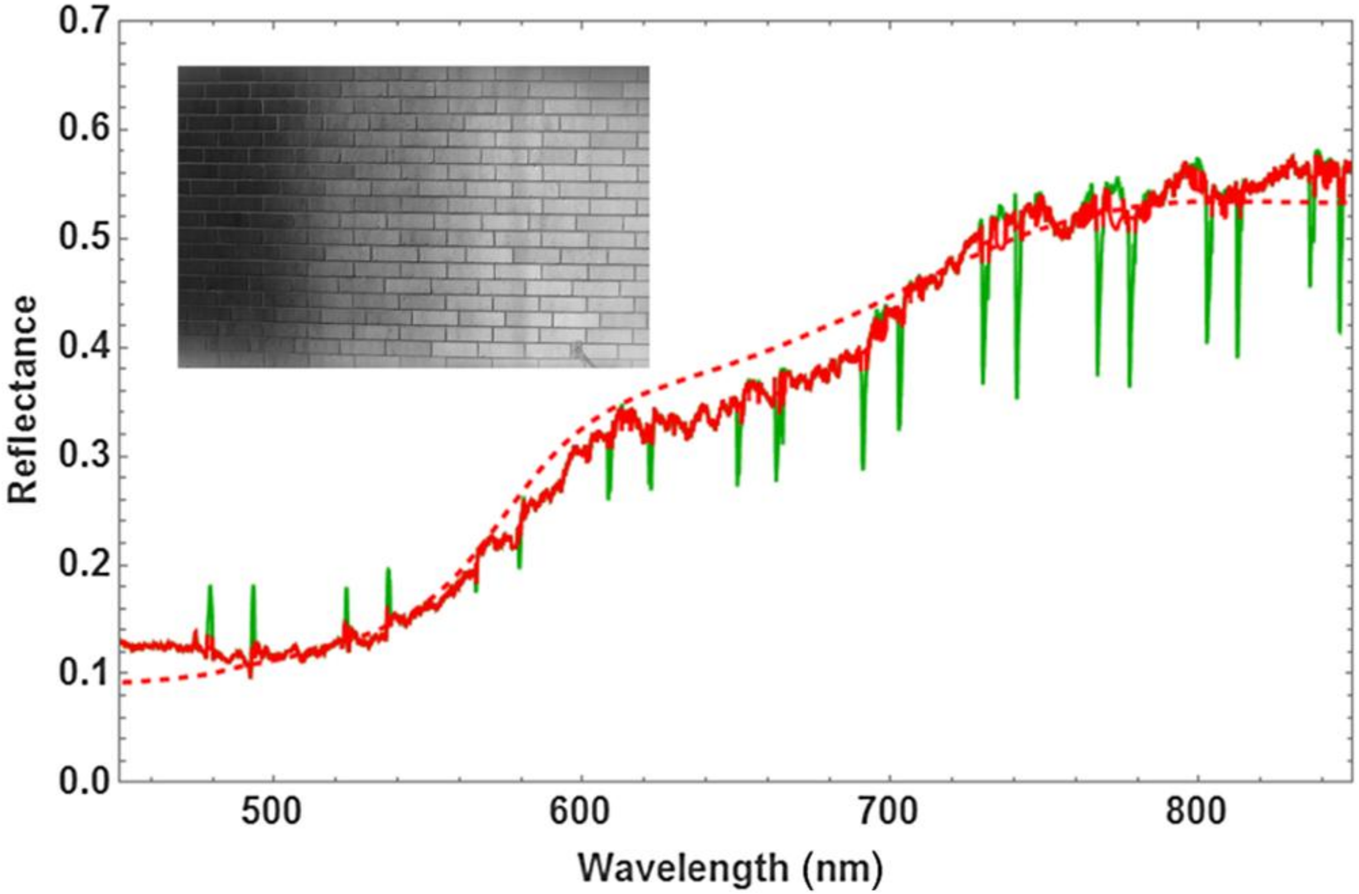

Spectrum of a brick wall shown in red. The joints shown in green as narrow spikes have been treated as outliers. The spectral median value has been obtained using several rows in the image. Dashed red line is red brick taken from the ASTER database.

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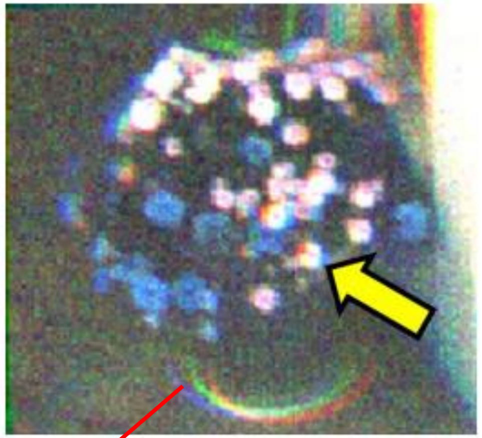
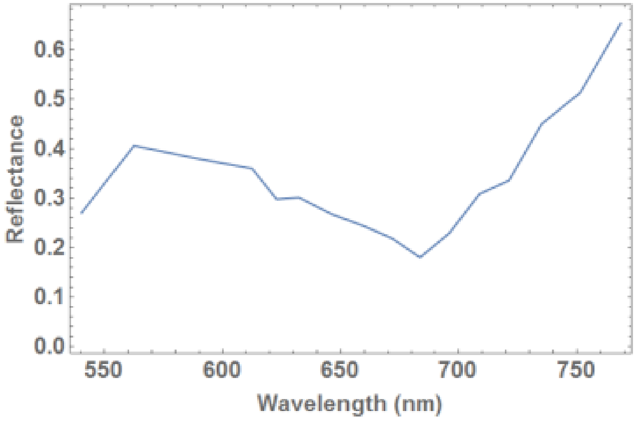
Detection of the bricks in a small section of the scene above using spectral angle mapping is shown. The variation in contrast with respect to the brick interval is due to aliasing.

Ingmar G. E. Renhorn, David Bergström, Julia Hedborg, Dietmar Letalick and Sebastian Möller; High spatial resolution hyperspectral camera based on a linear variable filter.
Opt. Eng. 55(11), 114105 (Nov 17, 2016).
http://dx.doi.org/10.1117/1.OE.55.11.114105

(a) Acquiring image data by flying in circuits around an office building.



(b) The flower pot seen by the airborne hyperspectral camera. The arrow points at one of the flowers chosen for example spectrum extraction.



Estimated spectrum of the flower marked in Figure 5b.

(b) Two views of the resulting 3D model created by Spotscale AB, in these pictures shown with texture from an "ordinary" RGB camera.

