# Realization of a UV fisheye hyperspectral camera

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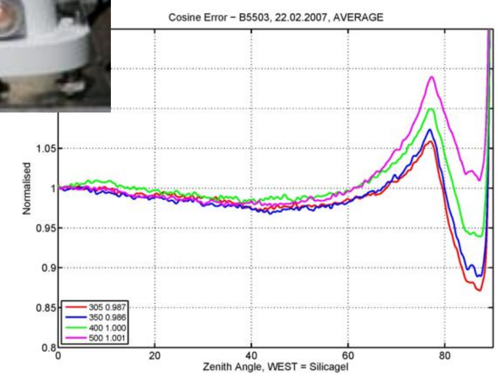
UVNet Workshop, Davos 27-28 August 2013

# Outline

- Purpose of the instrument
- Required specs
- Hyperspectral technique
- Optical design
- Realization and preliminary tests

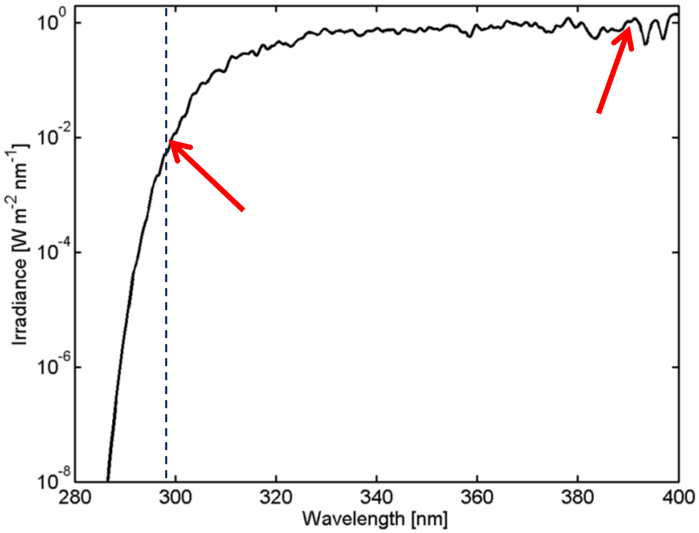
# Purpose of the instrument

- Purpose of the device is to create a complete spectro-gonoiometric map of the irradiance of the sky in the UV
- The map will be used to correct cosine error typical of commercial UV spectroradiomters
- The target could be acheived with a scanning spectroradiometer, but we prefer to use Hyperspectral Imaing technique because is much faster




# Specifications

- Specs
  - Field of view > ± 80°
  - Spatial resolution ≤ 1°
  - Spectral range 310-400 nm
  - Spectral resolution ≤ 5 nm
  - Good dynamic range
- The instrument must be compact and transportable to be easily calibrated and operated in the field



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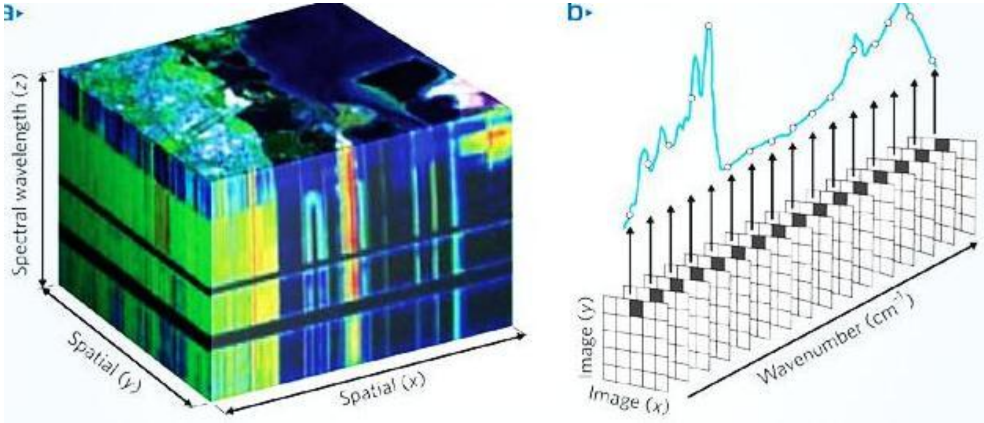
# Hyperspectral Imaging

A hyperspectral imaging system (HI) is a combination of imaging device (a digital camera) and a spectrophotometer.

The obtained data set, known as “hyperspectral cube”, is a 3D matrix formed by a 2D image combined with a third dimension that is the spectral composition of each pixel of the image.

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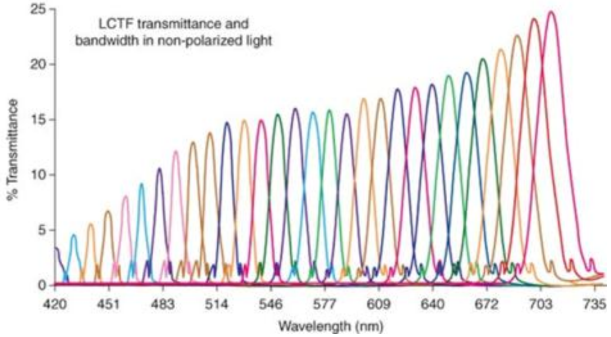
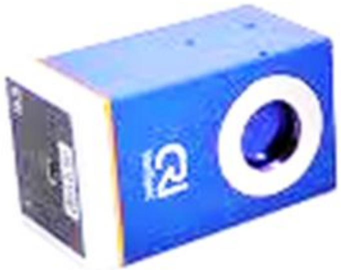
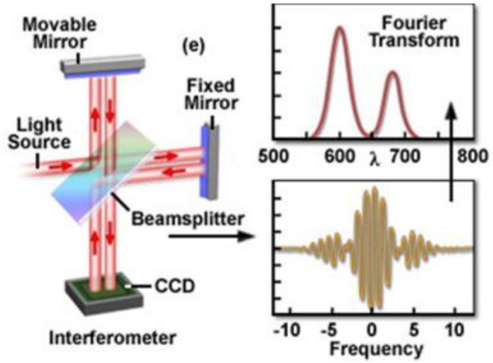
# Classical hyperspectral devices

- Dispersive (pushbroom)
- Tunable filter (LCTF)
- Michelson interferometer (FTS)



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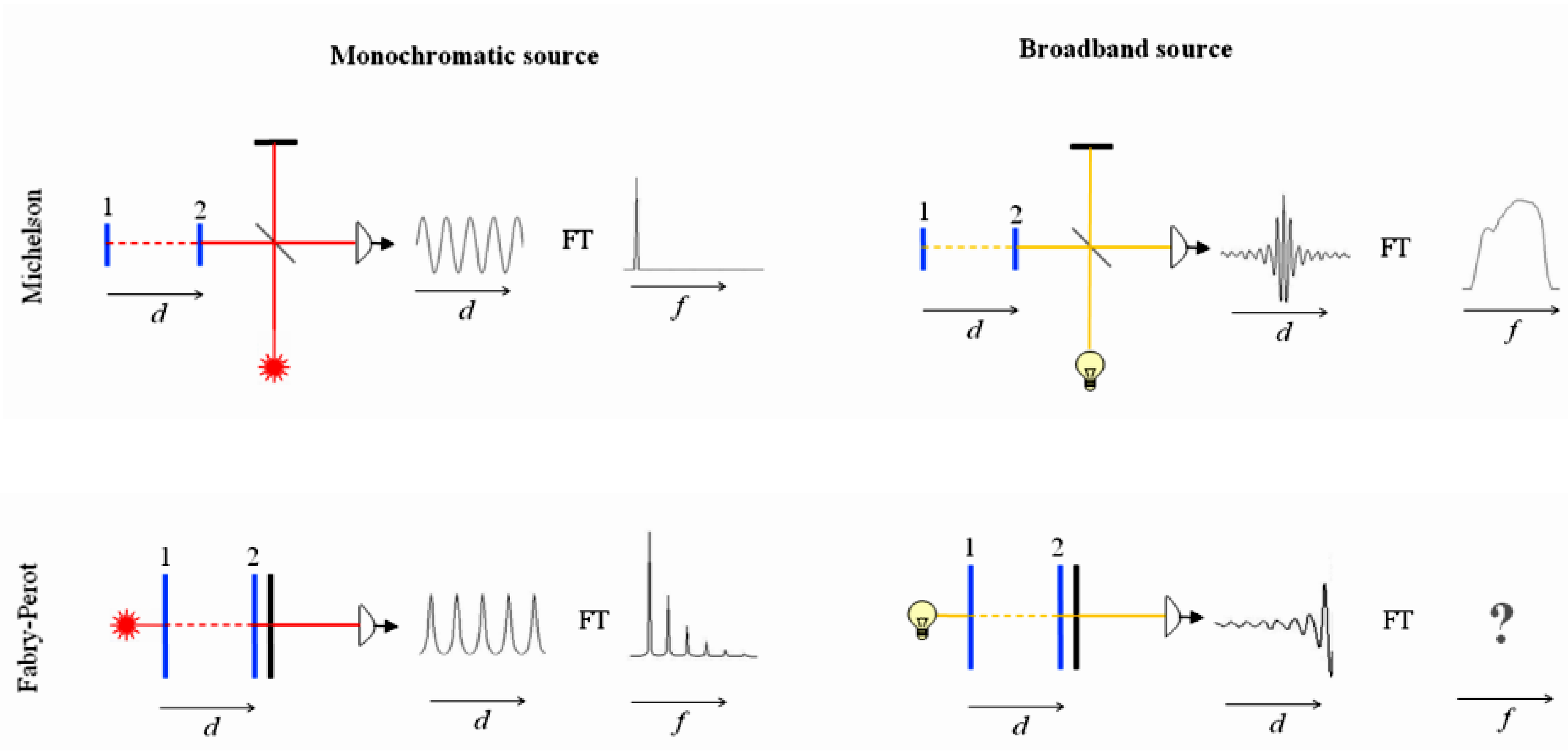
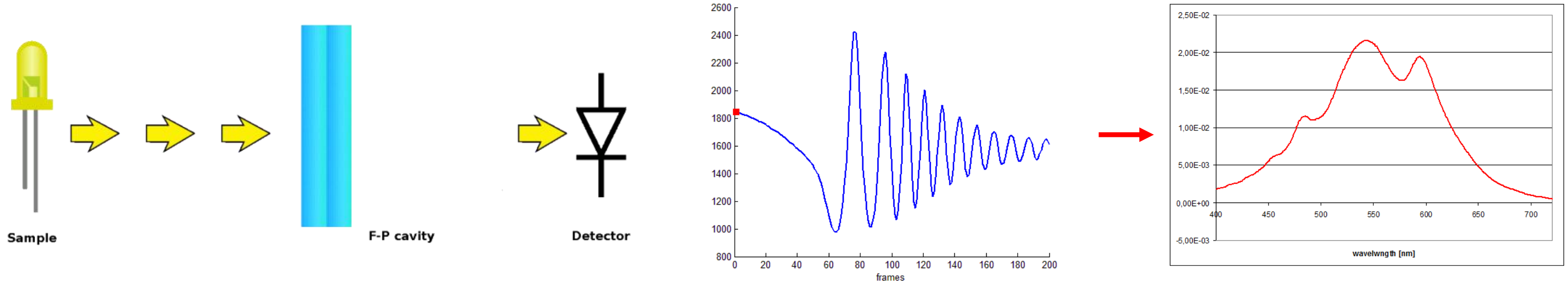
# A new concept: from Michelson to F-P resonator used as a two beams interferometer






M. Pisani and M. Zucco, Optics Express, 17 (10), pp.8319-8331, (2009)

# IG reconstruction and spectrum calculation

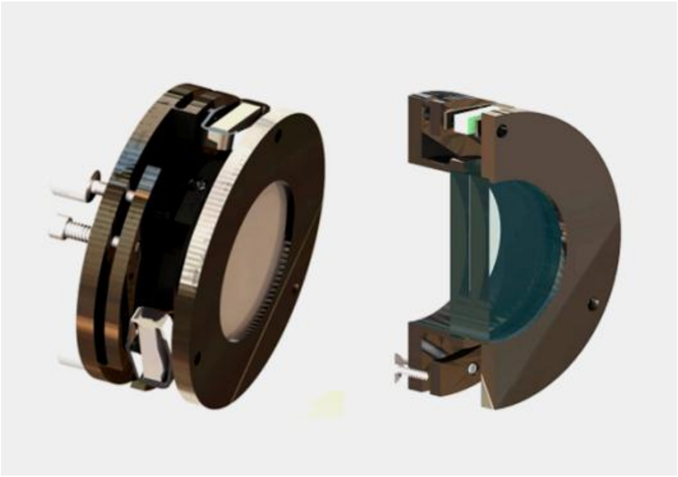


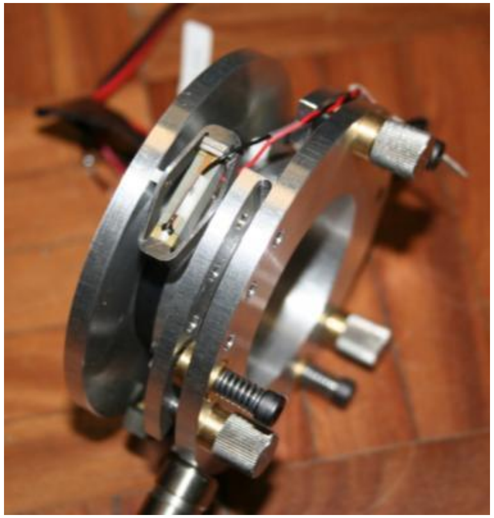

- The intensity modulated light signal is captured in a video during the F-P cavity length scanning.

