MUSKY: Multispectral UV Sky camera

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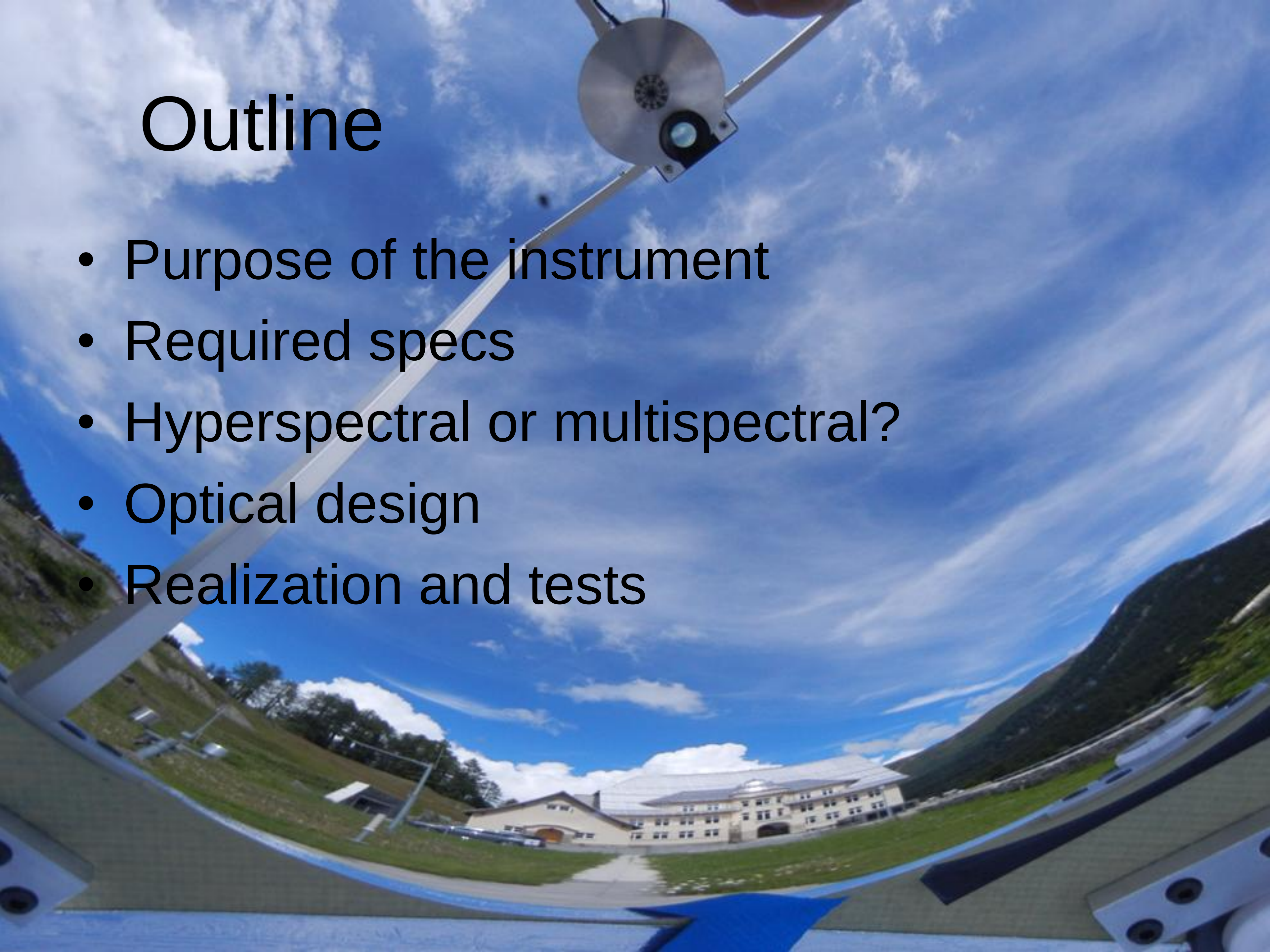
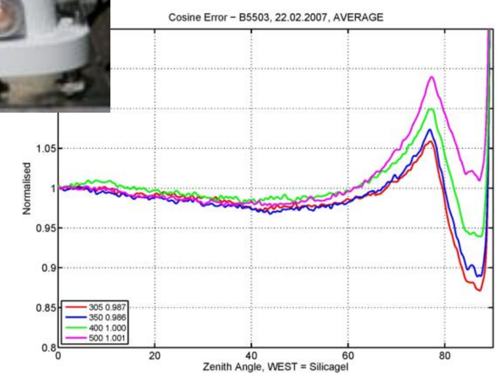
Outline

- Purpose of the instrument
- Required specs
- Hyperspectral or multispectral?
- Optical design
- Realization and 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 an imaging technique is preferrable because is much faster



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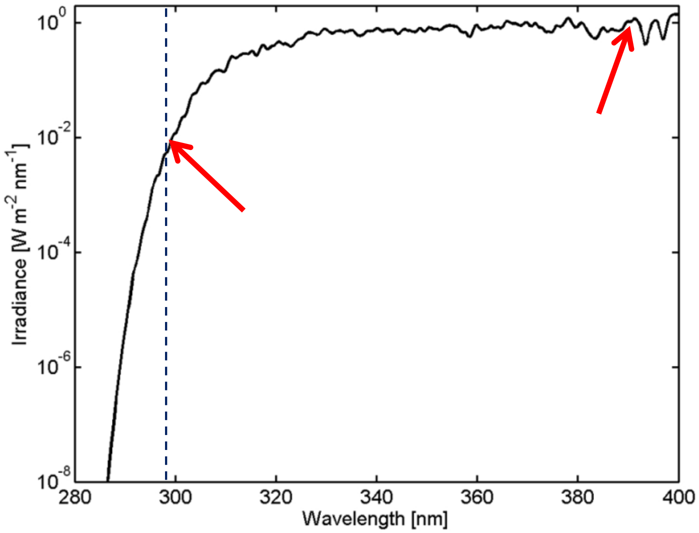
Specifications

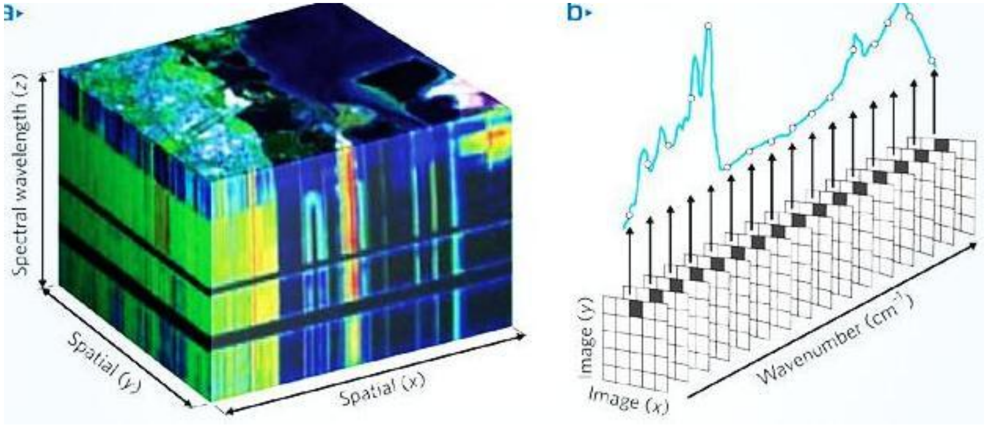
- Goal Specs
  - Field of view > ± 80°
  - Spatial resolution ≤ 1°
  - Spectral range 300-400 nm
  - Spectral resolution ≤ 5 nm
  - Good dynamic range > 10^4
- The instrument must be compact and transportable to be easily calibrated and operated in the field