Jörgen Ahlberg, Ingmar G. Renhorn, Tomas R. Chevalier, Joakim Rydell and David Bergström; Three-dimensional hyperspectral imaging technique. Proc. of SPIE Vol. 10198, 1019805; https://doi.org/10.1117/12.2262456

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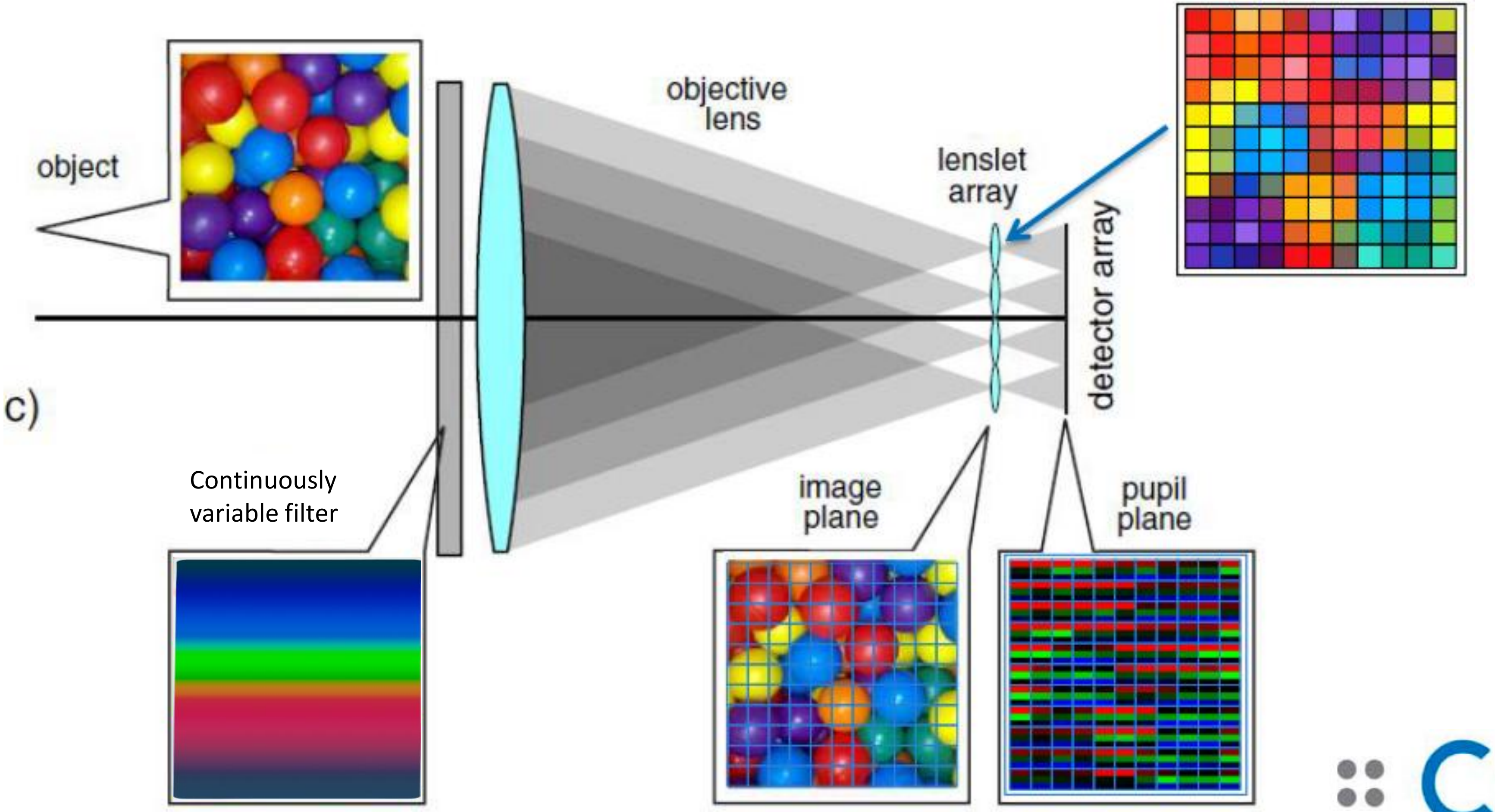
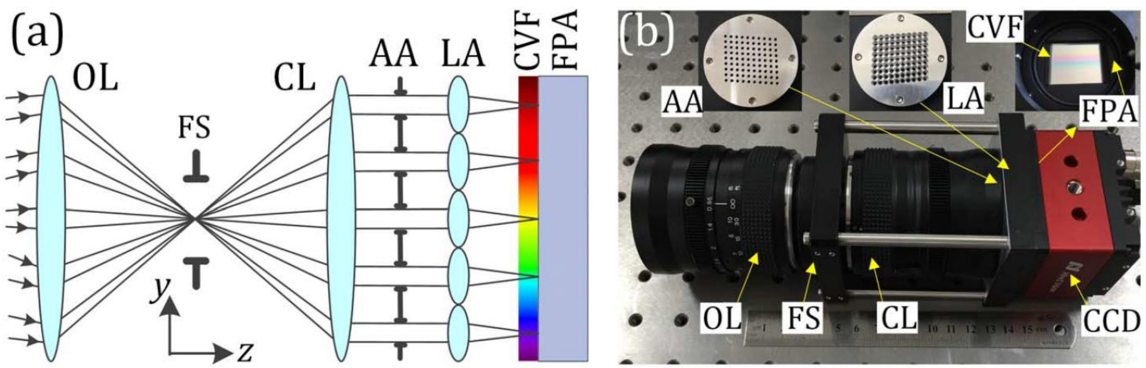
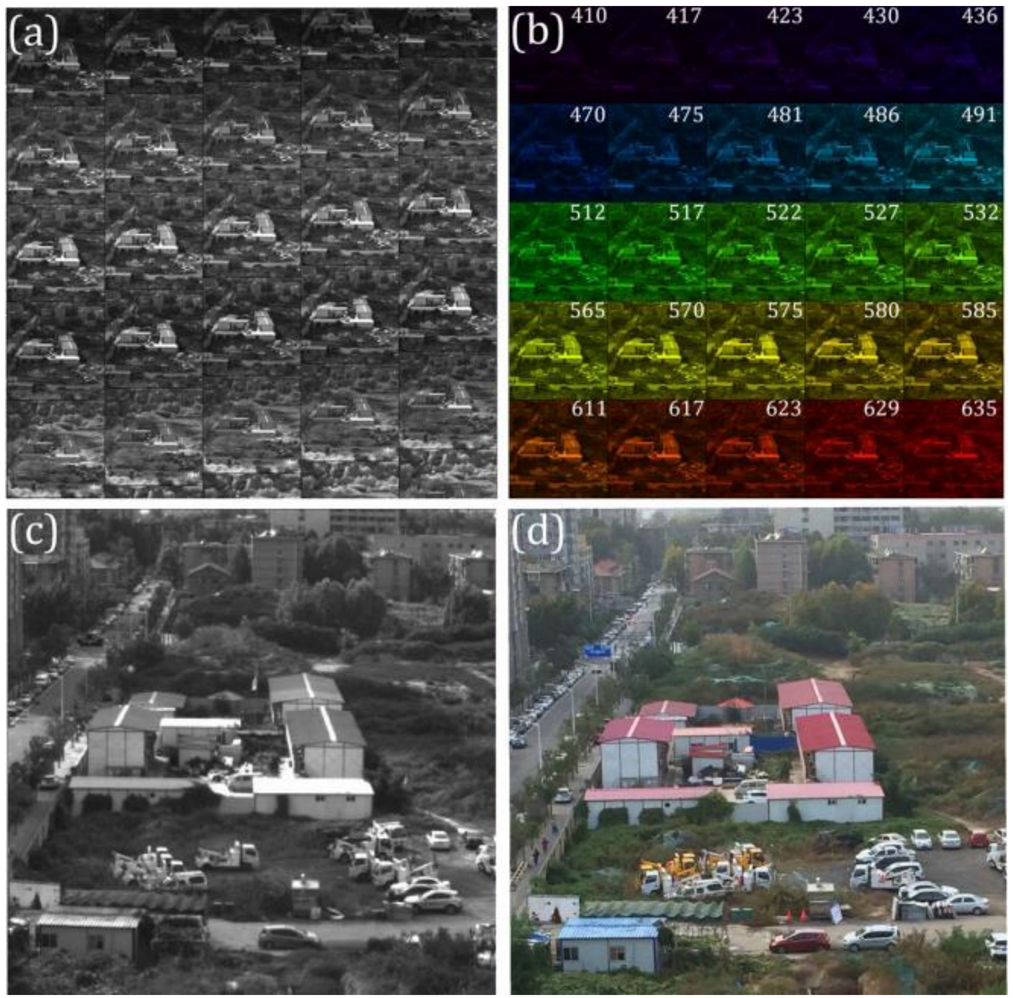
Snapshot HSI with light-field camera by CSEM