- The spectral composition is calculated by means of a Fourier Transform based algorithm from the interferogram.

# The INRIM scanning F-P interferometer

The Fabry-Perot interferometer is made of two glass mirrors mounted in aluminum frames.

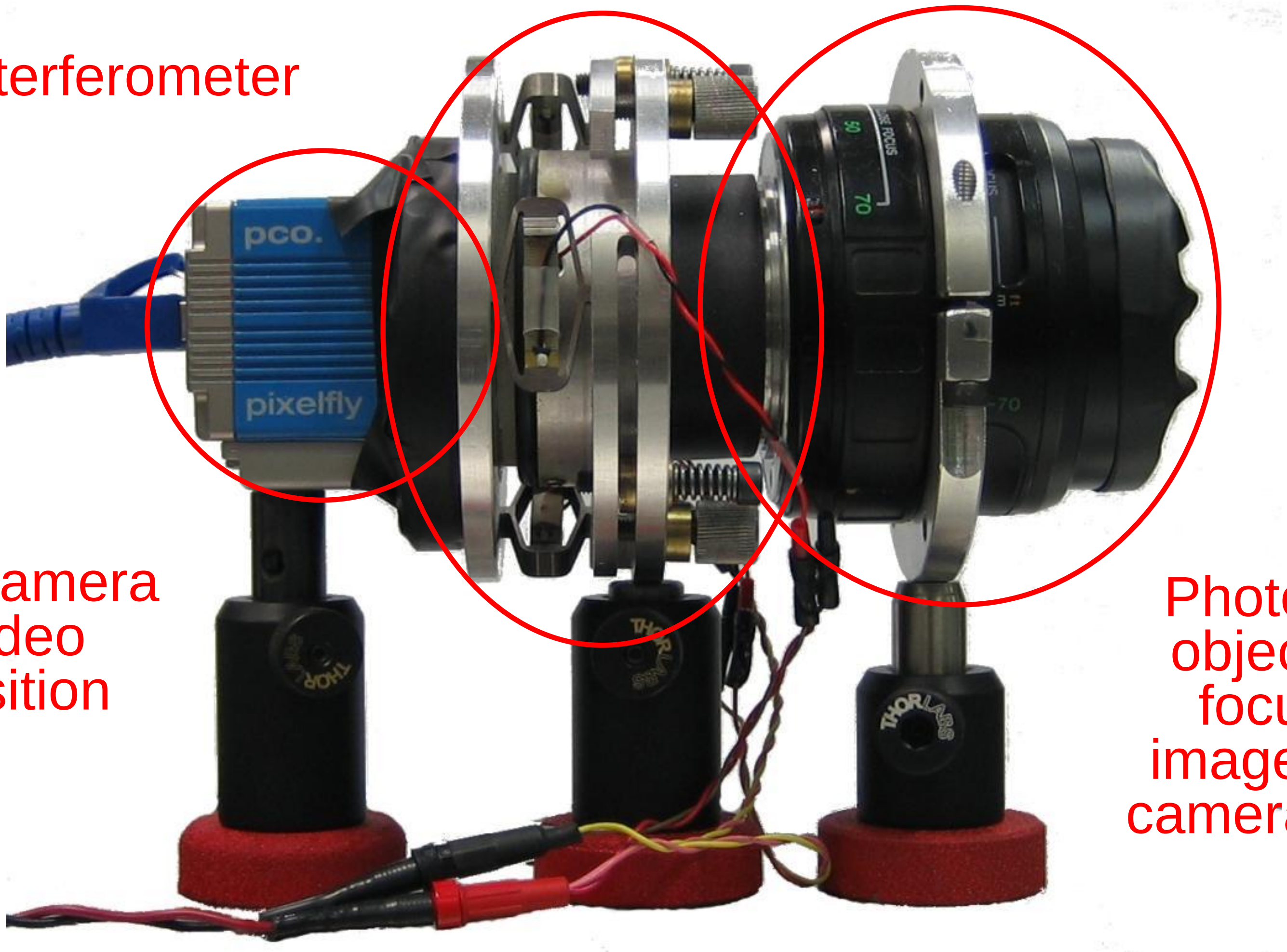




The distance between mirrors is varied by means of three piezo actuators.