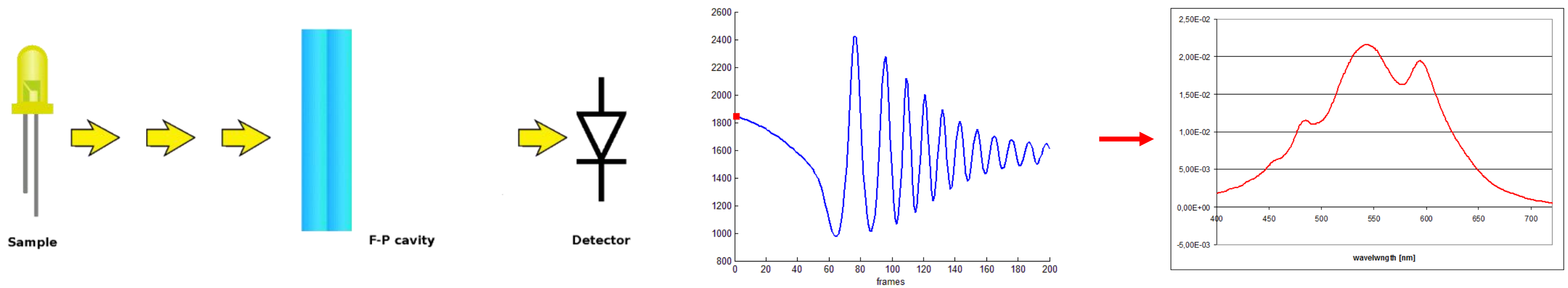
Hyperspectral or Multispectral?

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.



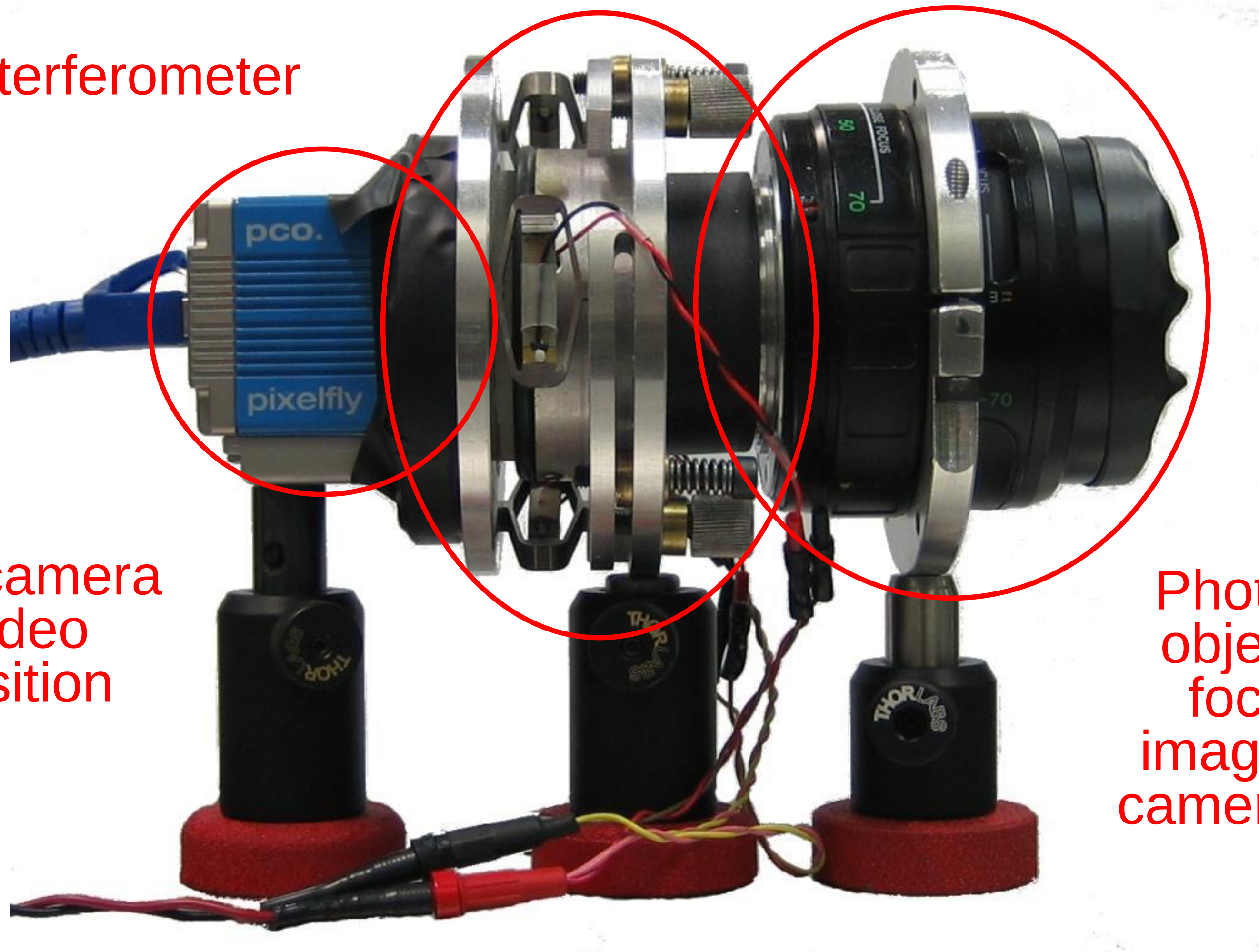
The INRIM imaging spectrometer: a F-P resonator used as a two beams interferometer



- The intensity modulated light signal is captured in a video during the F-P cavity length scanning.
- The cavity length starts fro zero i.e. mirrors in contact
- The spectral composition is calculated by means of a Fourier Transform based algorithm from the interferogram.

