A compact Hyperspectral Camera for Remote Sensing from the Ultraviolet to the Thermal Infrared

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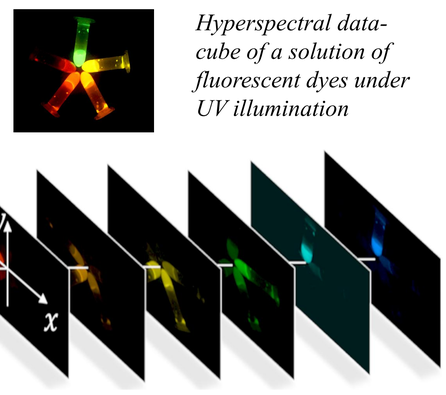
We present a compact **hyperspectral camera** using the **Fourier-transform approach**, which enables hyperspectral imaging with higher spectral accuracy compared to standard dispersive systems. The camera is based on an **ultrastable birefringent interferometer** and performs remote-sensing imaging of ground objects in the visible, the near-infrared and in the **thermal infrared** range. It promises to be a powerful technology for **satellite remote sensing in an ultrabroadband range**.

Introduction

HYPERSPECTRAL IMAGING (**HSI**): collects the continuous spectrum of light in each pixel of an image.



Hyperspectral data-cube of a solution of fluorescent dyes under UV illumination

TRADITIONAL APPROACHES:
- band-pass *filters*
- dispersive elements + spatial *filter*

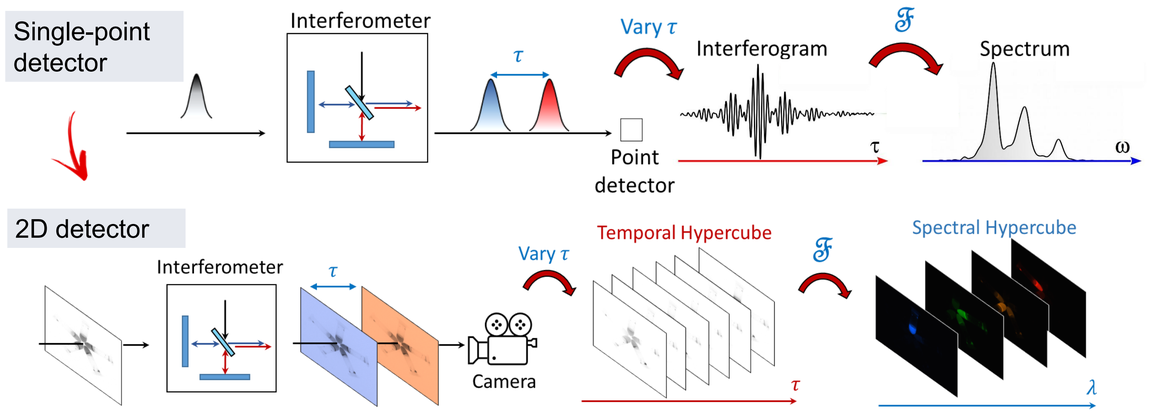
✗ low light throughput [1]

OUR APPROACH:
- **Fourier-Transform** (**FT**) spectroscopy

✓ higher throughput and signal-to-noise ratio
✓ flexible spectral resolution.

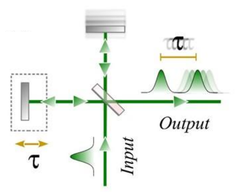
THE CONCEPT OF THE FT APPROACH

Two delayed replicas of the light give rise to an interferogram; the Fourier transform produces the intensity spectrum.

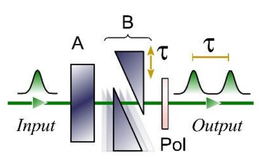


CHALLENGE: τ must be controlled better than 1/100 of the optical cycle (2 fs @600 nm).

SOLUTION: an innovative birefringent *common-path interferometer* (TWINS) [2]: compact, lightweight, ultrastable (delay accuracy <1/360 of the optical cycle).



Traditional interferometers (e.g. Michelson): cumbersome and sensitive to external perturbations.



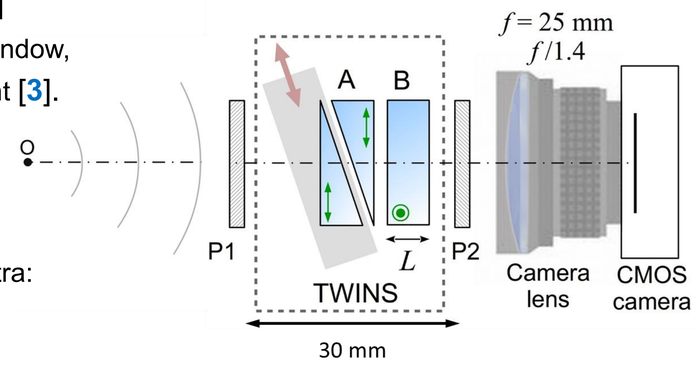
The TWINS interferometer: a common mode interferometer, robust against perturbations

Hyperspectral Camera in the VIS-NIR

We developed a **portable hyperspectral camera** by coupling the birefringent interferometer to an imaging system.