# Device main elements

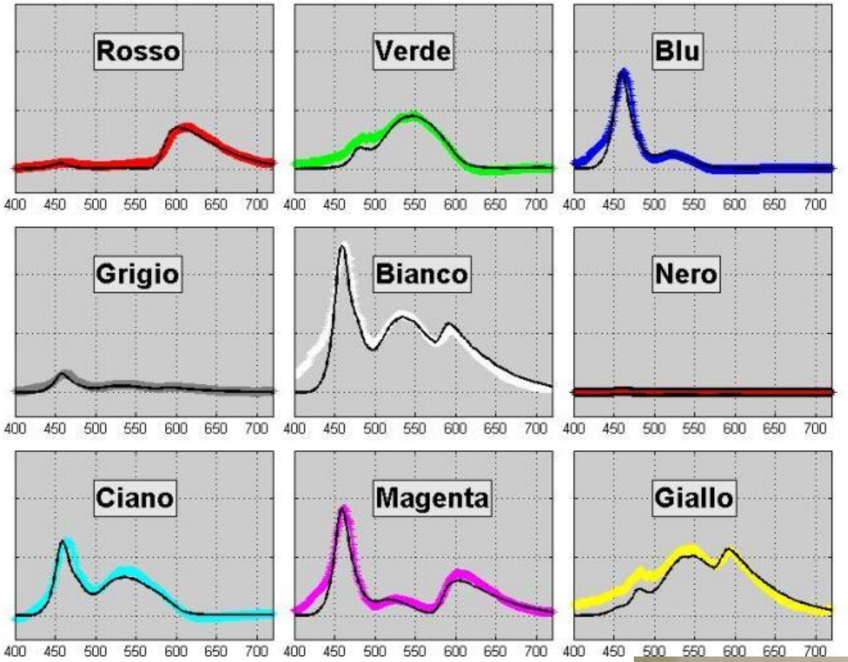
F-P interferometer



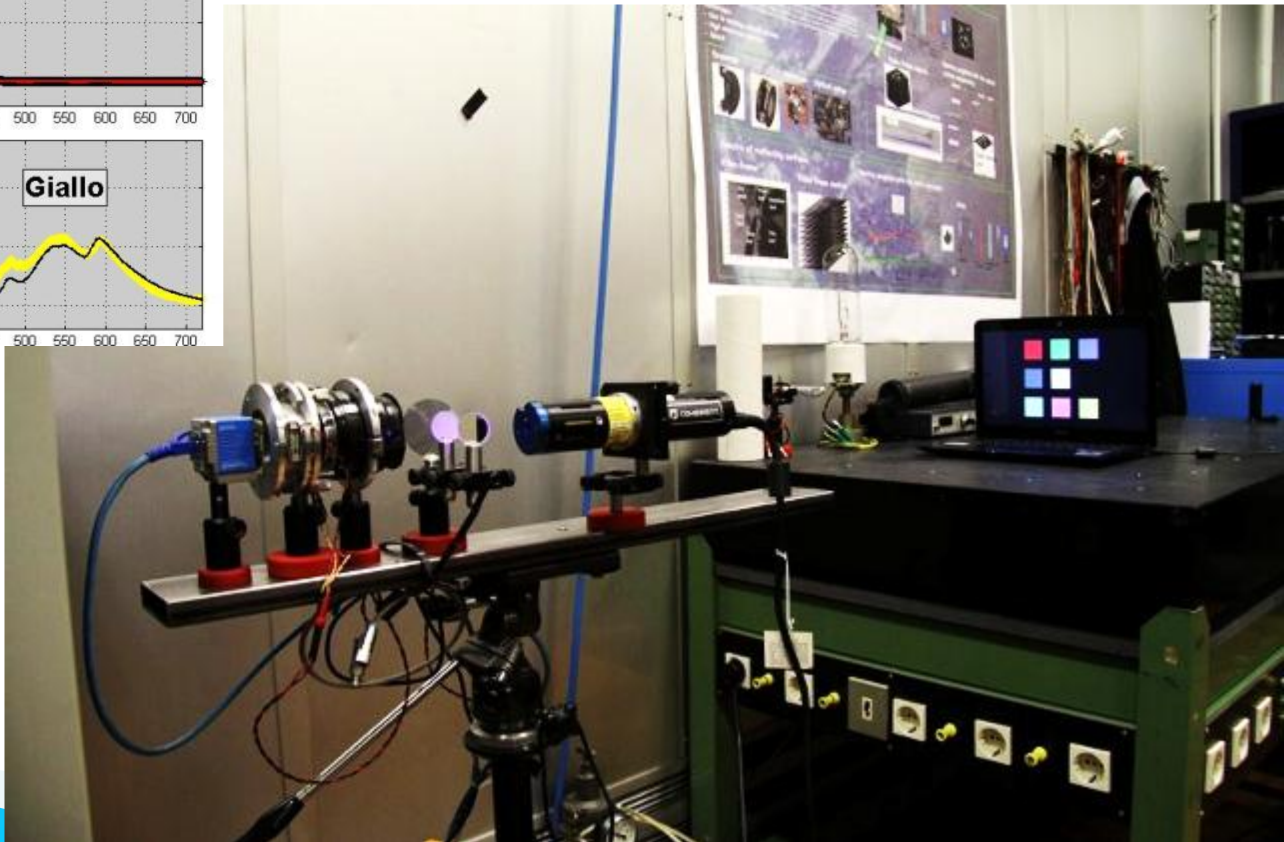

Digital camera for video acquisition

Photogrphic objective to focus the image on the camera sensor

# Emission spectra




Coloured pattern from LCD display with LED backlight



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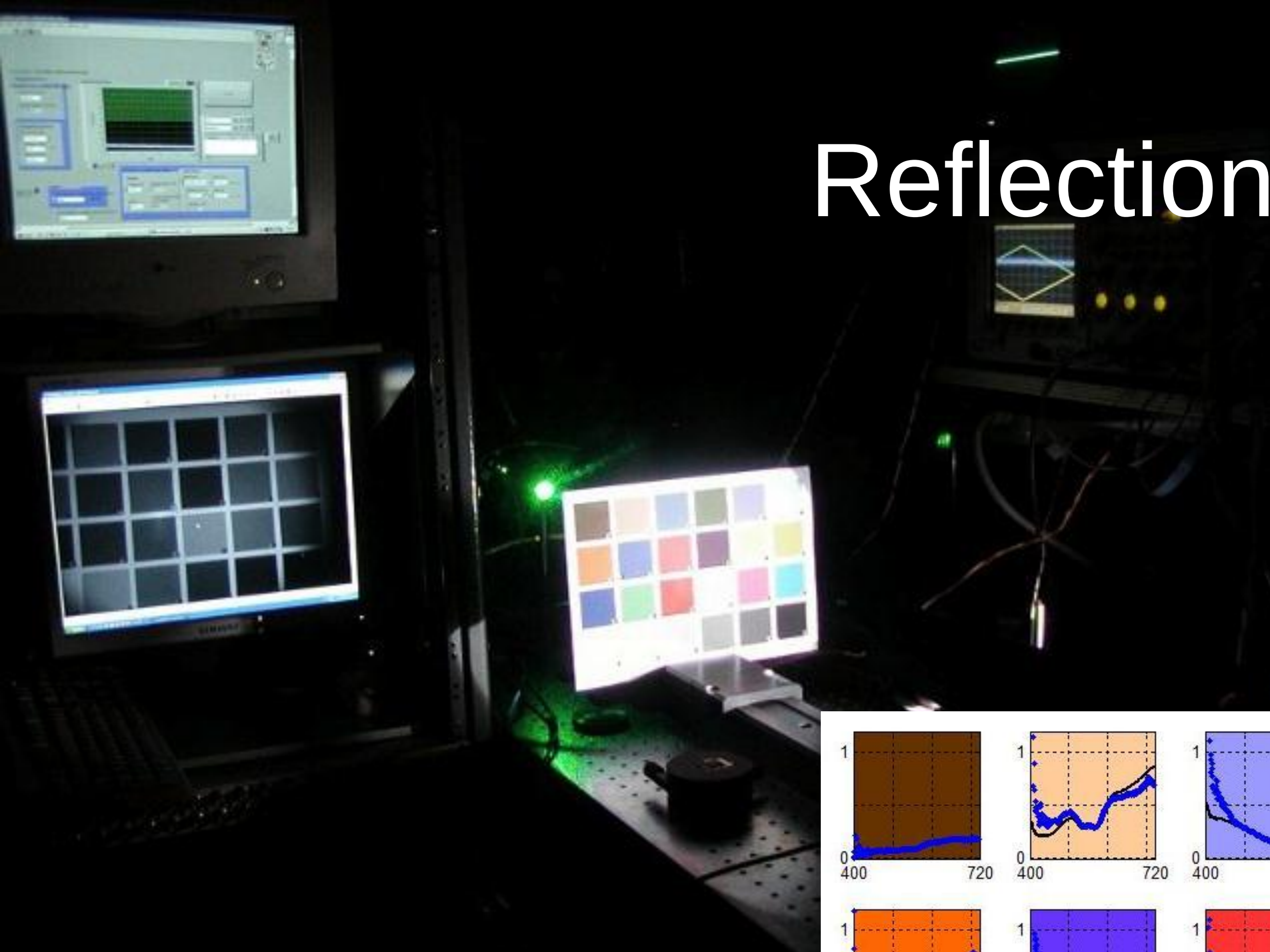
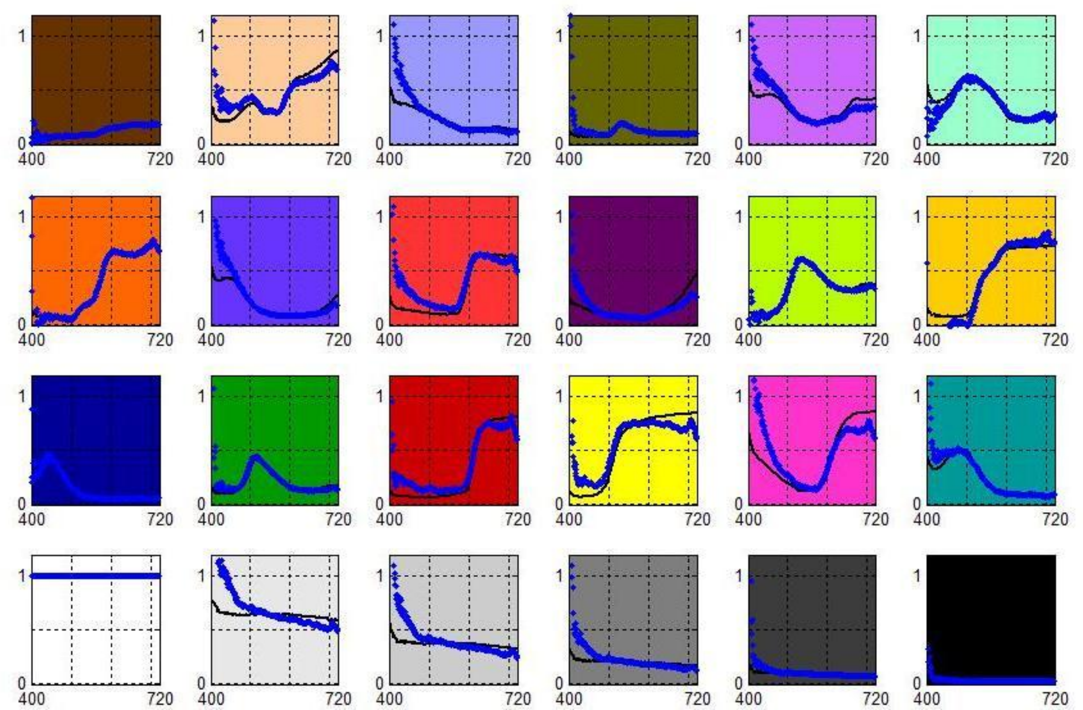
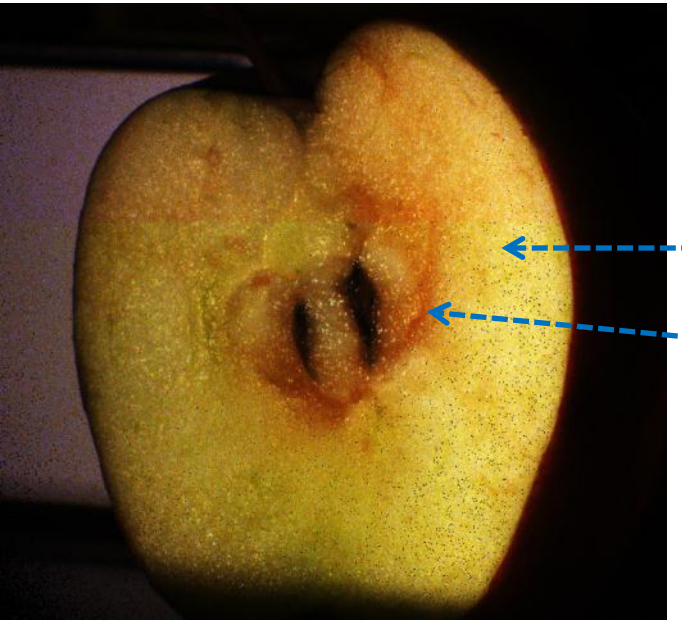
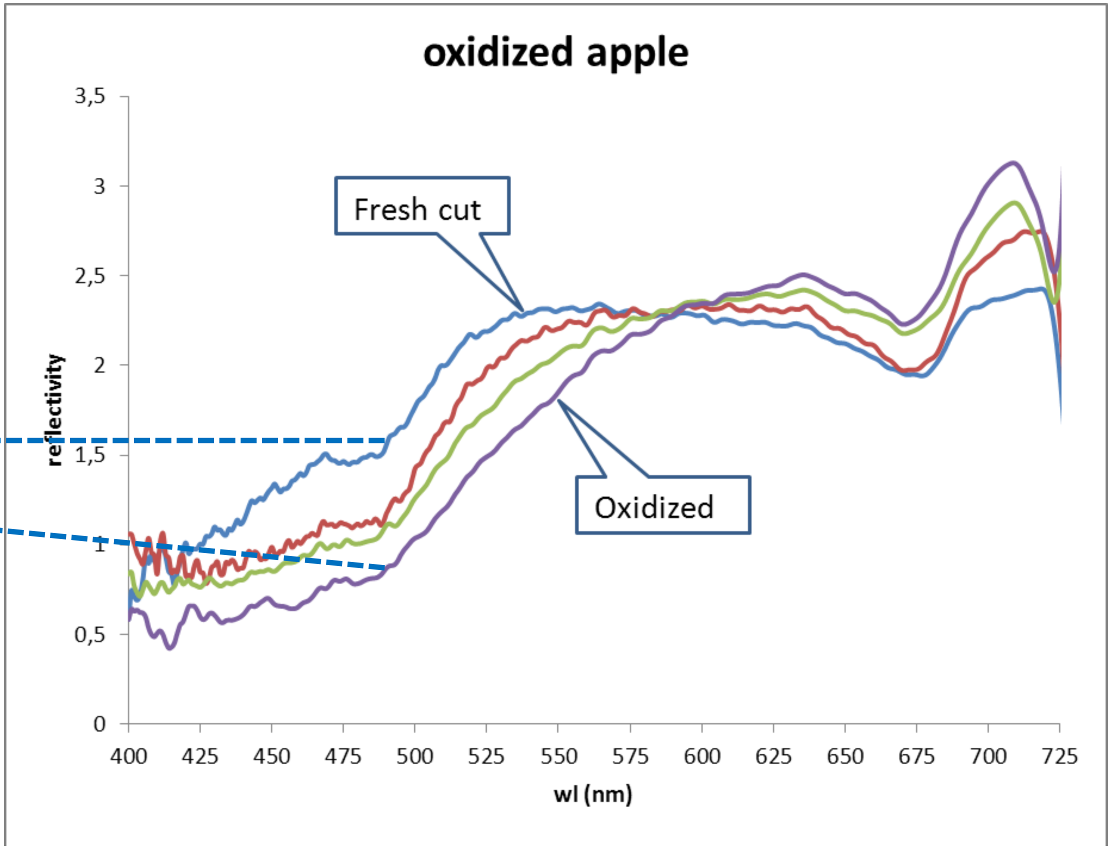
# Reflection spectra