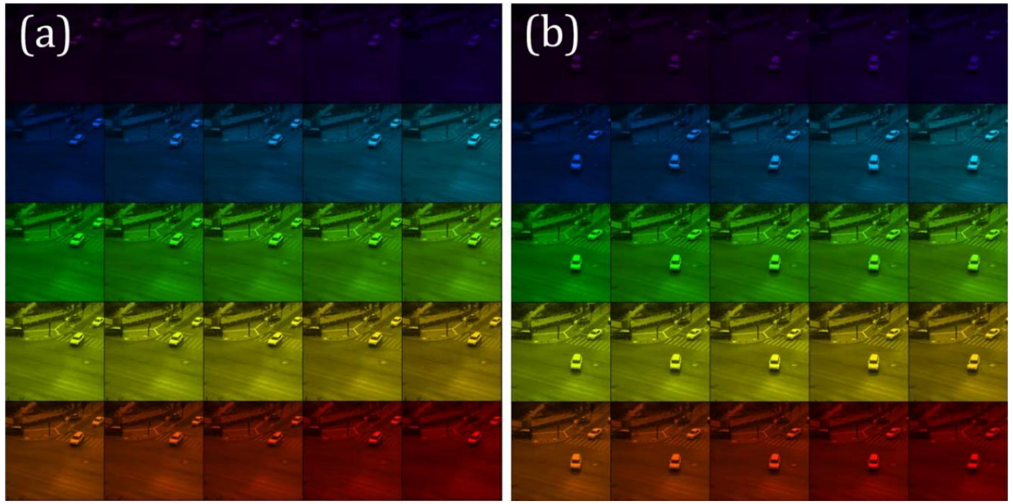


Hyperspectral imaging using a commercial light-field camera
Ross P . Stanley, Amina Chebira, Alireza Ghasemi, Andrea L . Dunbar, Ctr . Suisse d'Electronique et de Microtechnique SA (Switzerland)