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

Hyperspectral device main elements

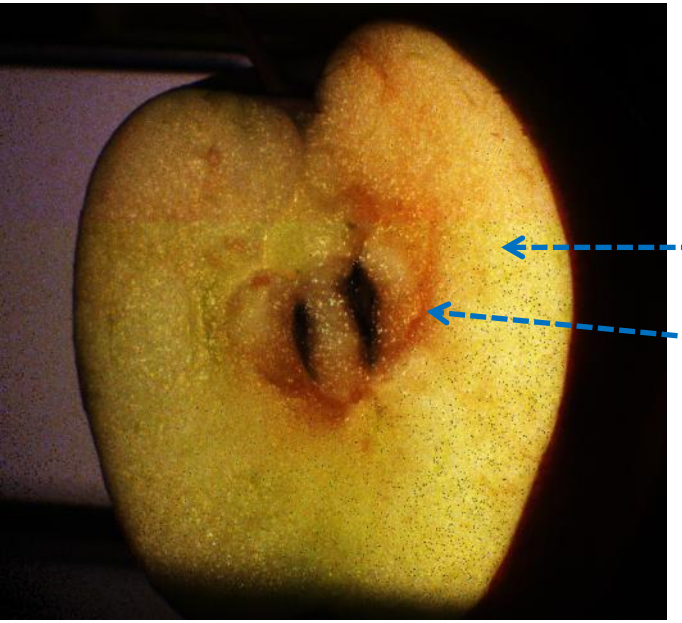


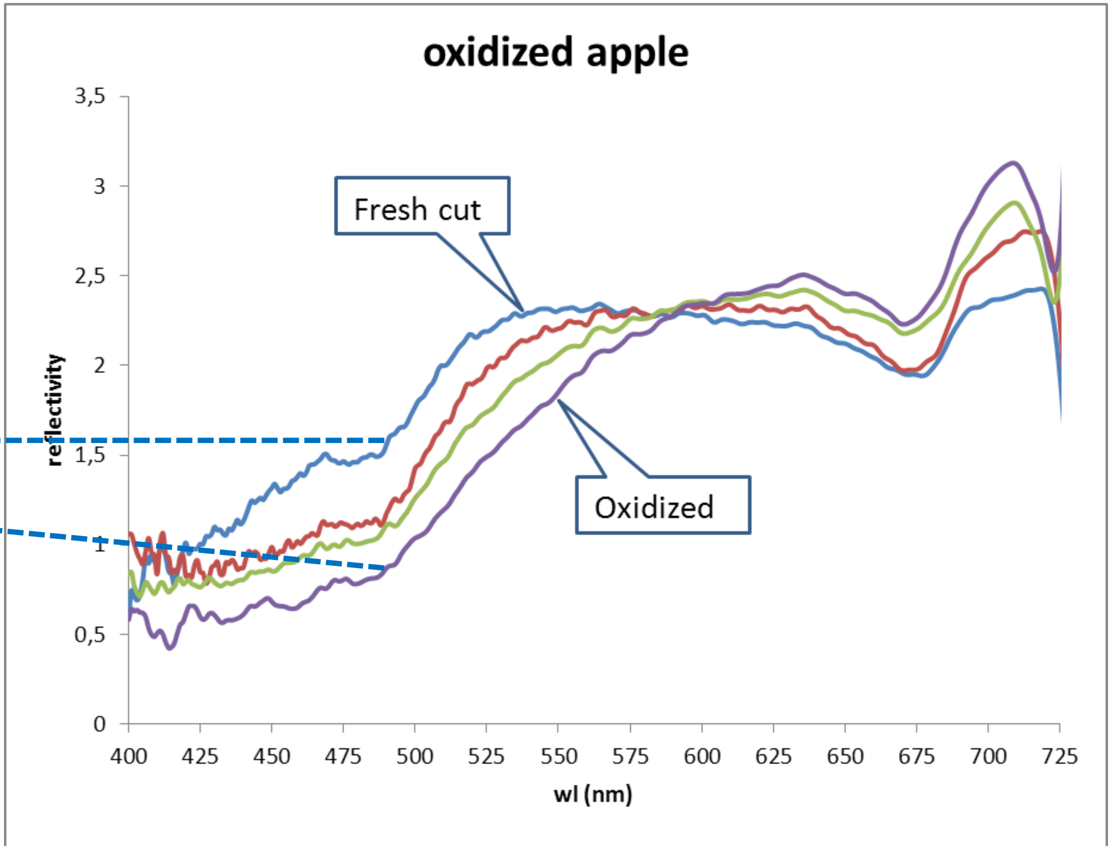
F-P interferometer

Digital camera for video acquisition

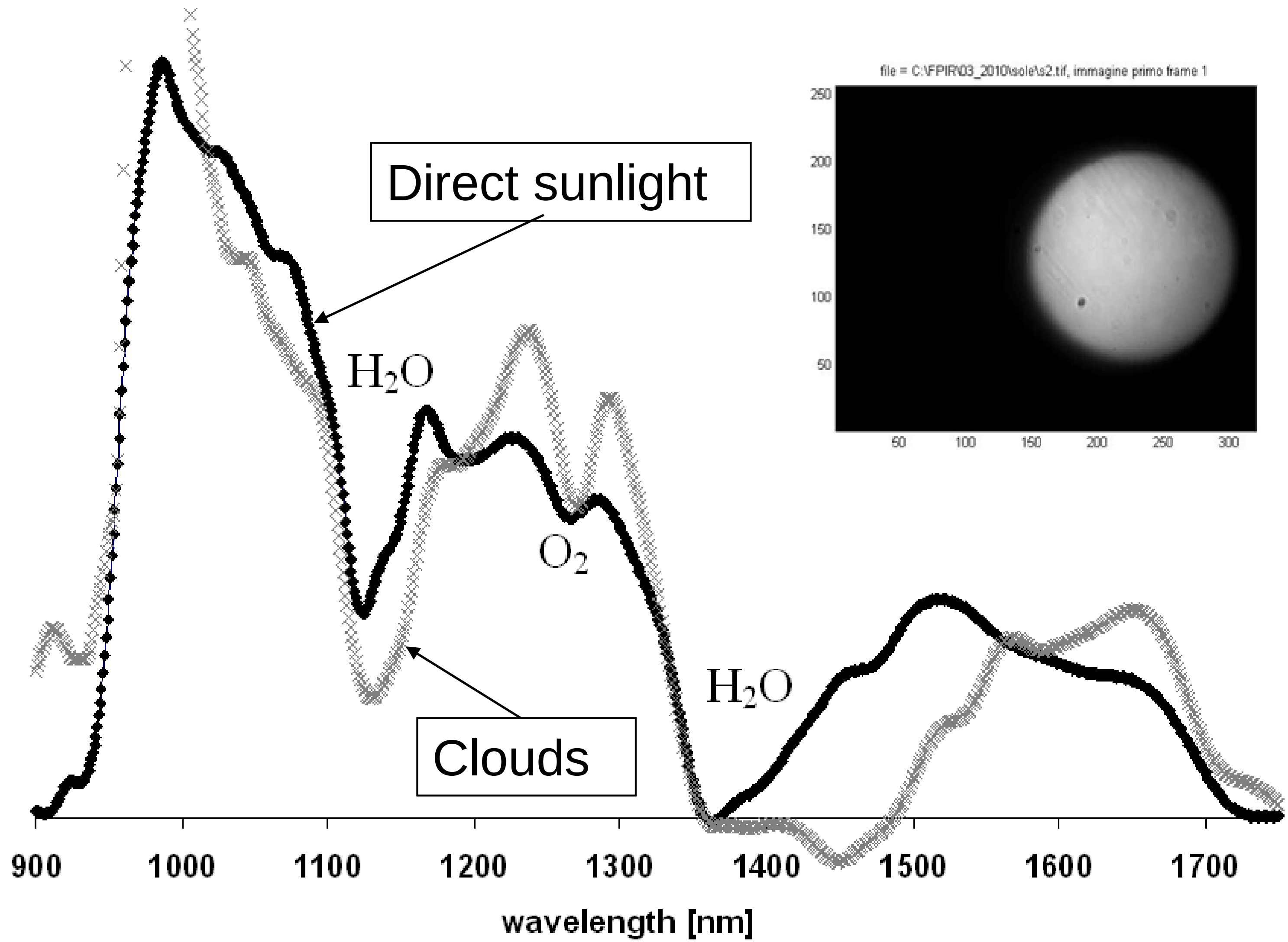
Photogrphic objective to focus the image on the camera sensor