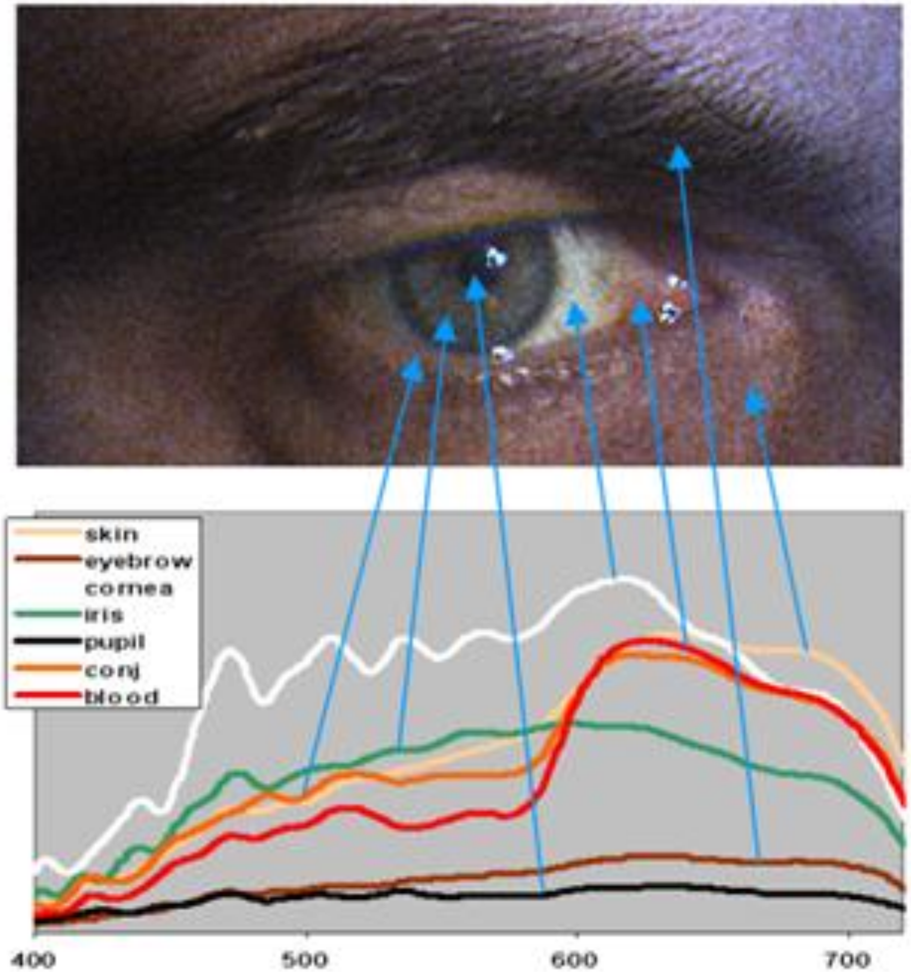


# Spectral analysis in the visible range





# In Vivo Hyperspectral Imaging

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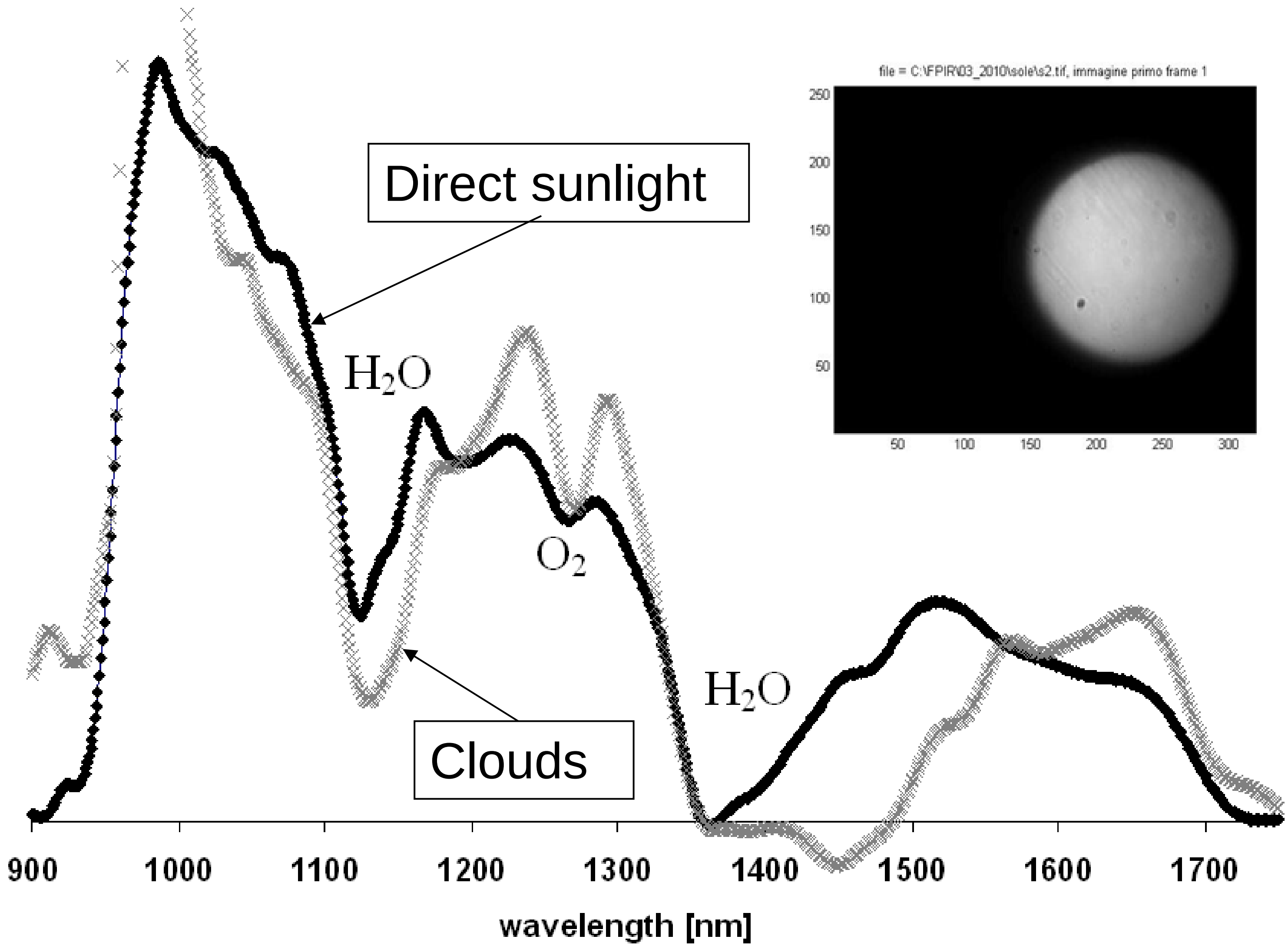
# Spectroscopy in the IR region: Long distance atmospheric absorption

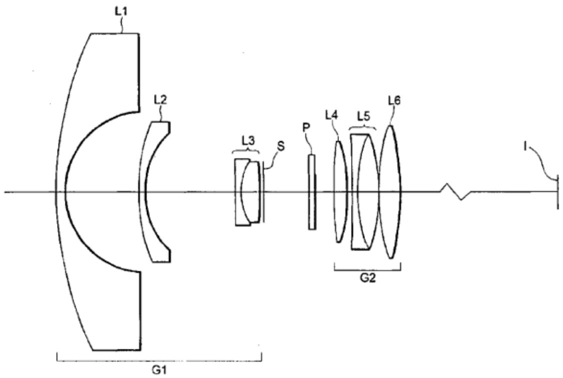


# The F-P cavity in the UV

A new F-P cavity more compact and robust is under construction and will be integrated in the optical system

The new F-P will be based on motor actuators in order to compensate for temperature induced deformations

# Design of the optical system




- A fisheye objective with good efficiency in the 280-400 nm range is required
- A fisheye objective in the UV is not commercially available must be designed from scratch
- A refractive design although possible would be extremely complex



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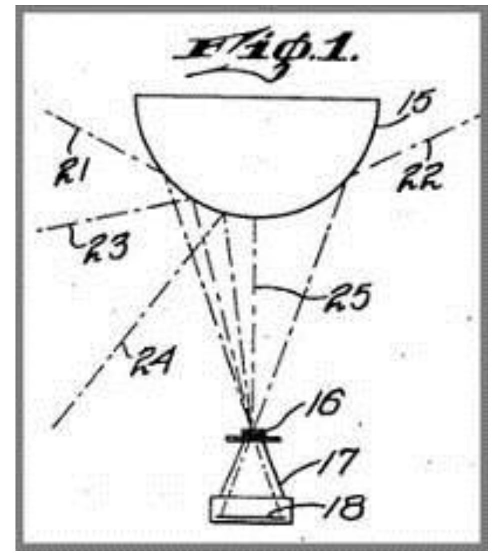
# Catadioptric solution

- A wide angle image can be easily obtained by looking «through» a convex mirror.
- A catadioptric system combines a traditional refractive system with a mirror




**Catadioptric scheme from an early 20$^{th}$ century patent**

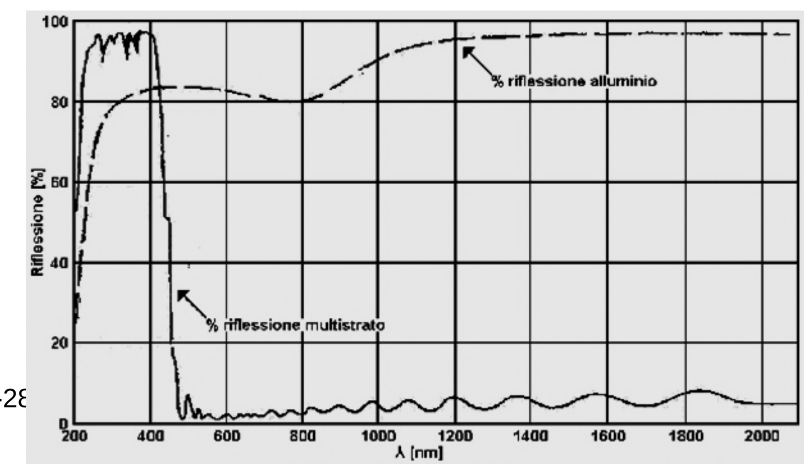
# Catadioptric solution

- Commercial devices are available but not compliant with UV requirements

**Fisheye catadioptric commercial camera from Nanophotonics**

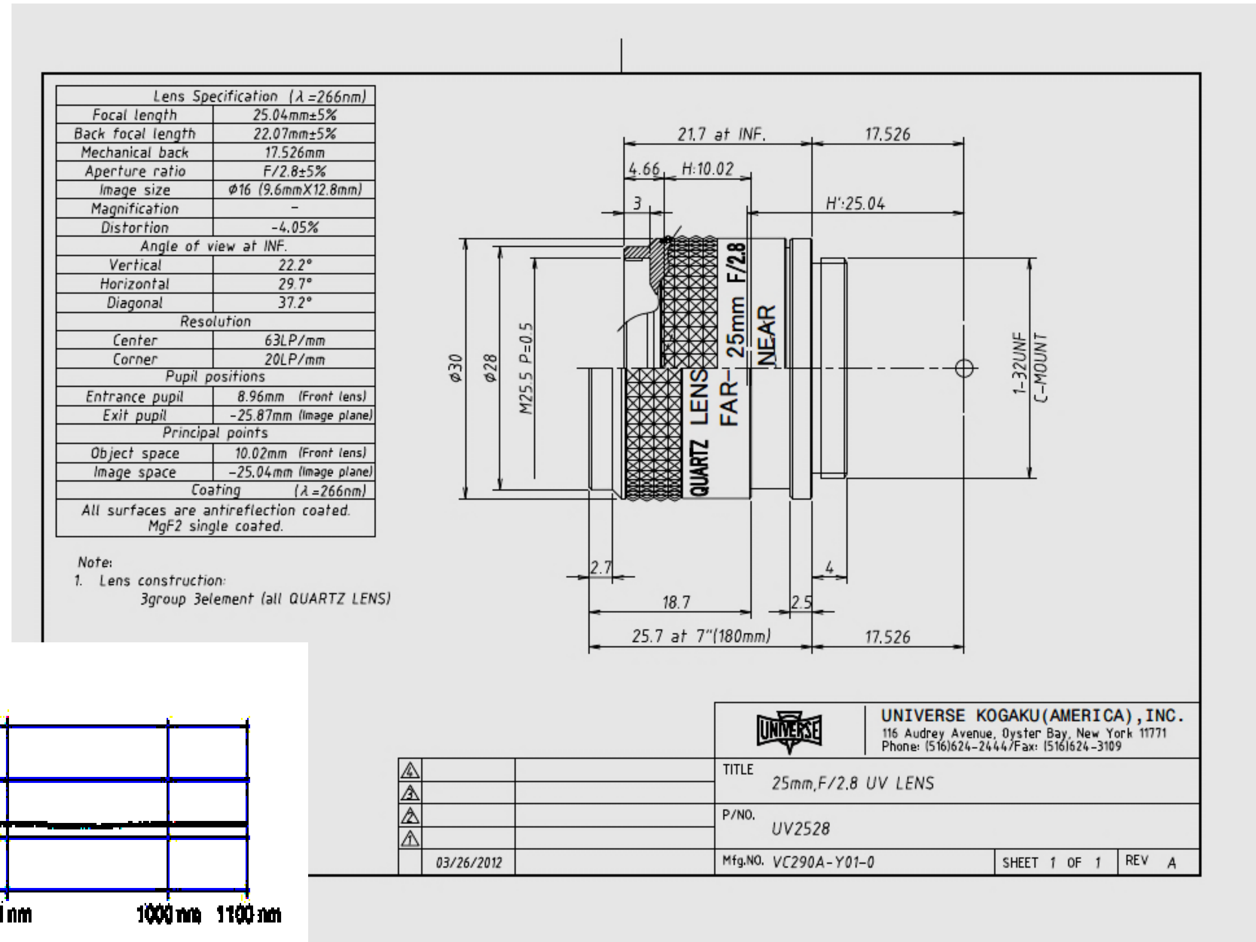
# Realization of the mirror

The miror has been realized starting from a glass lens vacuum coated with aluminium protected by a thin layer of $SiO_2$
The reflectivity exceeds 80% in the range of interest