Snapshot HSI with light-field camera by Xi ’ an Jiaotong University

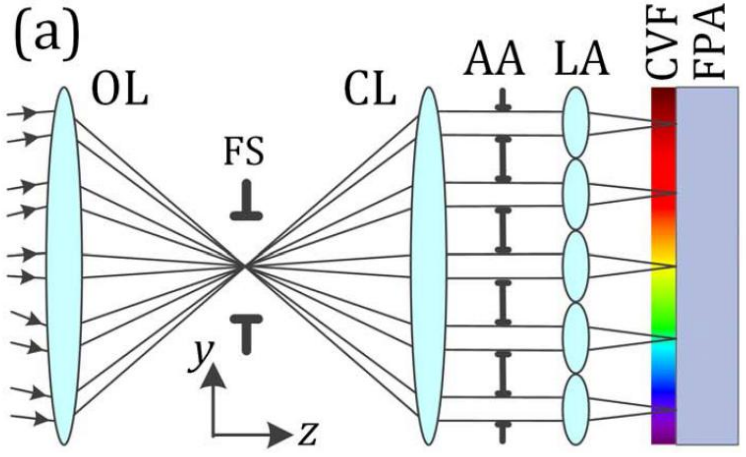


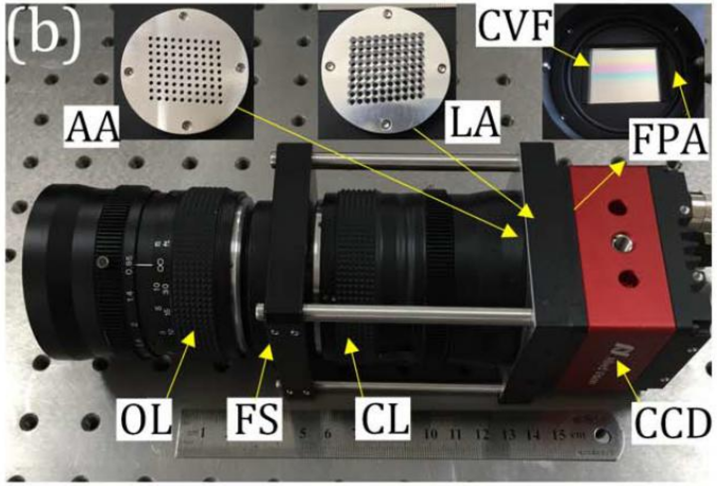


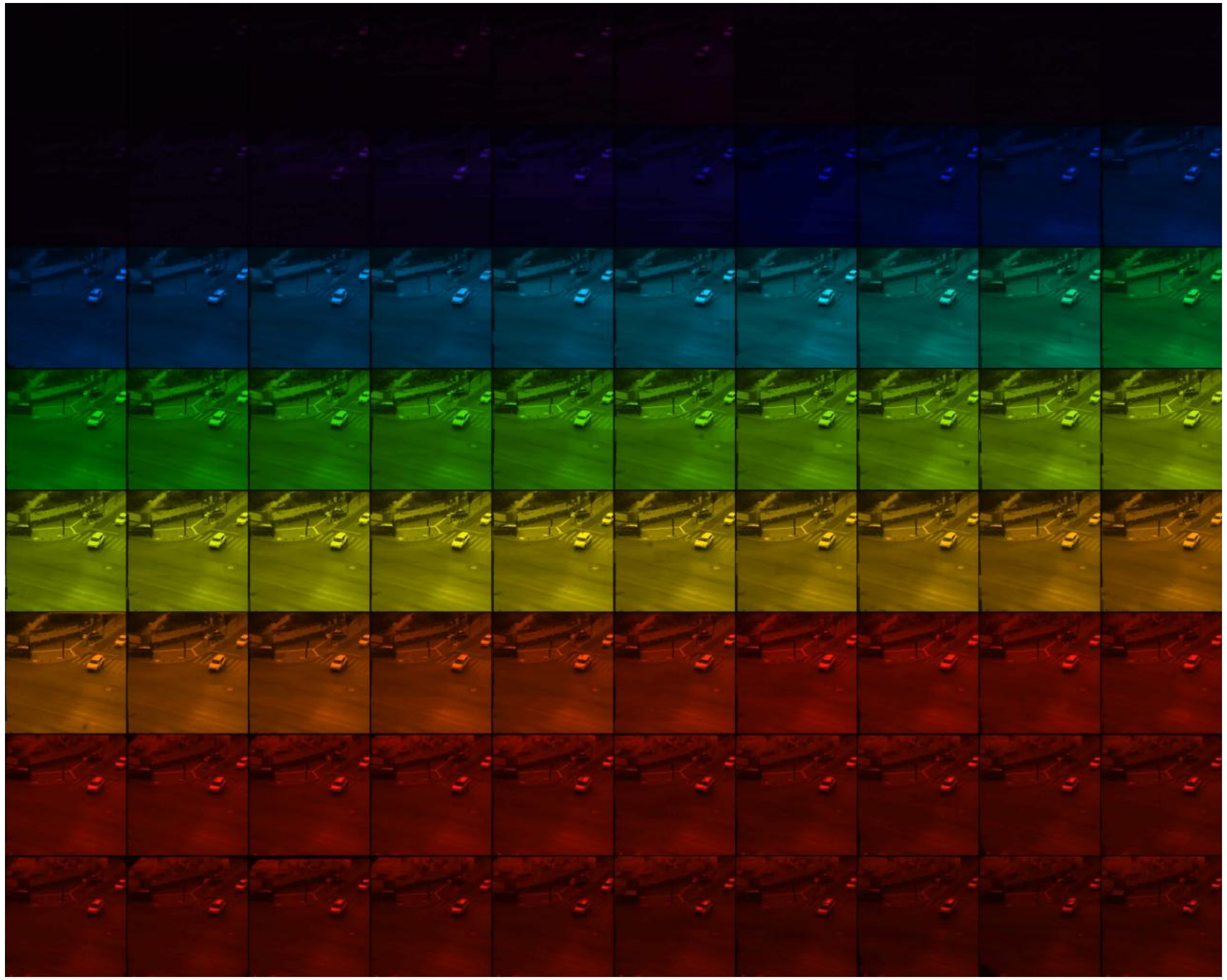


Compact snapshot optically replicating and remapping imaging spectrometer (ORRIS) using a focal plane continuous variable filter
Tingkui Mu, Feng Han, Donghao Bao, Chunmin Zhang, Rongguang Liang

Snapshot HSI with light-field camera by Xi ’ an Jiaotong University







Compact snapshot optically replicating and remapping imaging spectrometer (ORRIS) using a focal plane continuous variable filter
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Snapshot HSI with light-field camera by Xi ’ an Jiaotong University

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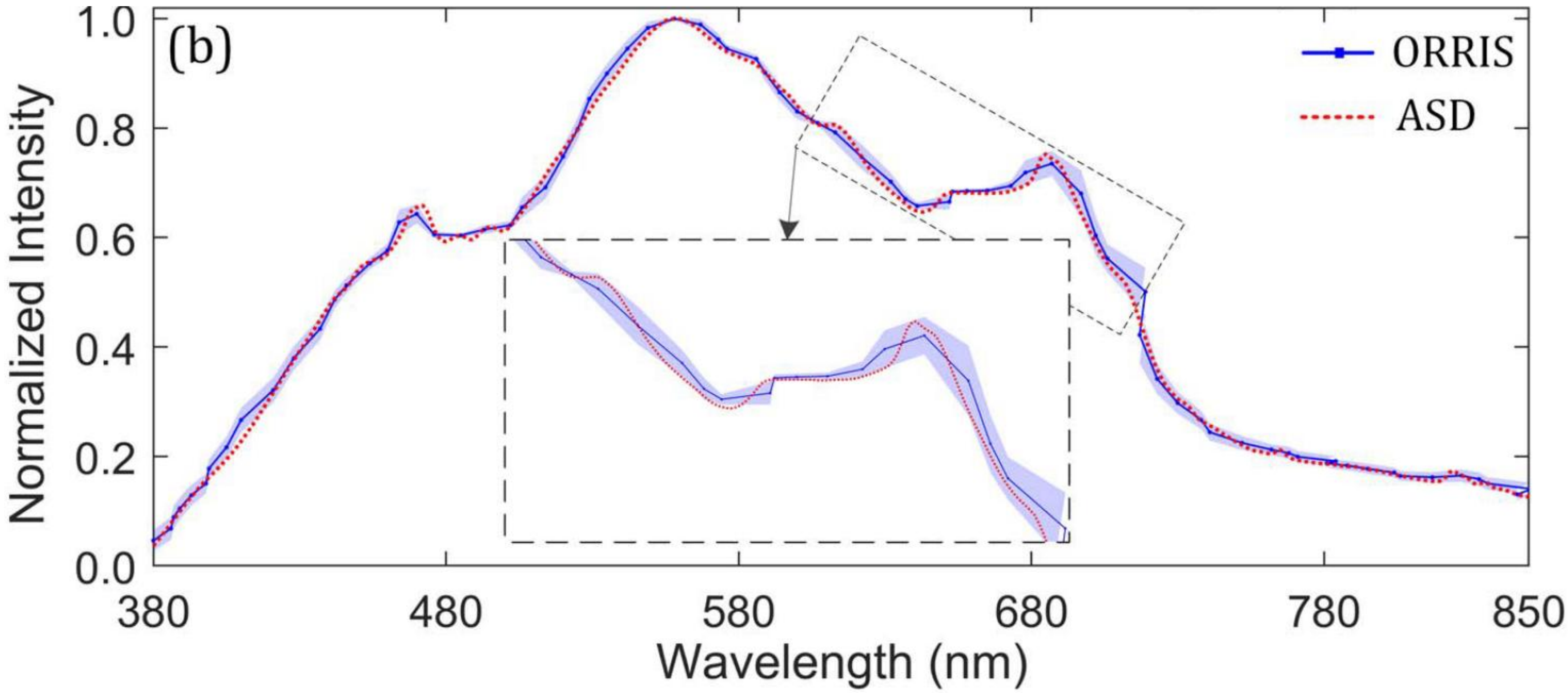