Spectral analysis in the visible range





Spectroscopy in the IR region: Long distance atmospheric absorption



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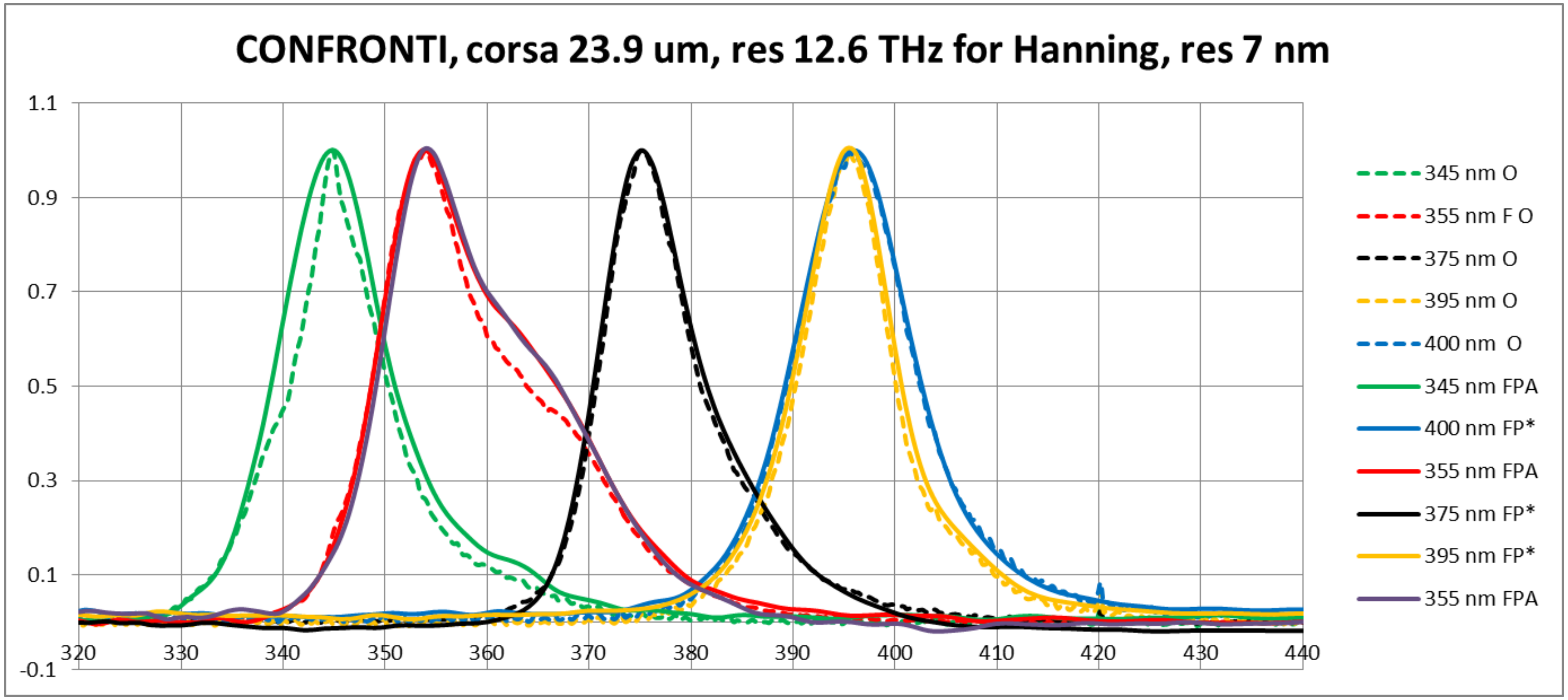
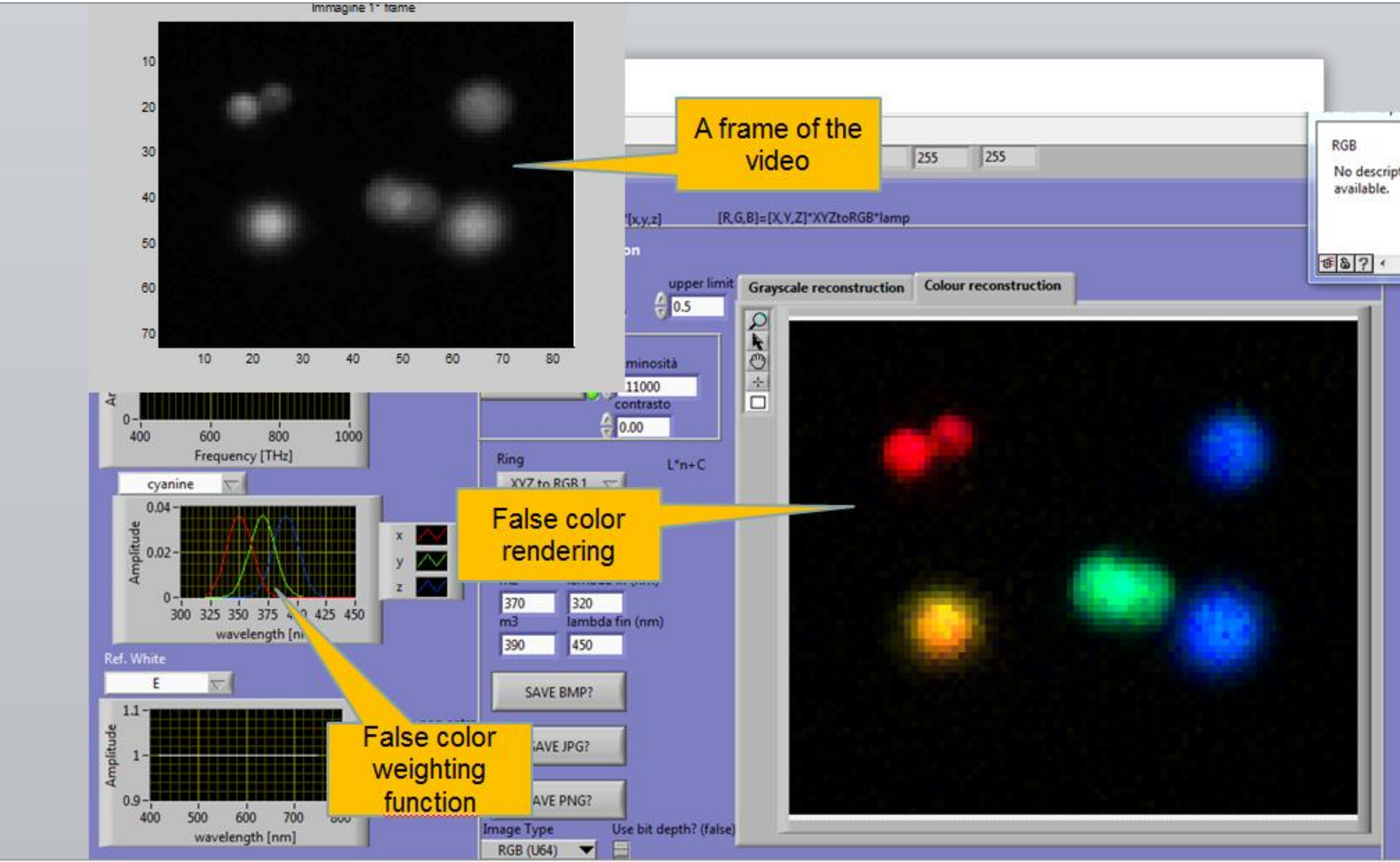
Hyperspectral in the UV