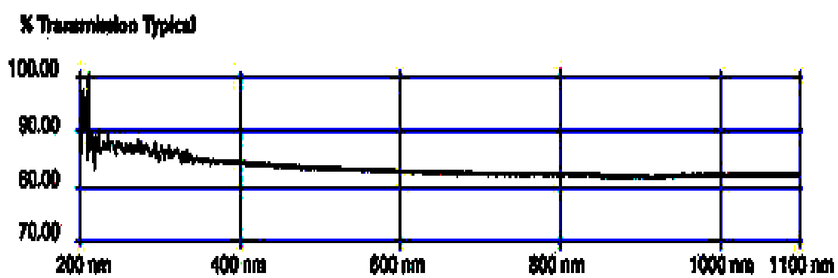
# The objective

The objective is made by UKA optics from quartz lenses coated $MgF_2$.
Is a 25 mm f= 2.8 lens with a transmittivity of 85% from 200 to 300 nm

| Lens Specification (λ =266nm) | |
|---|---|
| Focal length | 25.04mm±5% |
| Back focal length | 22.07mm±5% |
| Mechanical back | 17.526mm |
| Aperture ratio | F/2.8±5% |
| Image size | ø16 (9.6mmX12.8mm) |
| Magnification | – |
| Distortion | -4.05% |
| Angle of view at INF. | |
| Vertical | 22.2° |
| Horizontal | 29.7° |
| Diagonal | 37.2° |
| Resolution | |
| Center | 63LP/mm |
| Corner | 20LP/mm |
| Pupil positions | |
| Entrance pupil | 8.96mm (Front lens) |
| Exit pupil | -25.87mm (Image plane) |
| Principal points | |
| Object space | 10.02mm (Front lens) |
| Image space | -25.04mm (Image plane) |
| Coating | (λ =266nm) |
| All surfaces are antireflection coated. MgF2 single coated. | |



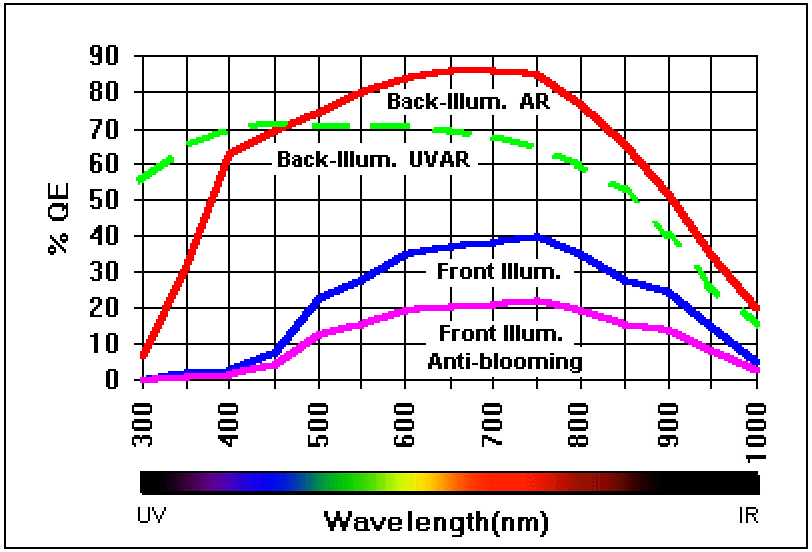


# Camera selection

- **small transversal size**, because we have to minimize the shadow projected by the camera itself on the spherical mirror in order to scan the maximum portion of the sky above the system;
- **sufficient absolute quantum efficiency** down to 300 nm;
- **high frame rate** in order to acquire a sufficient number of frames in a small time.

# Back thinned (or back illuminated) CCD

- The first choice because of its excellent efficiency in the UV.



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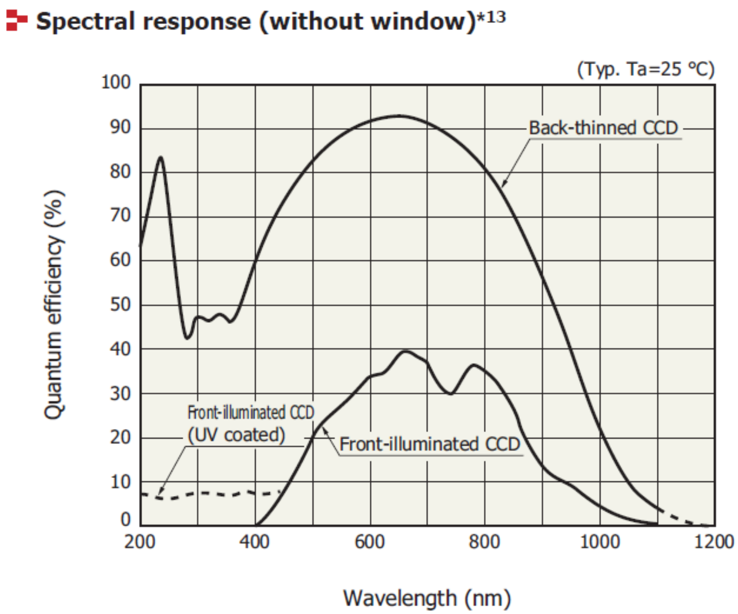
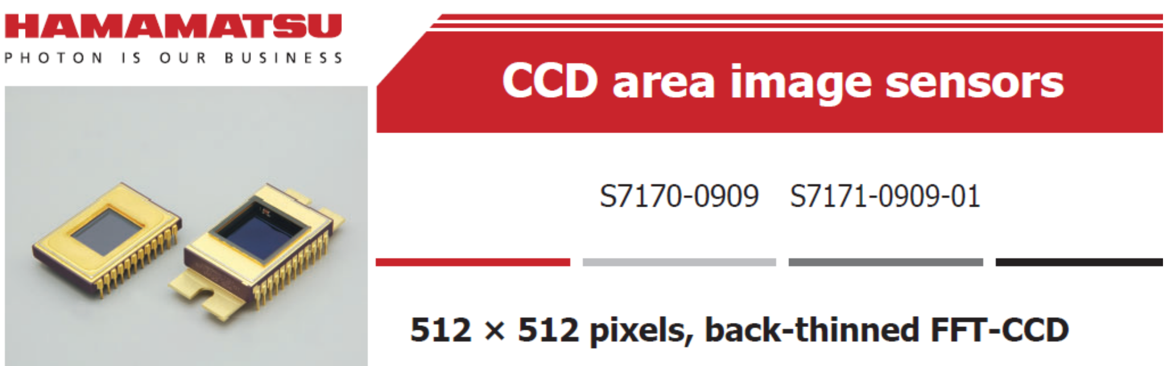
# Hamamatsu back thinned CCD




Quantum efficiency in the UV is excellent, but the speed is at best 1fps




# Kodak KAI 4022 CCD

- Scientific CCD with discrete responsivity in the UV (>5% @ 300nm), good dynamic range (16 bit) and speed, excellent spatial resolution (4 Mpixel)

KODAK KAI-04022 IMAGE SENSOR

2048 (H) X 2048 (V) INTERLINE TRANSFER PROGRESSIVE SCAN CCD

Ultraviolet (UV) Quantum Efficiency
without microlens

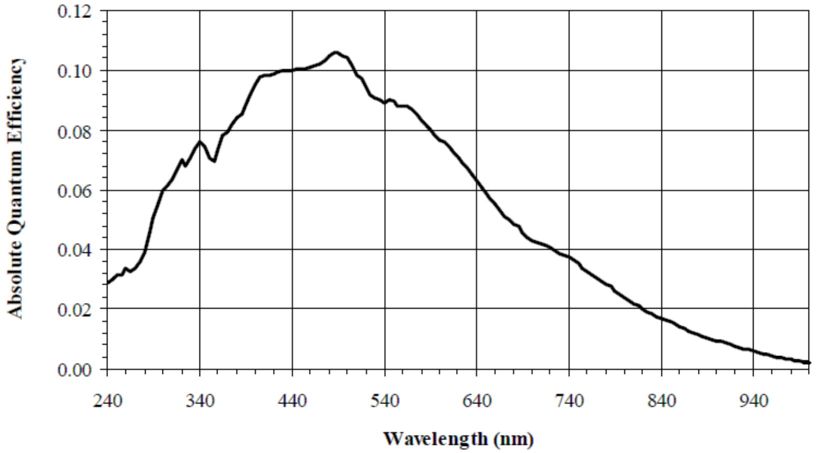
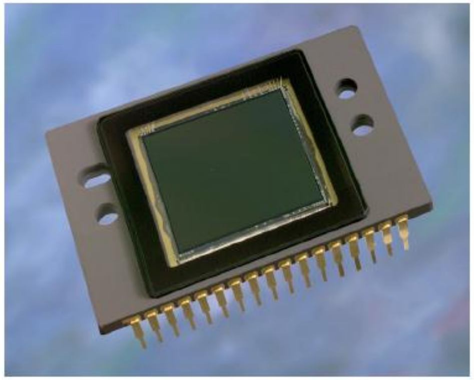
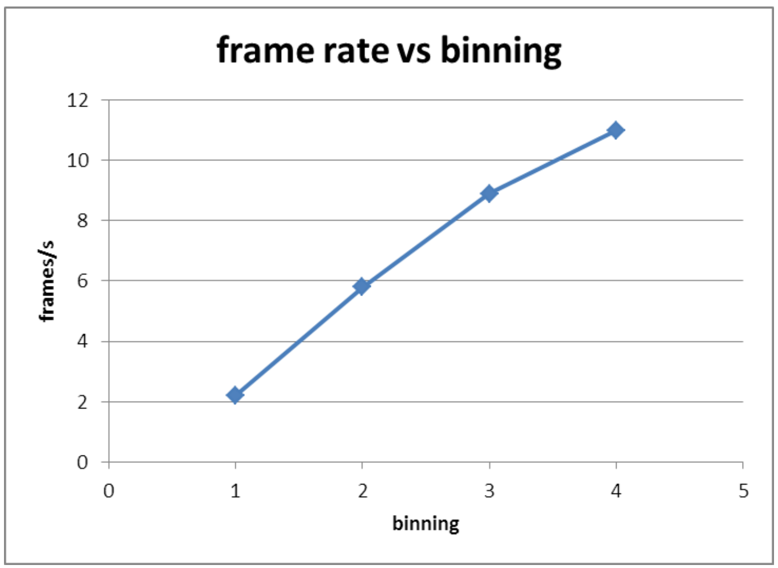