Compact snapshot optically replicating and remapping imaging spectrometer (ORRIS) using a focal plane continuous variable filter
Tingkui Mu, Feng Han, Donghao Bao, Chunmin Zhang, Rongguang Liang

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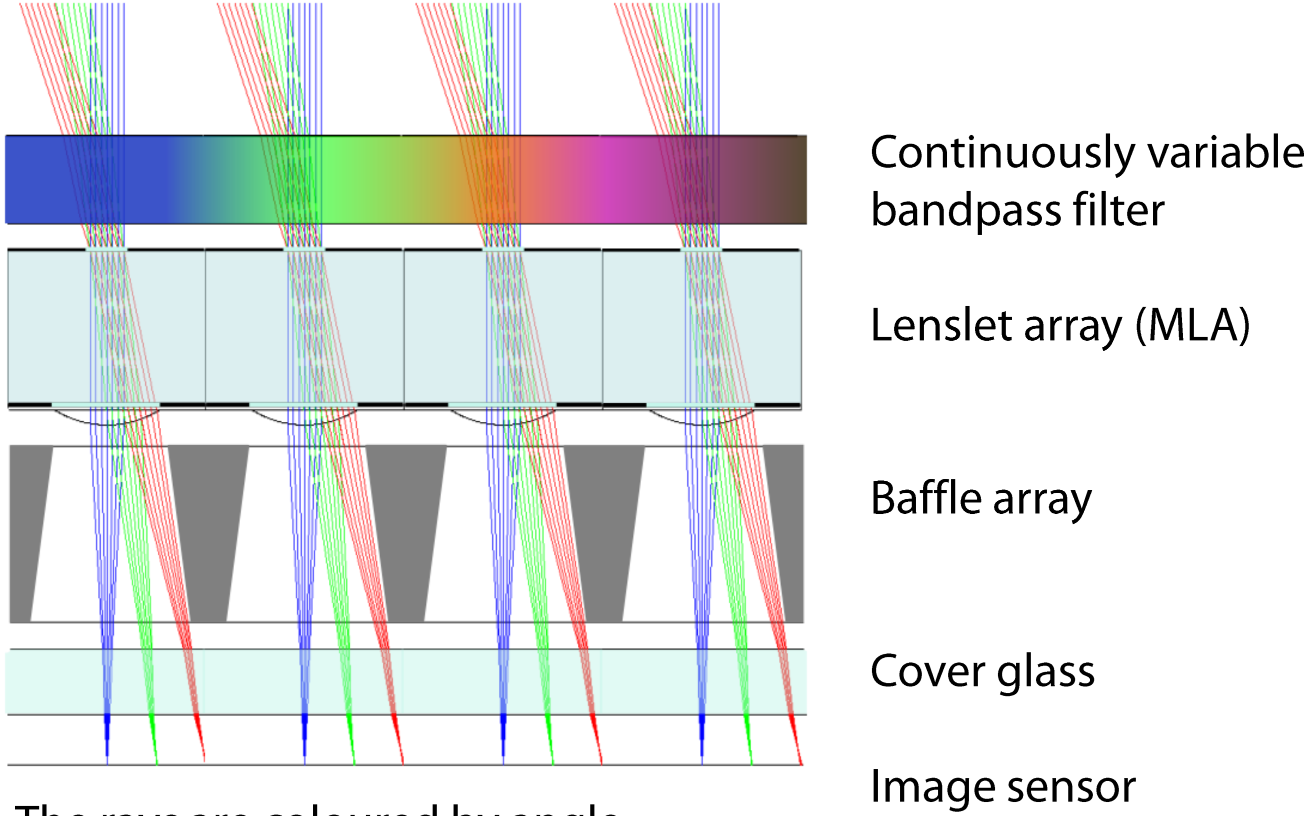
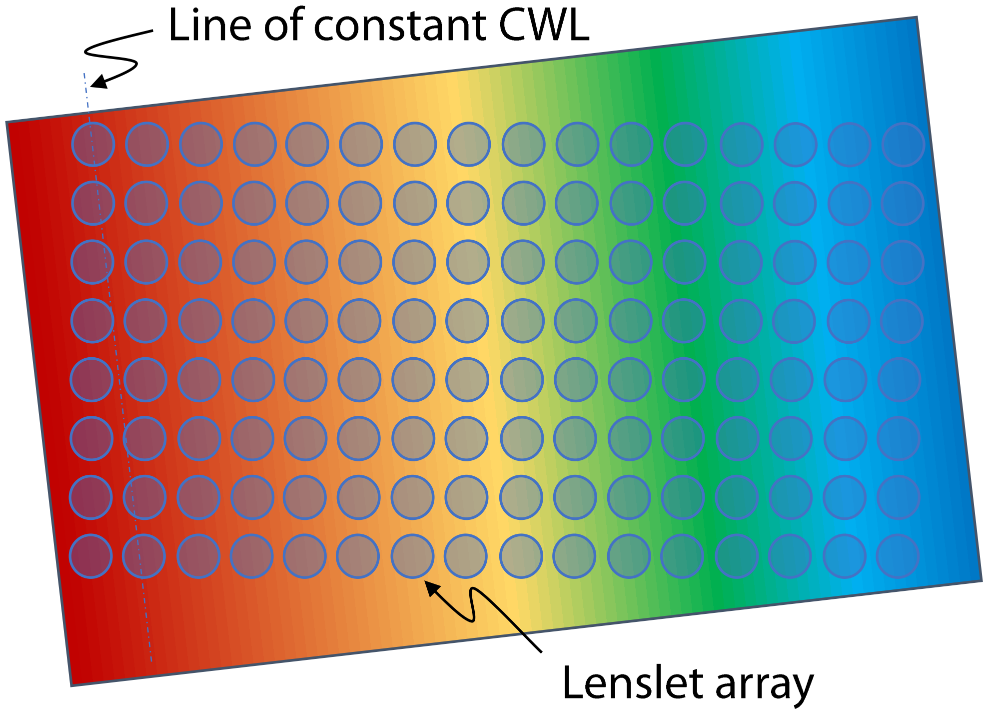
Snapshot HSI with light-field camera by Fraunhofer IOF



The rays are coloured by angle, not by wavelength!