- Difficulties encountered in finding the right substrates for the F-P mirrors and mostly the right coating
- After several attempts we proceeded with our original device made from metal coated glass

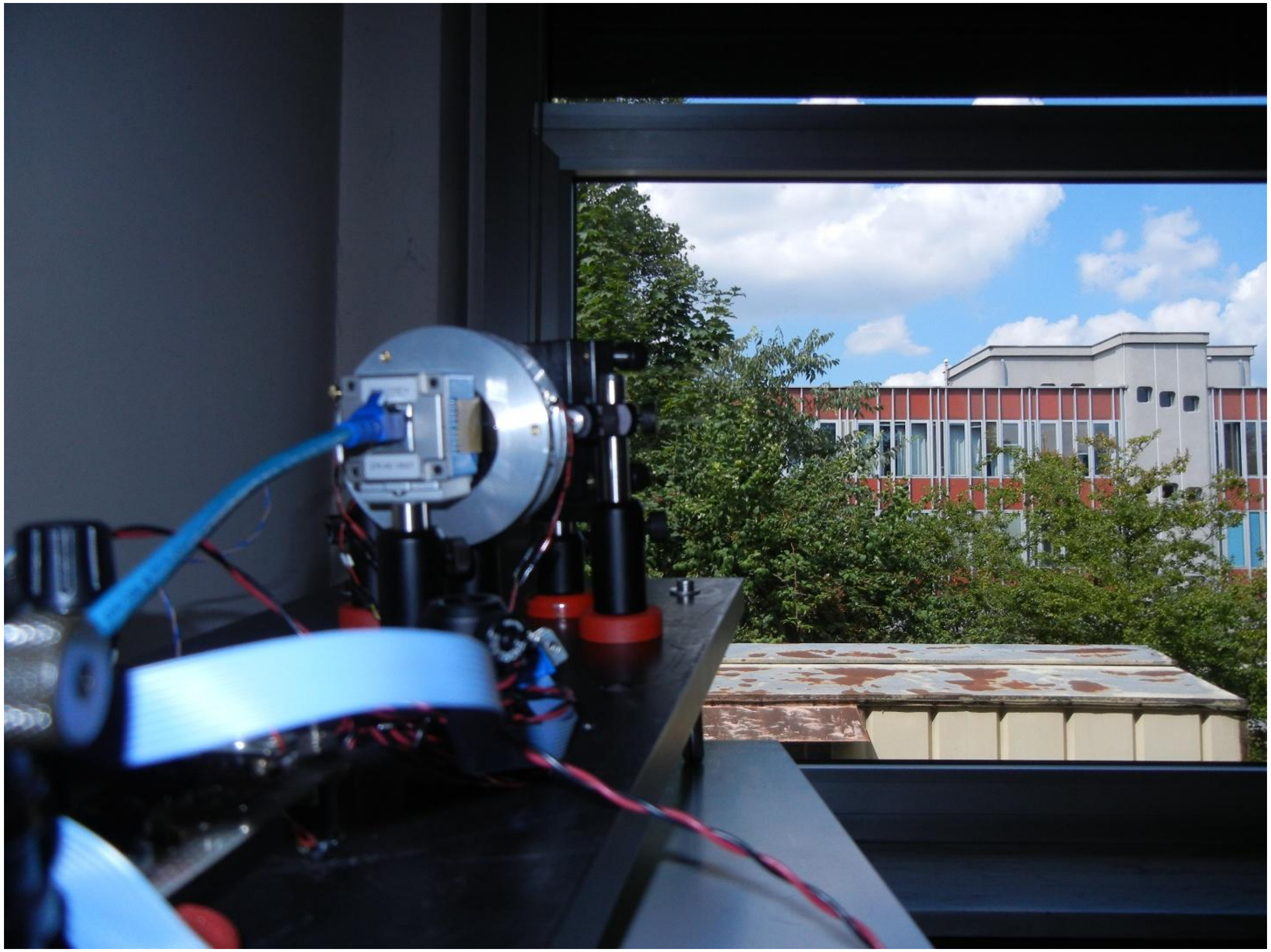
Test with 5 UV LEDs



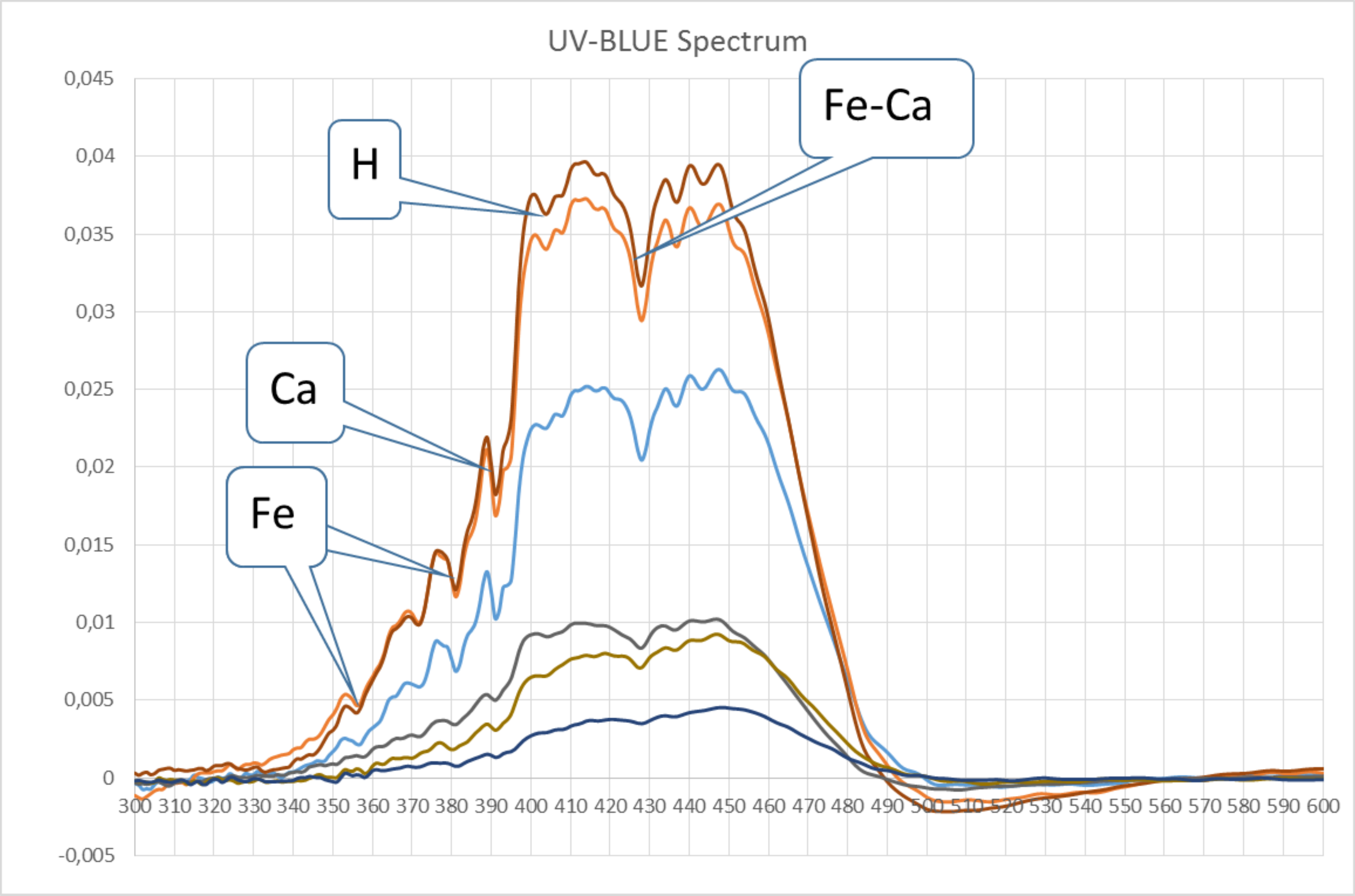
Hyperspectral analysis of LED target



Test with solar spectrum



Test with solar spectrum



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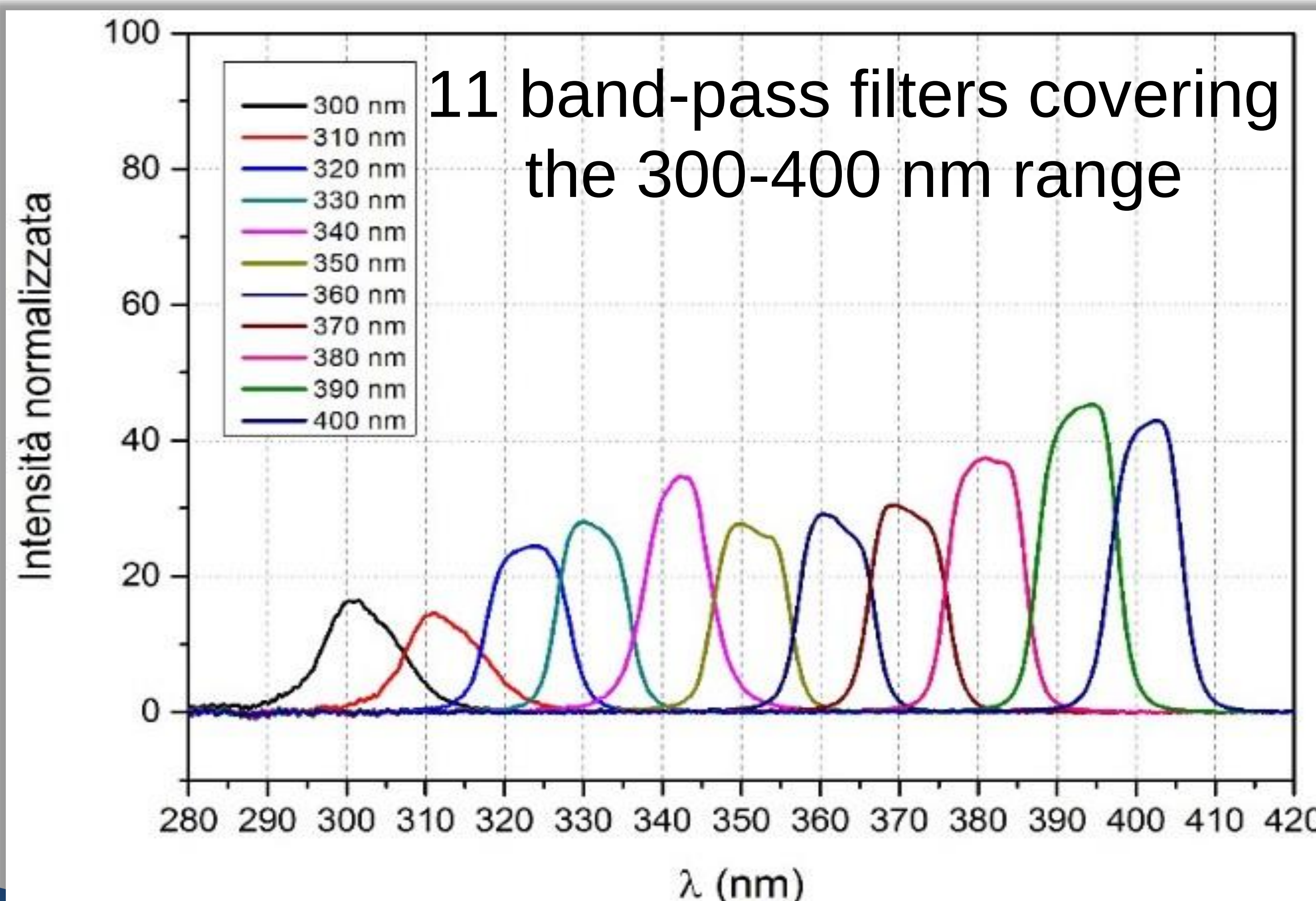
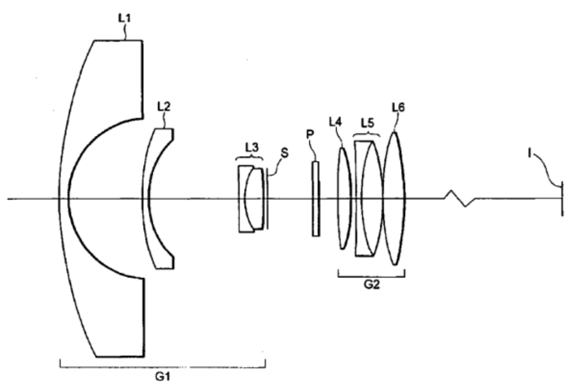
Hyperspectral in the UV

- Difficulties encountered in finding the right substrates for the F-P mirrors and mostly the right coating
- After several attempts we proceeded with our original device
- Preliminary results are good but limited to 320 nm because of the glass substrate

Multispectral solution: safer option



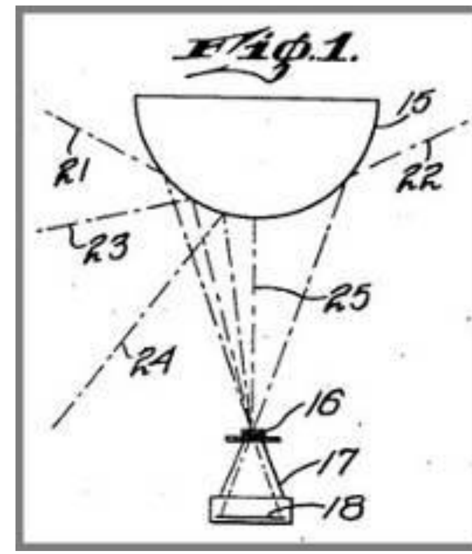
Design of the optical system



- A fisheye objective with good efficiency in the 300-400 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