Figure 12: Ultraviolet Quantum Efficiency



# Ascent 4000 camera

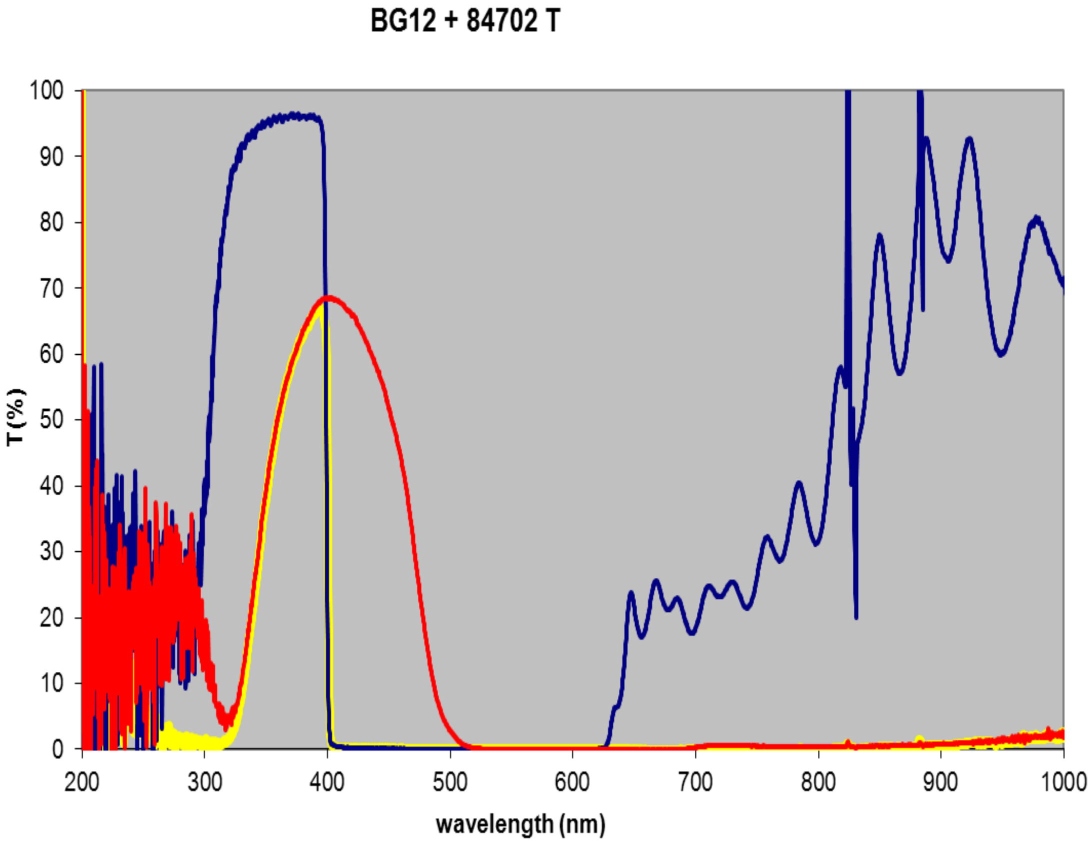
- Kodak sensor is integrated in the Ascent 4000 camera with dual 16 bit ADCs




# UV filter

In order to exploit the whole dynamic range of the camera a UV band pass filter is placed in front of the camera

We have combined a dichroic short pass filter (blue curve) with a coloured glass blue filter (red curve) obtaining a band pass UV filter (yellow curve)



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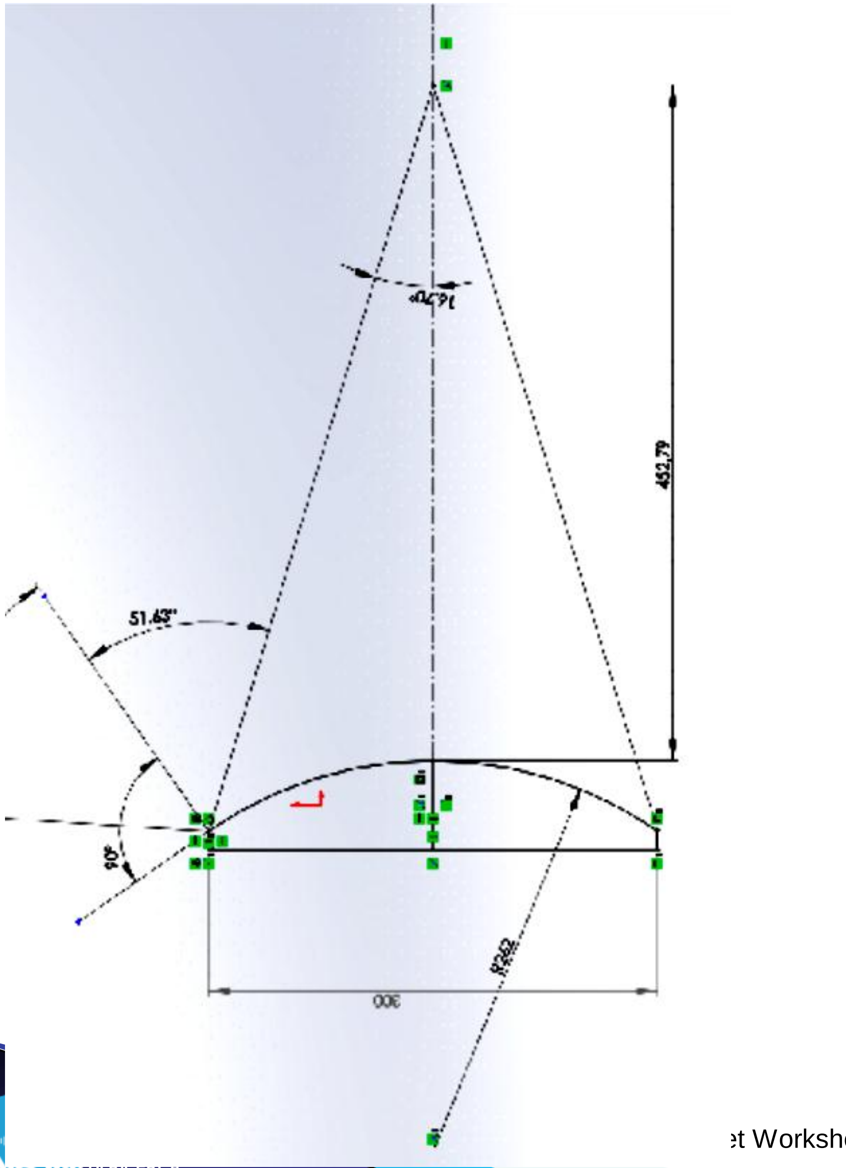
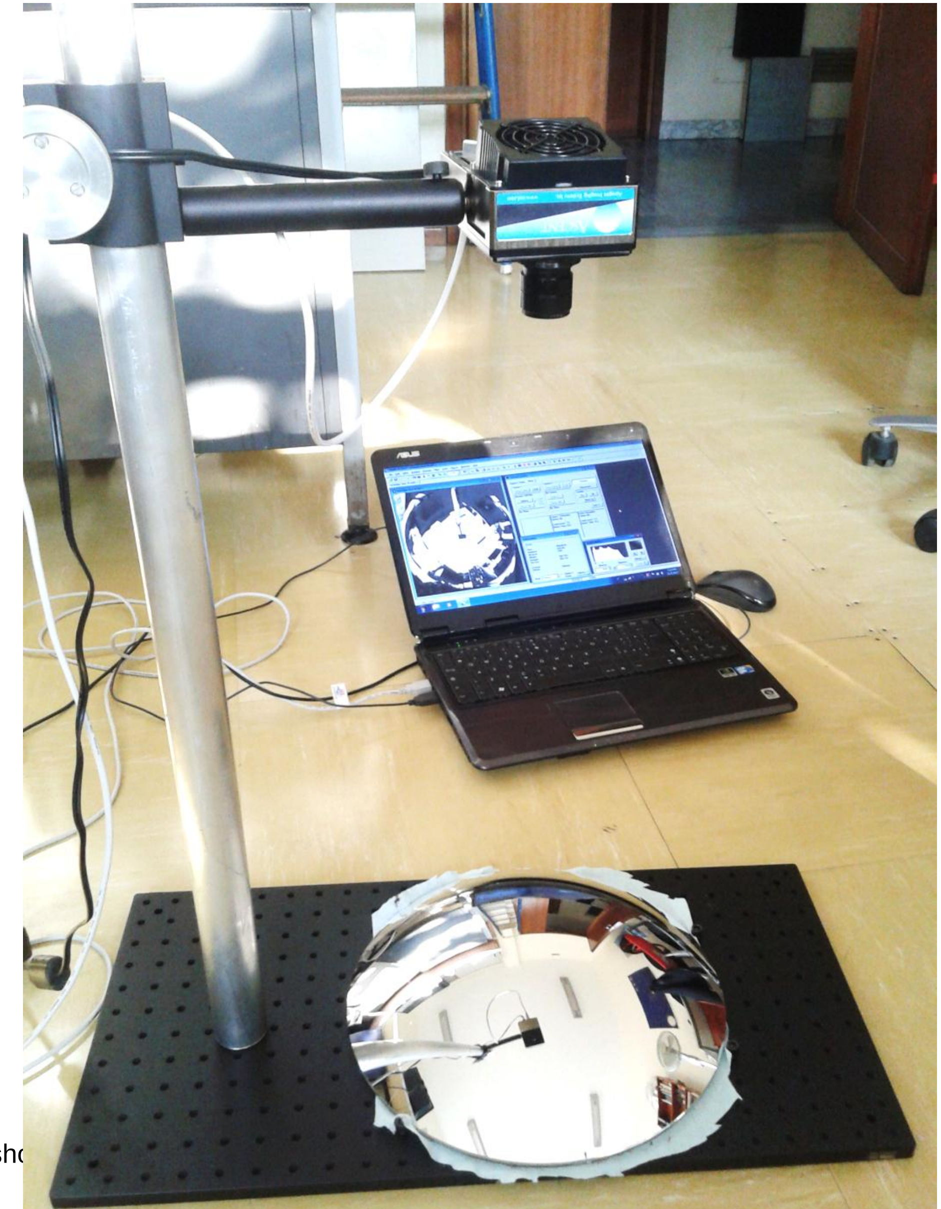
# The assembled system