Snapshot HSI with light-field camera by Fraunhofer IOF

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- $60x60x28\ mm^3$
- No external imaging lens
- Imaging lens included in MLA
- 66 spectral channels
- Image resolution $400x400\ px^2$

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Snapshot HSI with light-field camera by Fraunhofer IOF

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RGB image of the scene

Raw image of Multispectral camera: 11x6 spectral channels

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Snapshot HSI with light-field camera by Fraunhofer IOF

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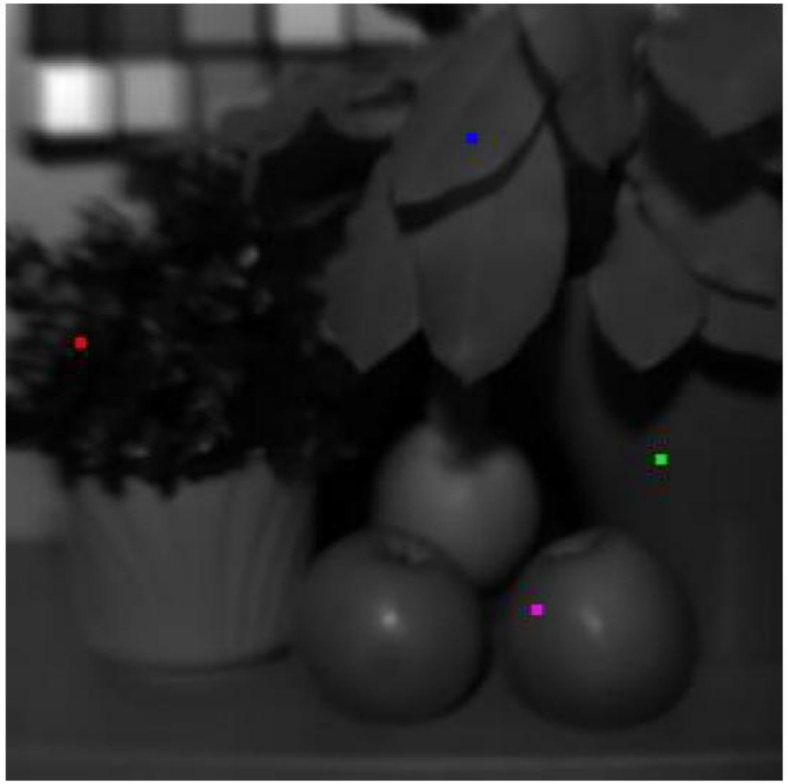

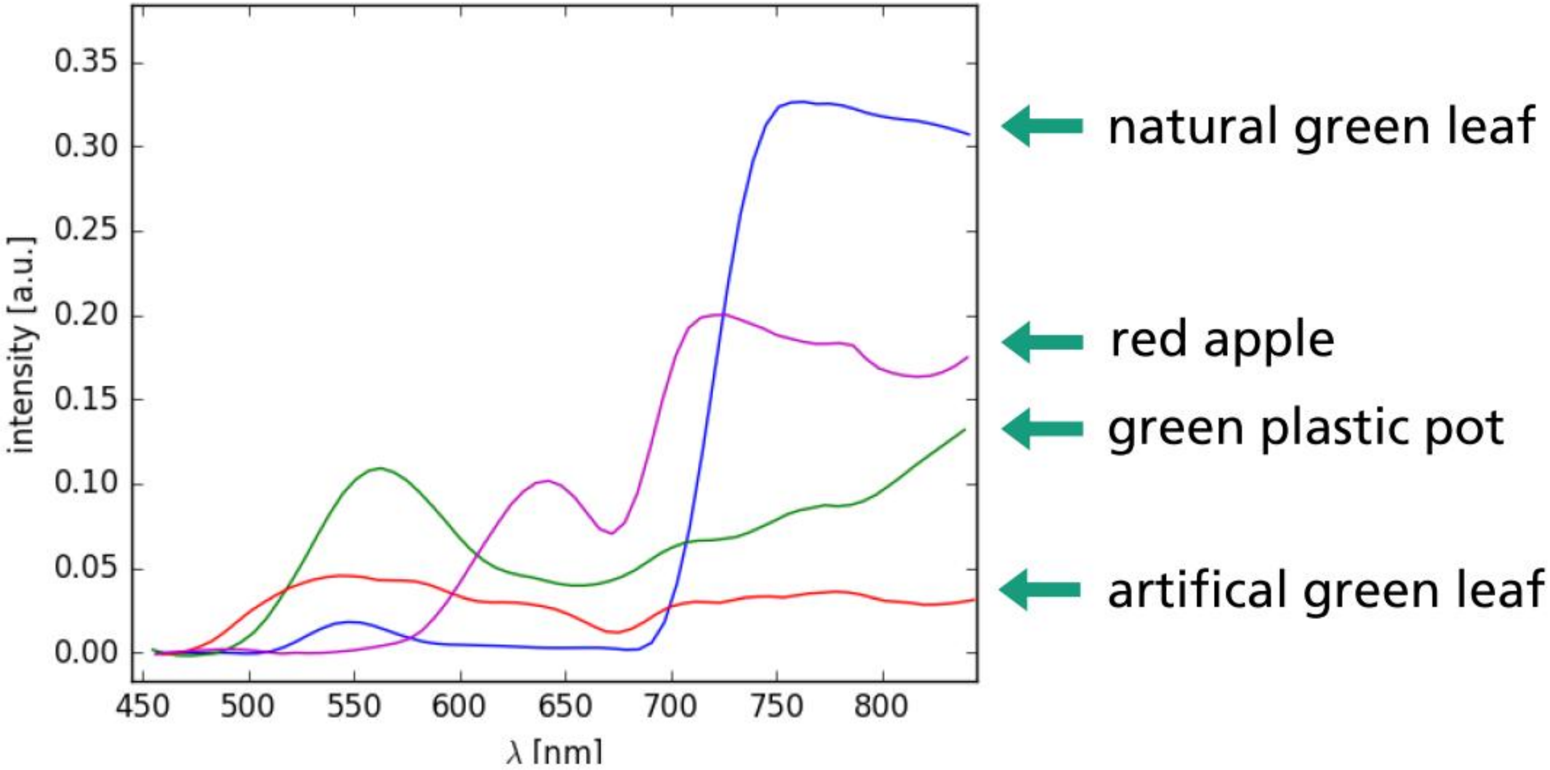

Industrial 3D snapshot camera from Cubert

Advantages

- 3D hyperspectral snapshot imager (x, y, λ)
- Incredible resolution
- Based on light field technology
- No pan-sharpening
- No scanning
- Ultrafast image acquisition
- No motion artifacts