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

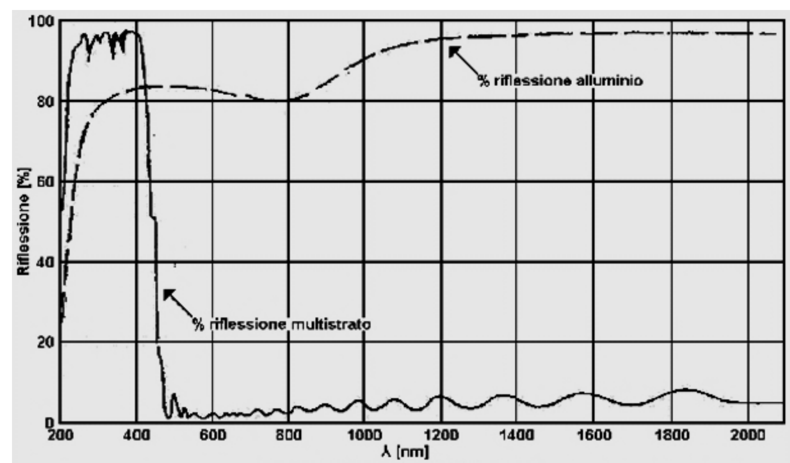


Catadioptric scheme from an early 20th century patent

Realization of the mirror

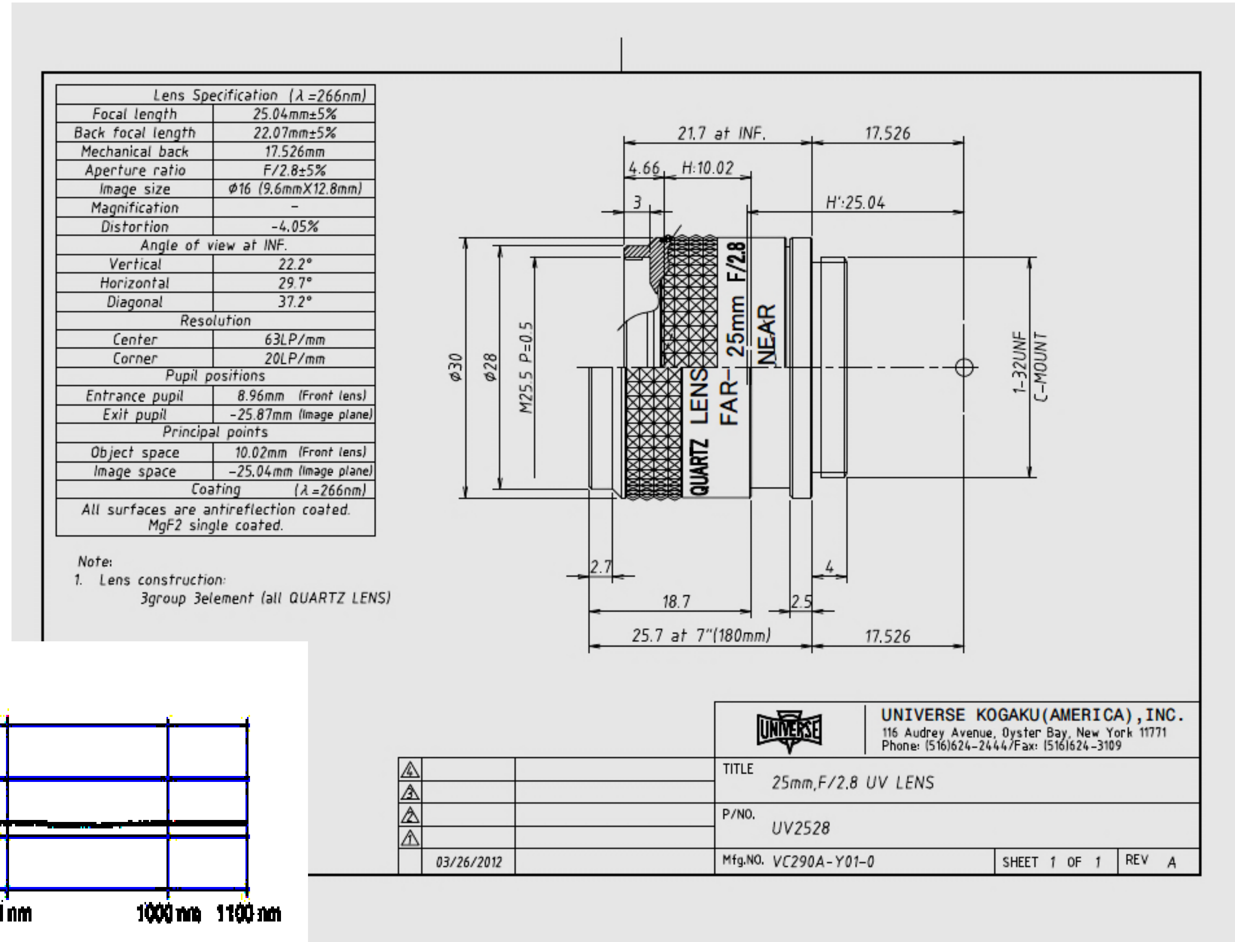
The miror has been realized starting from a glass lens vacuum coated with aluminium protected by a thin layer of SiO_2

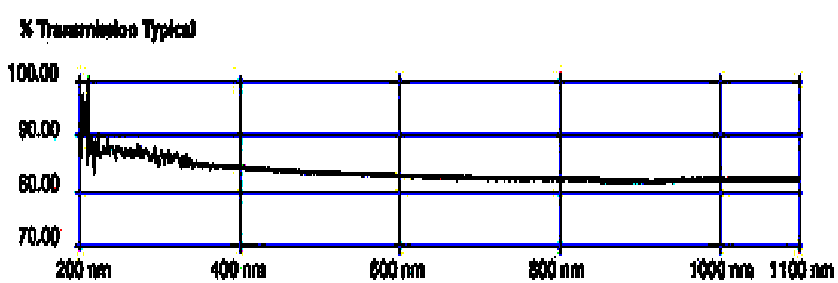
The reflectivity exceeds 80% in the range of interest