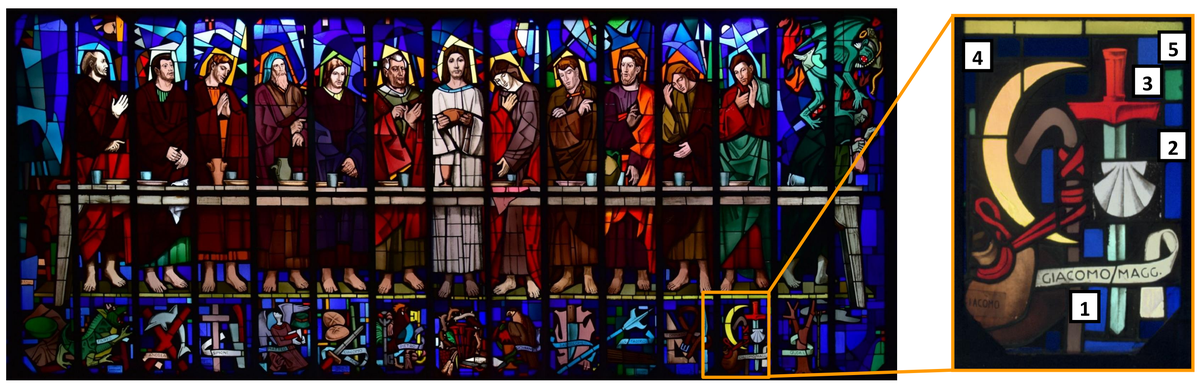
BIREFRINGENT MATERIAL: α-BBO (transparency: 200-3500nm)
DETECTOR: silicon CMOS (sensitivity range is 400-1050 nm)
PROOF: **remote sensing** of natural landscapes and a stained-glass window, back-illuminated by natural sunlight [3].

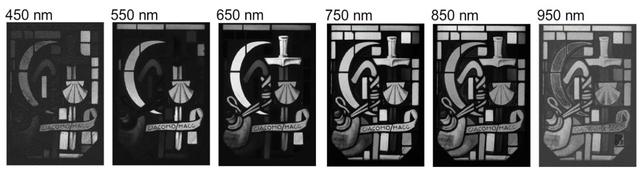
HSI reveals that tiles with similar visual colors have different transmission spectra:
✓ the instrument enables **materials identification**.



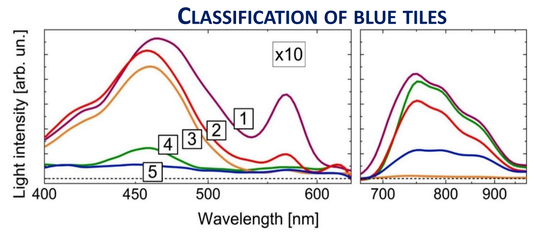
The hyperspectral camera based on the TWINS.

RGB FROM HYPERSPECTRAL DATA





CLASSIFICATION OF BLUE TILES

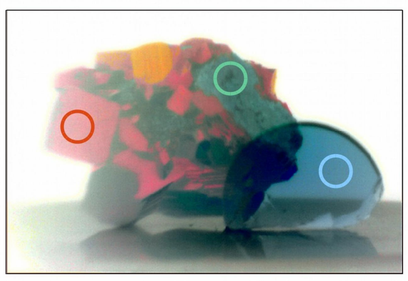


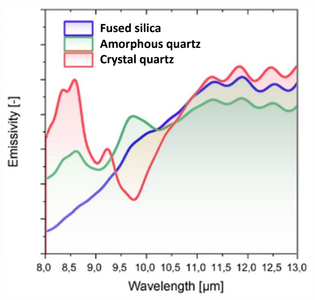
HSI of an artistic glass window (Church of Santo Spirito, Milan)

Extending to the Thermal Infrared Range

THERMAL IMAGING OF A MINERAL QUARTZ SAMPLE


Standard image in the visible


False-color image in the 8-10 μm range



Emissivity spectra from HSI

Thermal infrared spectral region (3-14 μm, TIR): enables detection of high-temperature events (*e.g.* wildfires, eruptions) and identification of materials according to their **vibrational fingerprint** [4]. We built a **novel birefringent camera working in the TIR** [5].

BIREFRINGENT MATERIAL: calomel (Hg_2Cl_2)
DETECTOR: microbolometer.
PROOF: We measured the 2D emissivity of **mineral** and **synthetic** quartz. The emissivity spectra allow us to distinguish materials that look similar in the visible range.

Conclusions

The hyperspectral camera, based on our birefringent TWINS interferometer, shows intrinsic delay stability, lightweight (few kg) and ultracompact (<1 dm^3) volume. It enables **HSI with high spectral accuracy in an ultrabroadband range** (from visible to TIR) which can be tuned according to the chosen crystal material and detector.

The camera characteristics make it ideal for harsh environments, promising to make it a **unique enabling technology for satellite remote sensing** based on unambiguous chemical identification.

[1] Qian, *Hyperspectral Satellites, Evolution, and Development History, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 14, 7032–56 (2021)
[2] Brida et al., *Phase-Locked Pulses for Two-Dimensional Spectroscopy by a Birefringent Delay Line*, *Opt.Lett.* 37, 3027 (2012)
[3] Perri et al., *Hyperspectral Imaging with a TWINS Birefringent Interferometer*, *Optics Express* 27: 15956 (2019)
[4] Manolakis et al., *Longwave Infrared Hyperspectral Imaging: Principles, Progress, and Challenges*, *IEEE Geoscience and Remote Sensing Magazine* 7, 72–100 (2019)
[5] M. Corti et al., *A thermal infrared hyperspectral camera based on a birefringent interferometer. APL Photonics 10,101302 (2025)*

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