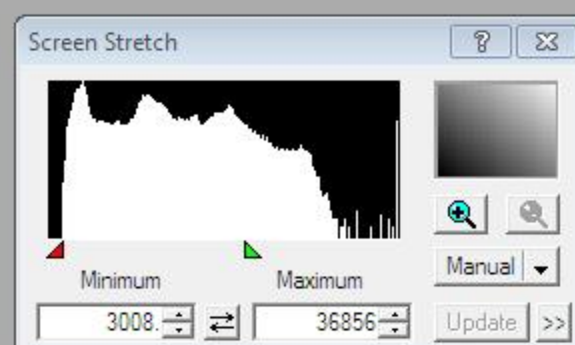



# Resolution and sensitivity test

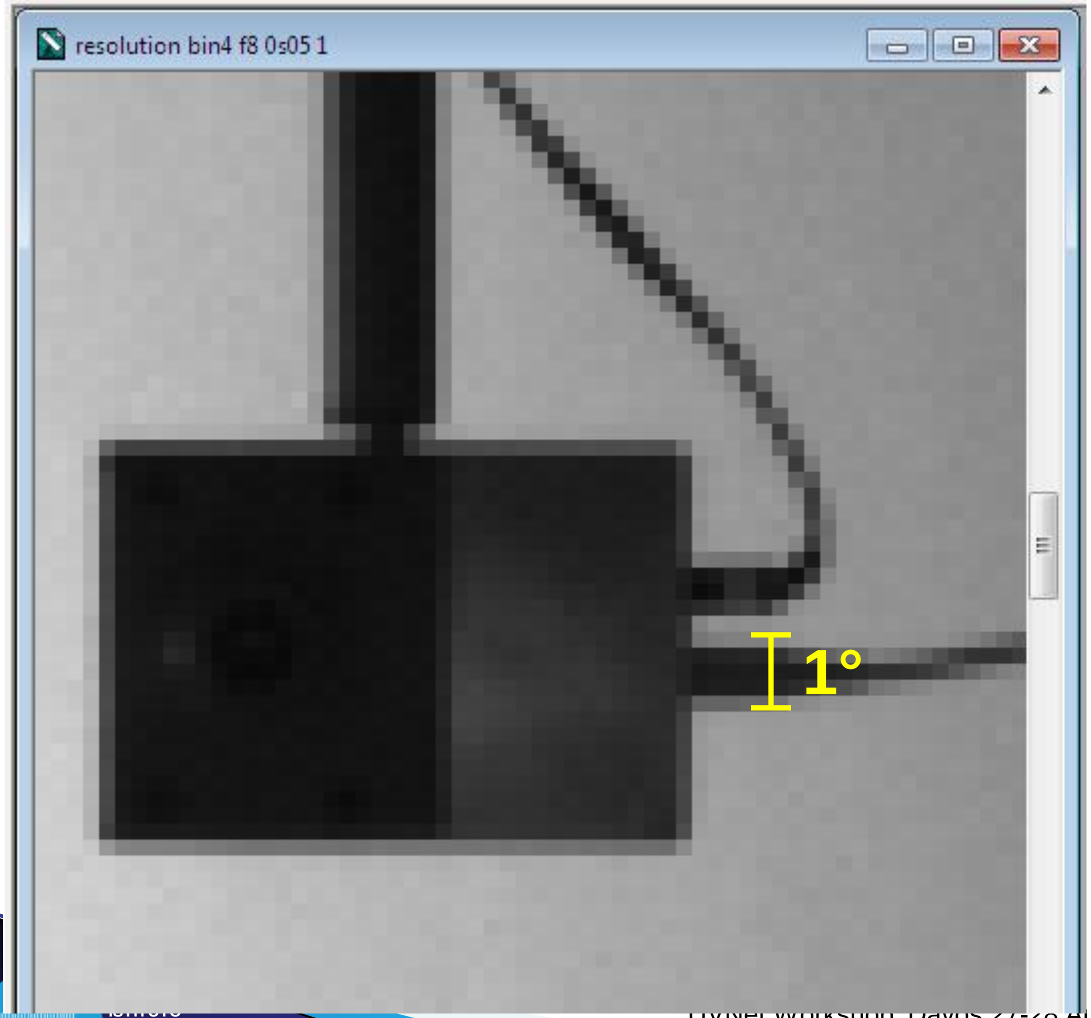

Camera set:

4x4 binning = 512x512 pixel image

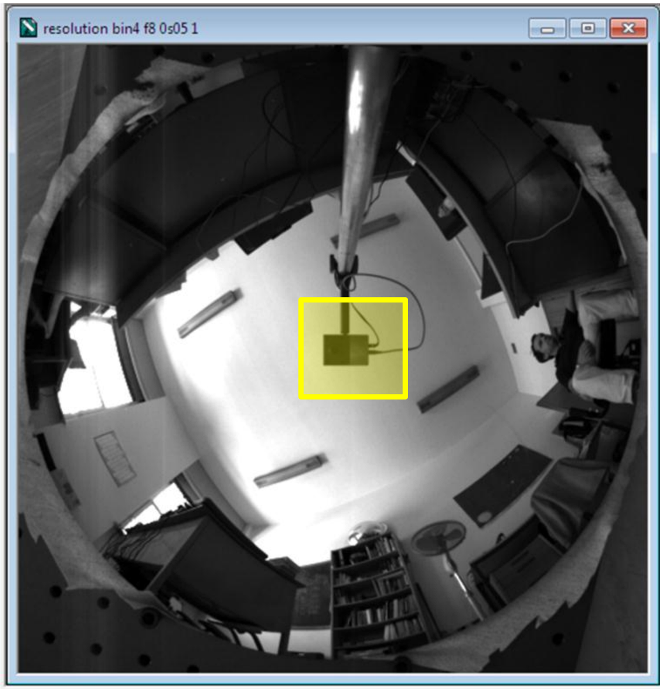
Objective aperture f=8



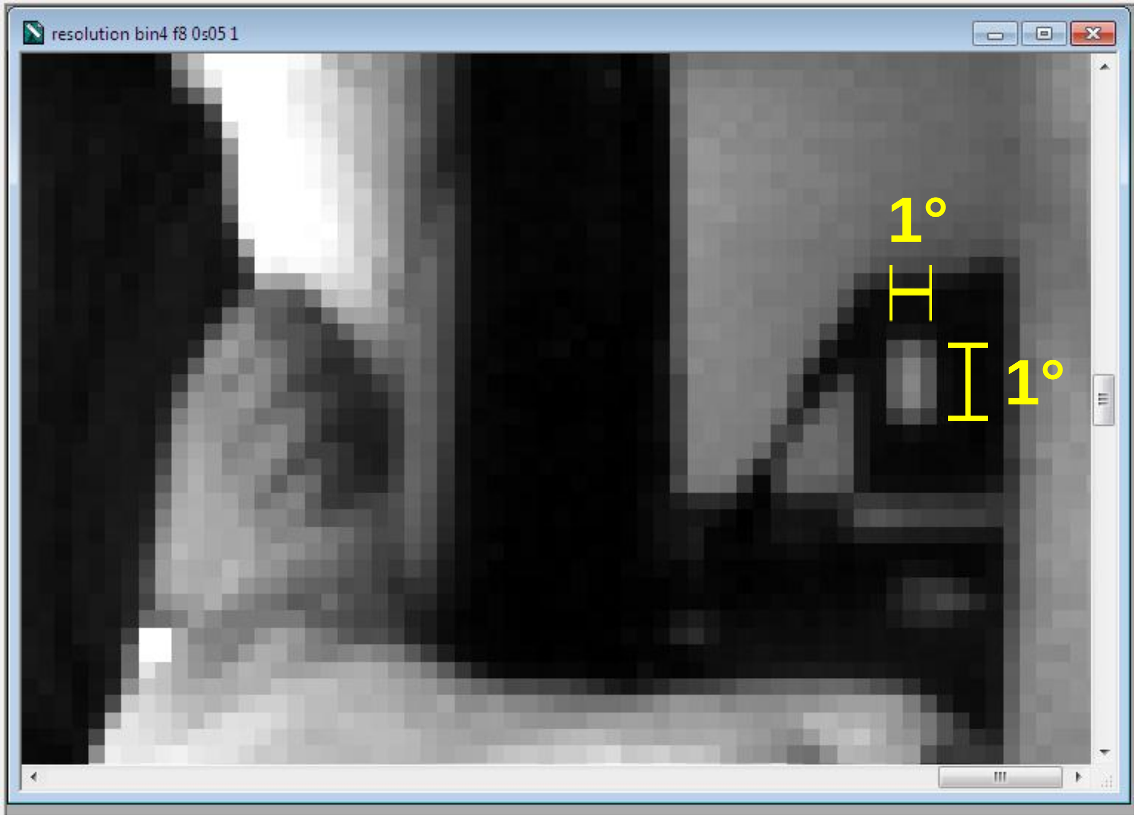
# Resolution at zenith



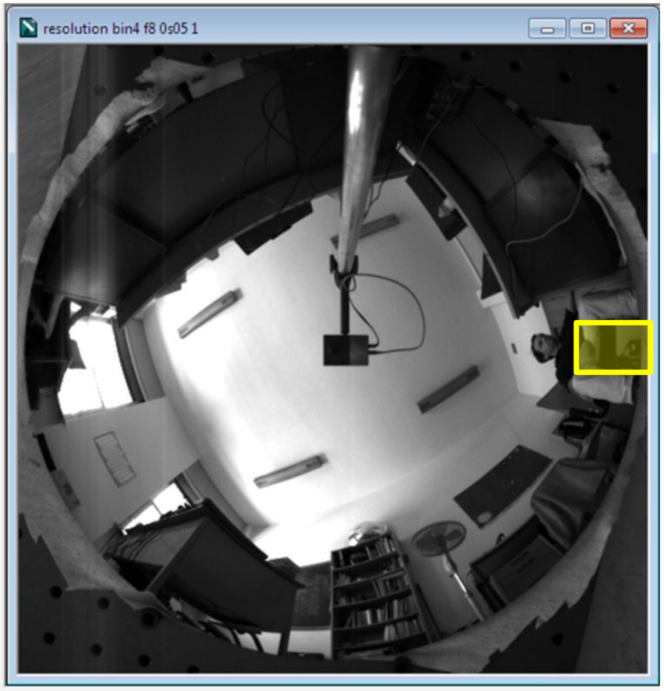

- Angular resolution << 1°
- Angular sensitivity
  ≈ 4.4 pixel/deg



# Resolution close to the horizon




- Angular resolution < 1°
- Azimuth sensitivity
  ≈ 4.4 pixel/deg
- Zenith sensitivity
  ≈ 2.5 pixel/deg



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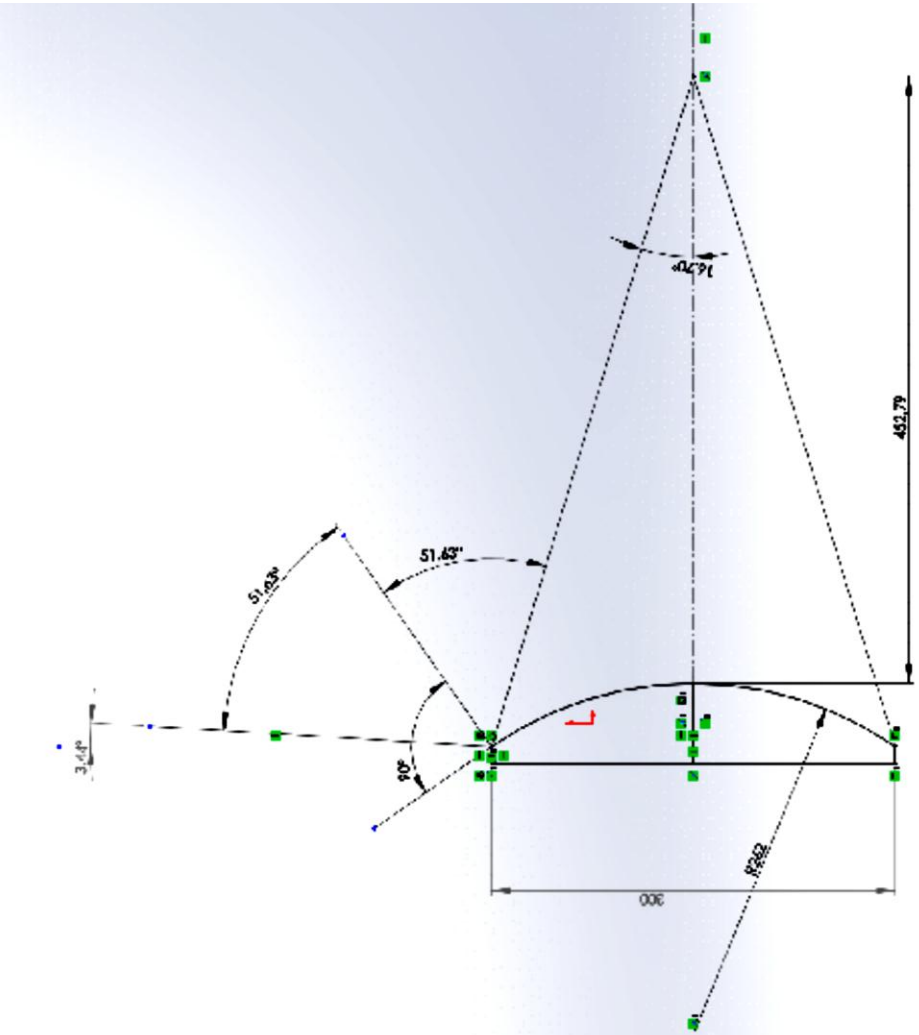
# Angle of view