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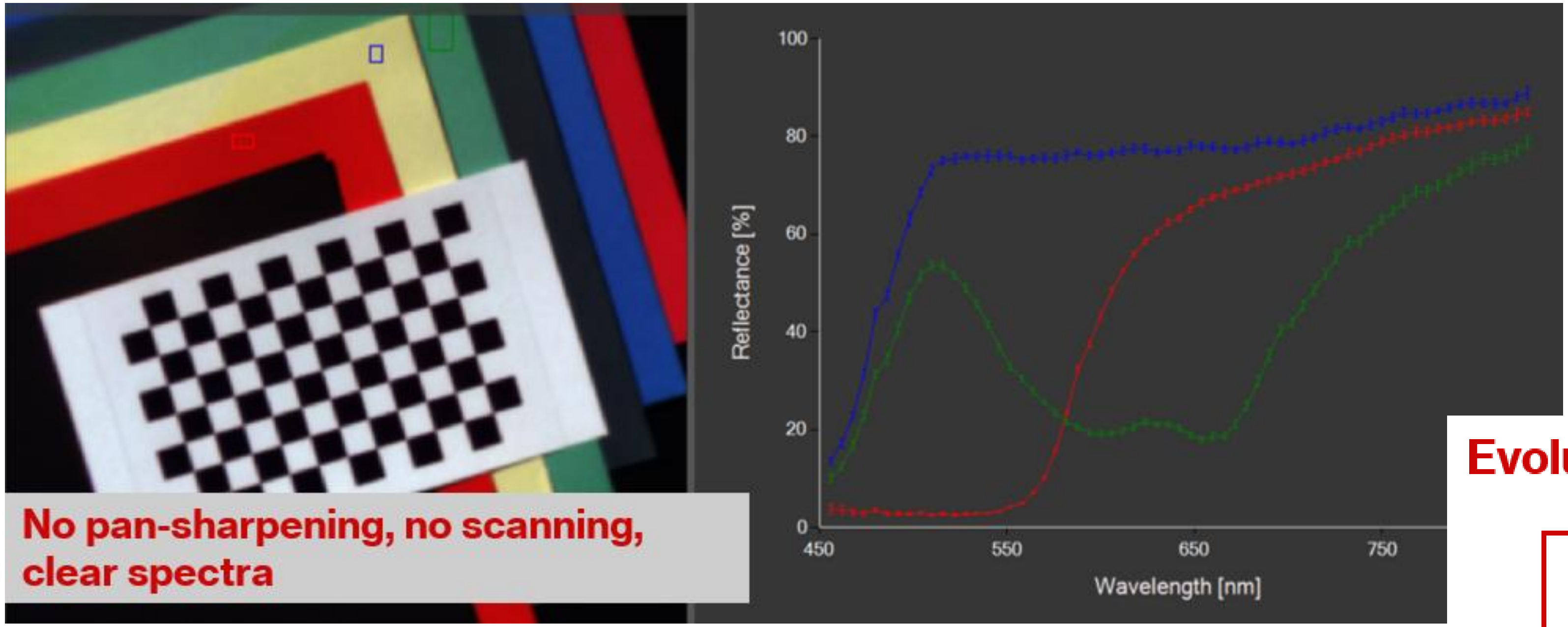
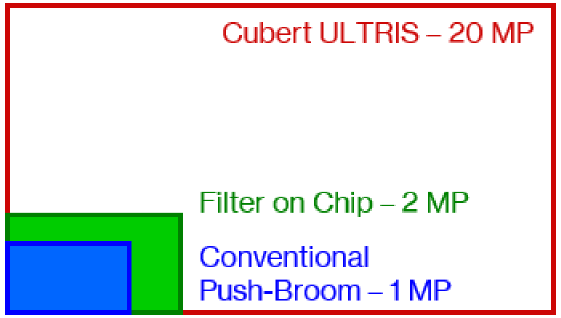
Industrial 3D snapshot camera from Cubert



Evolution of Spectral Imaging



Typical sensor size of different hyperspectral imaging concepts

Industrial 3D snapshot camera from Cubert

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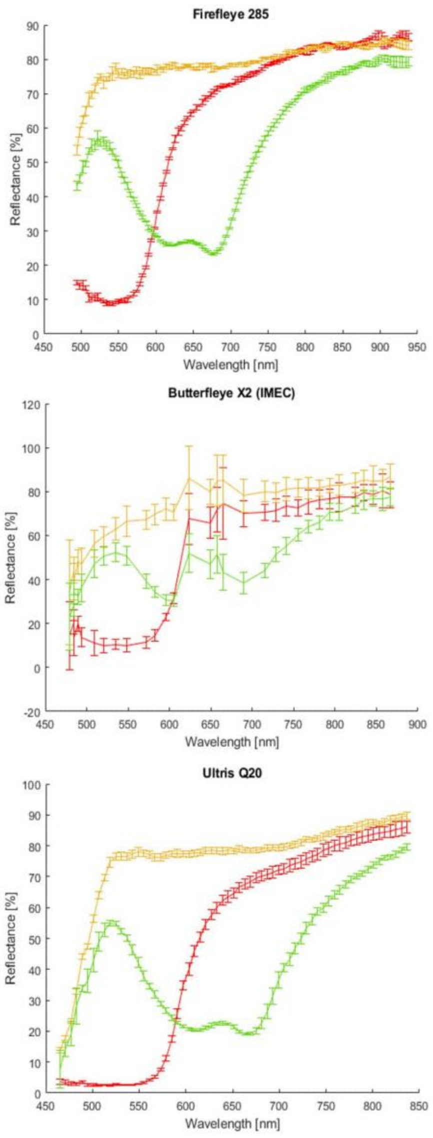