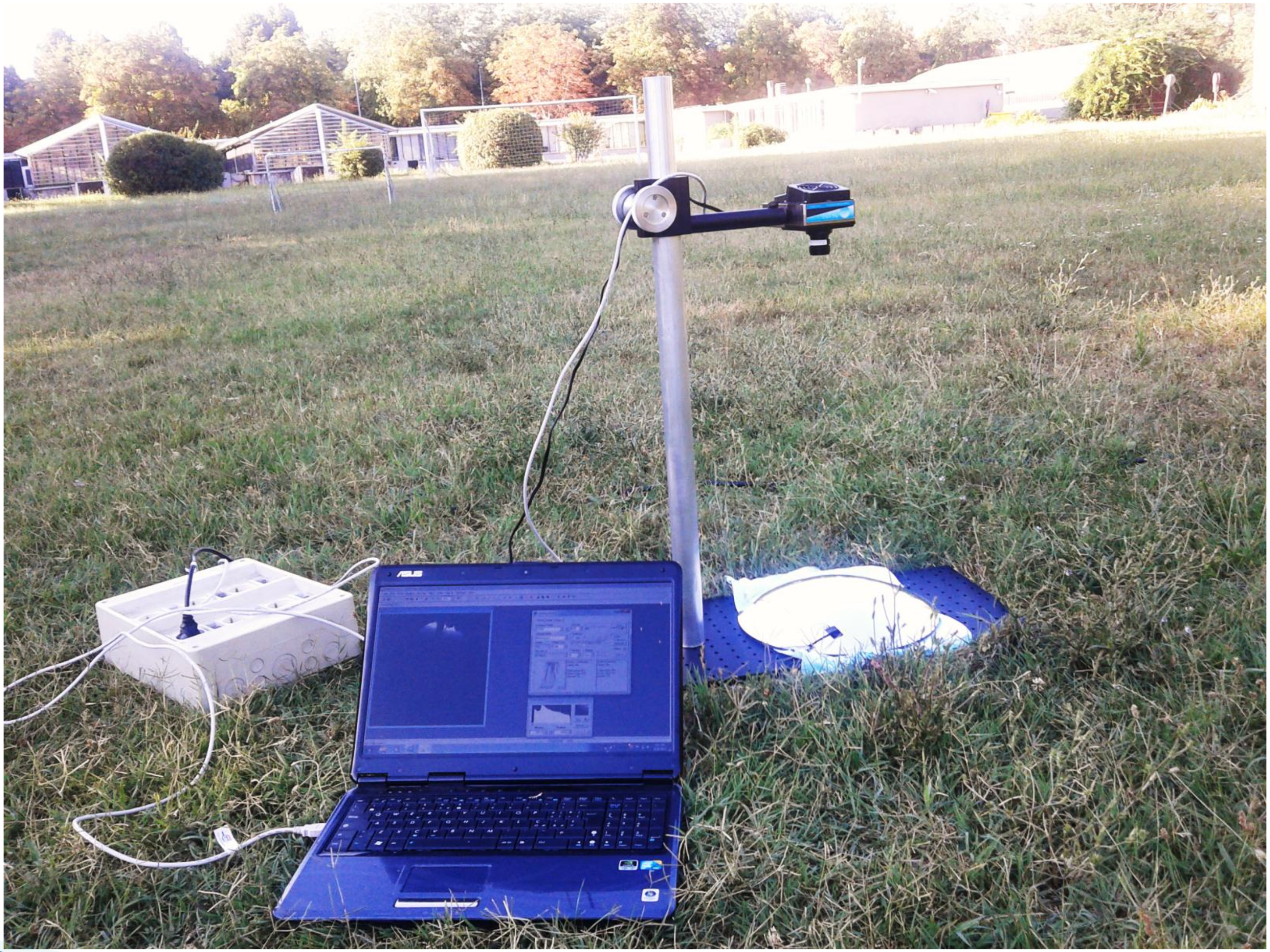

The angle of view has been evaluated theoretically and verified experimentally. Sky coverage exceeds ± 80° as required.


**Edge of the mirror ≈ 6.5° above the horizon**

# Resolution and mapping

- With 4x4 binning the worst resolution exceeds 2pix/deg, so a 8x8 binning could be acceptable for a 1° resolution reducing the number of acquired spectra from 200 k to 50 k
- A complete mapping of the angular coordinate of each pixel will be obtained experimentally

# Test in the field



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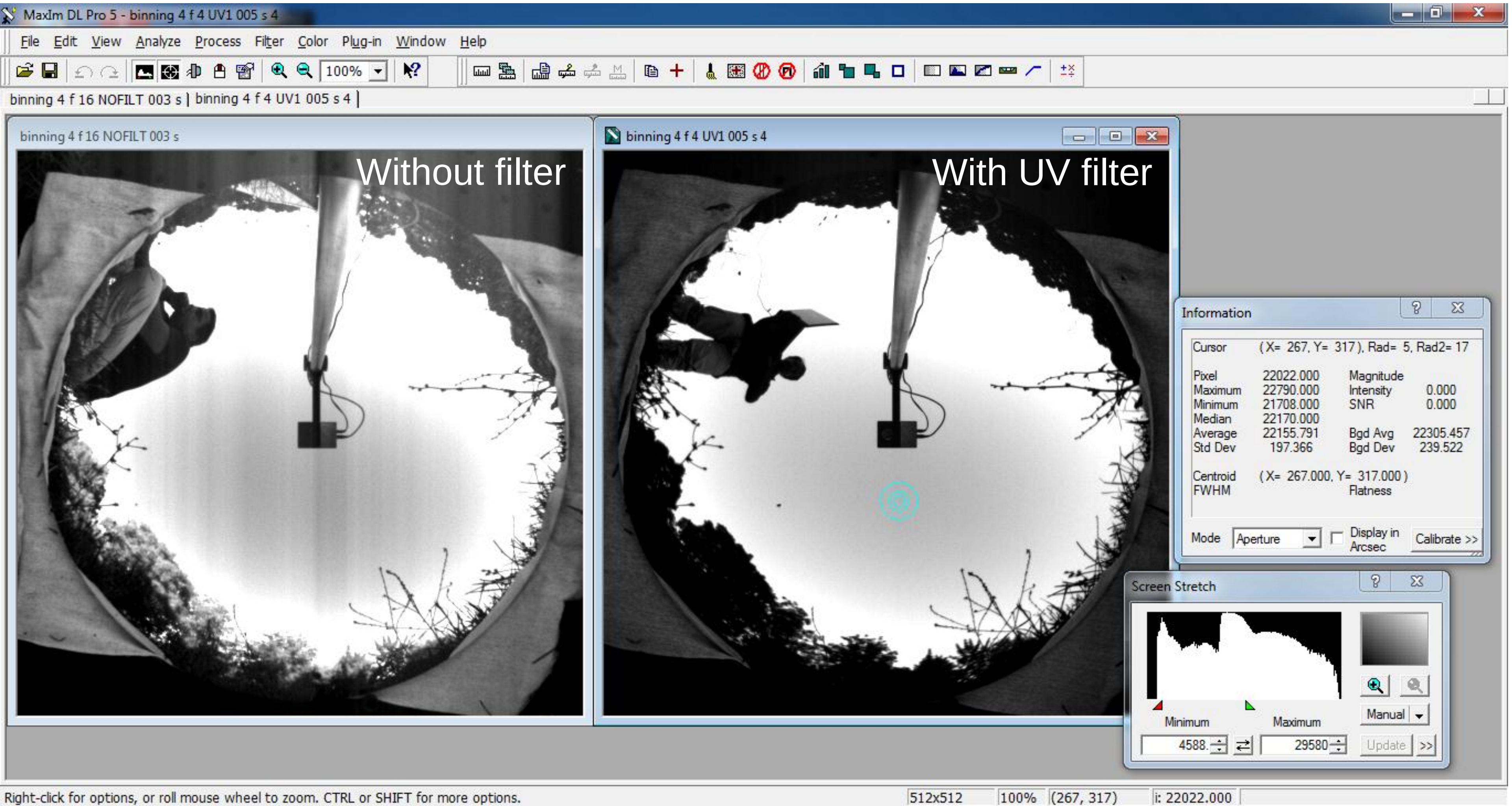
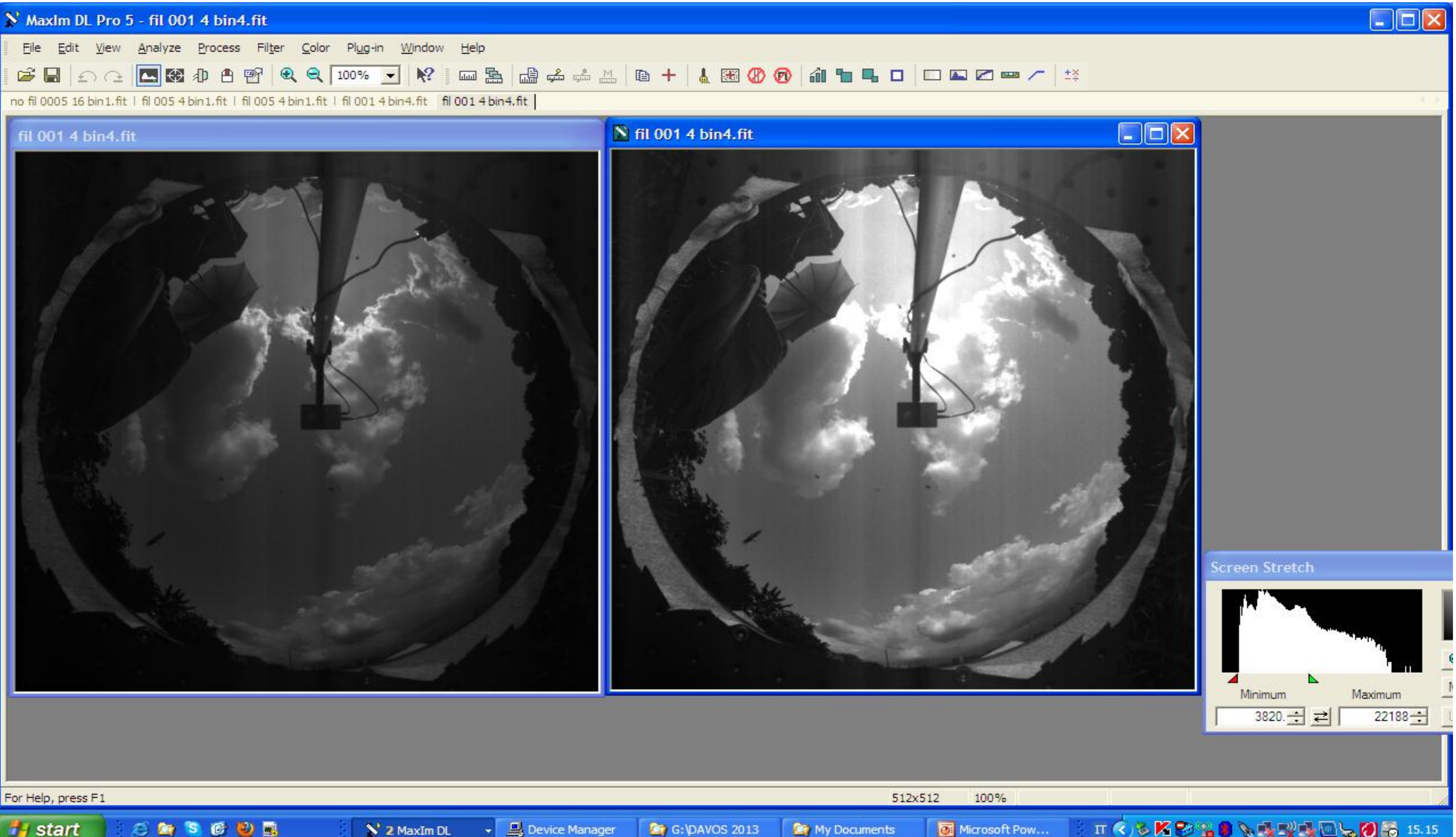
# Test of the camera sensitivity in the UV



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# To be done yet

- Integration of the Fabry-Perot device in the camera
- Spectral characterization
- Angular characterization
- In field measurements and comparison with reference instruments (classical spectrogoniometers)

# Thank you!

http://www.inrim.it/res/hyperspectral_imaging/