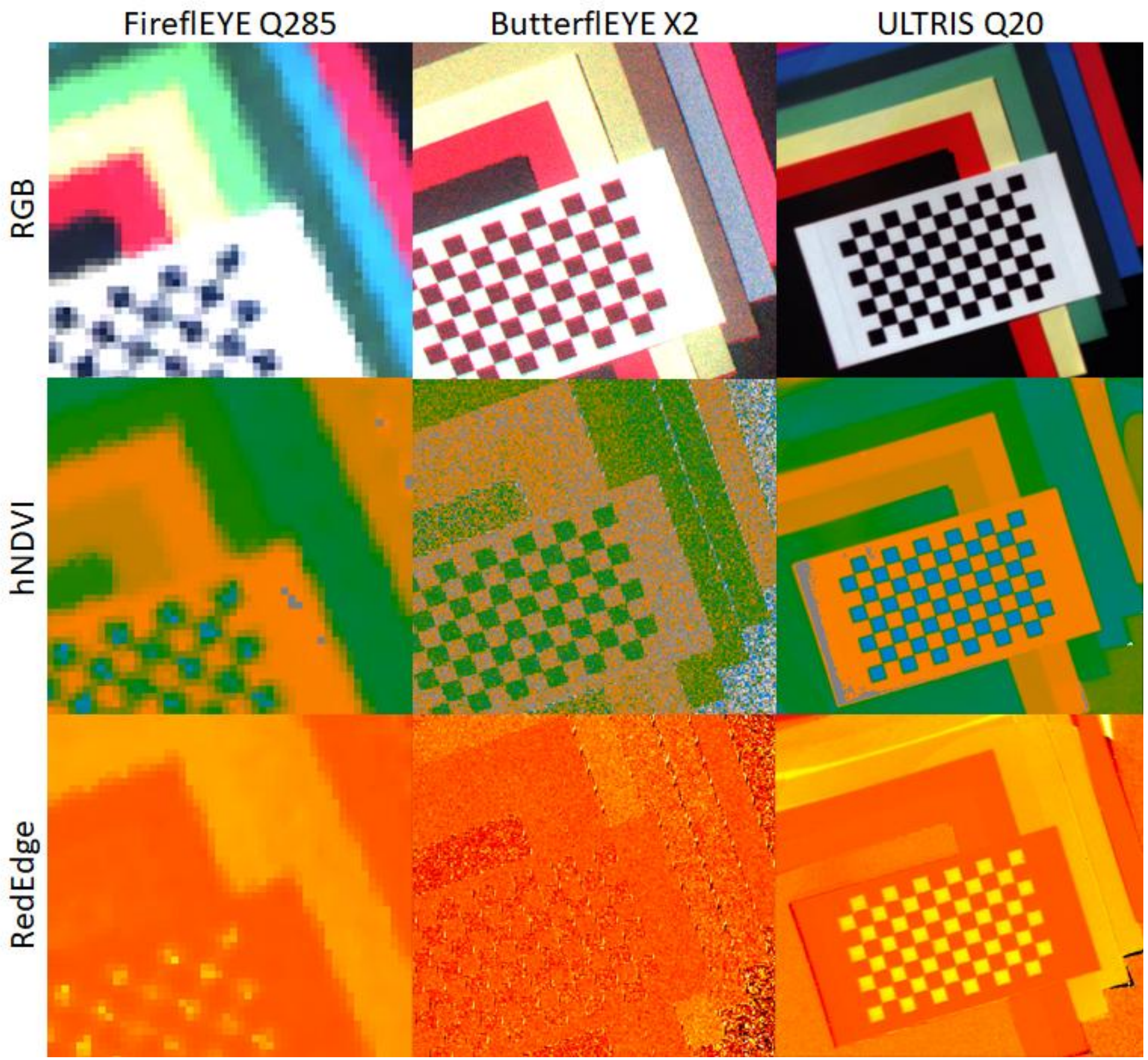

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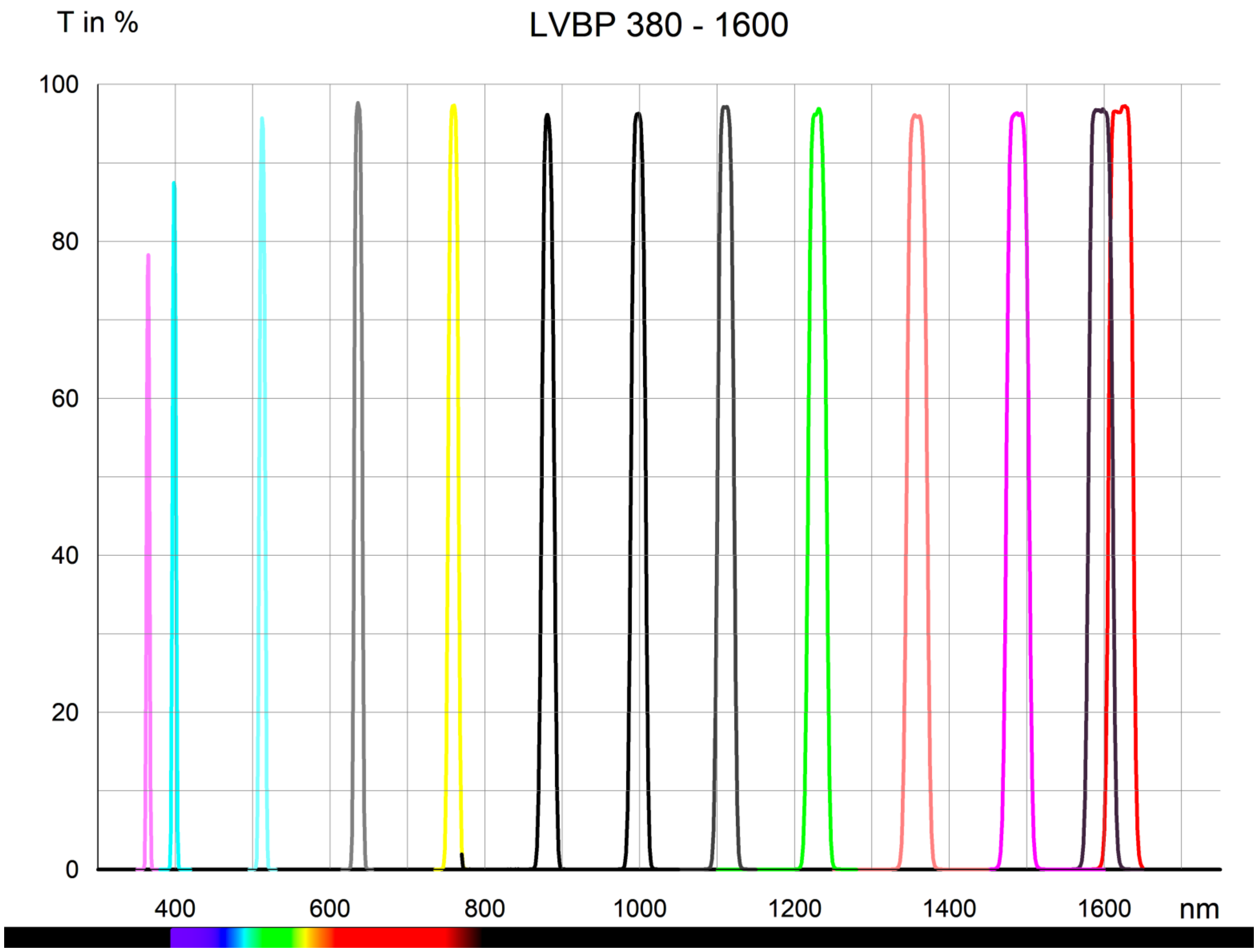
Exciting possibilities with brand new LVF technology



- Higher transmission
- Wider wavelength range
- Higher dispersion

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Thank you very much for your attention!

Looking forward to your questions!

SCAN ME

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