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



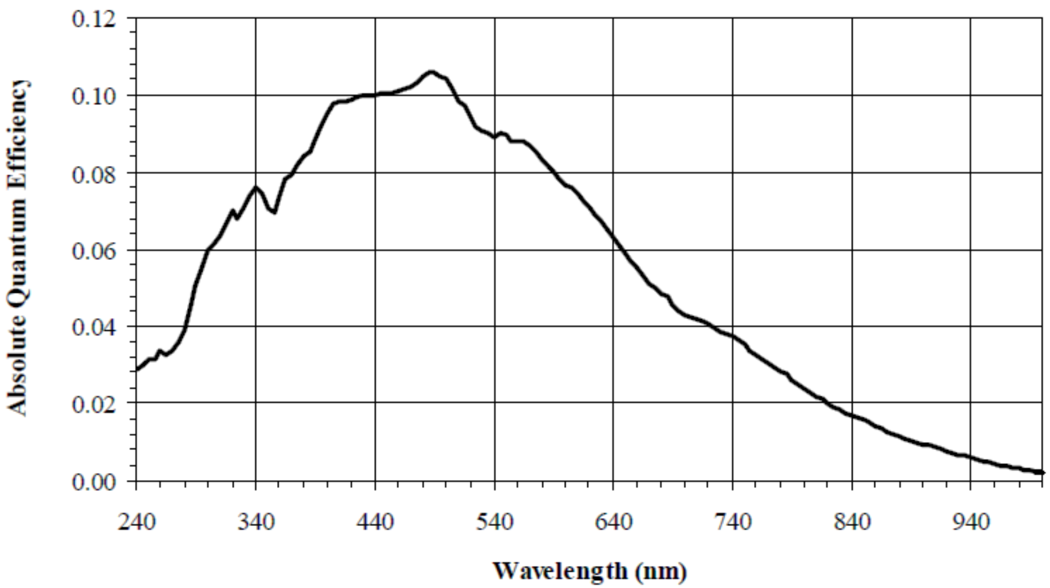


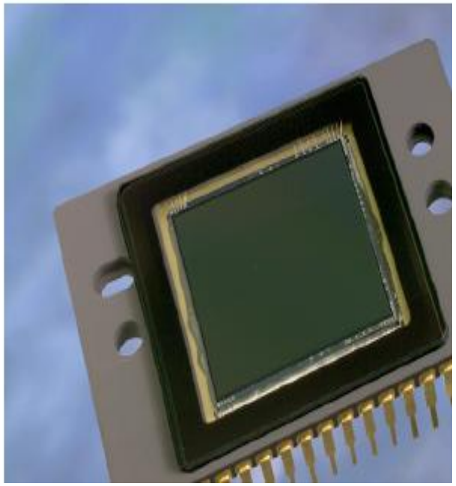
CCD/camera requiriments

- **sufficient absolute quantum efficiency** down to 300 nm;
- **high frame rate** in order to acquire a sufficient number of frames in a small time (in case of hyperspectral imaging).
- **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;

Selected: Kodak KAI 4022 CCD

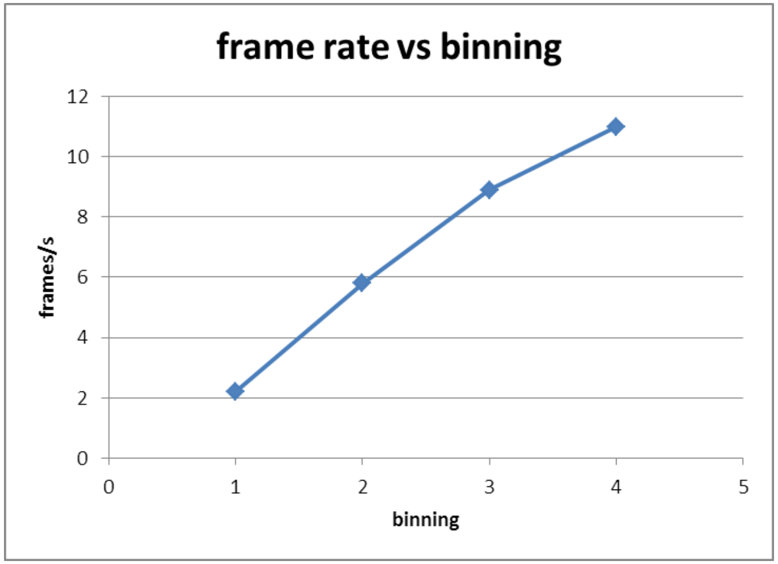
- Scientific CCD with sufficent responsivity in the UV (>5% @ 300nm), good dynamic range (16 bit) and speed, excellent spatial resolution (4 Mpixel)



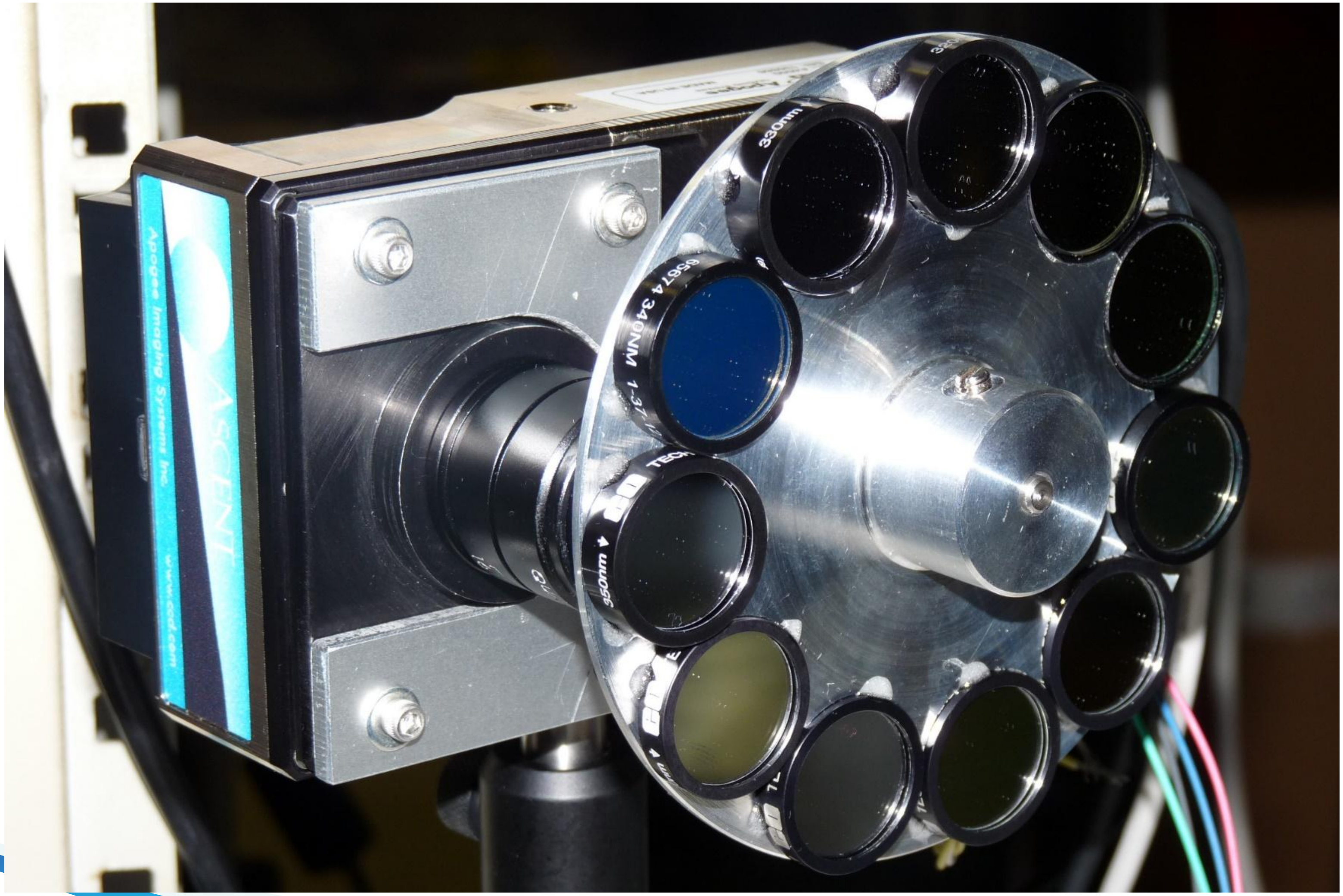


Ascent 4000 camera

- Kodak sensor (version without microlenses) is integrated in the Ascent 4000 camera with dual 16 bit ADCs. Compact and cooled



Building a compact filter wheel



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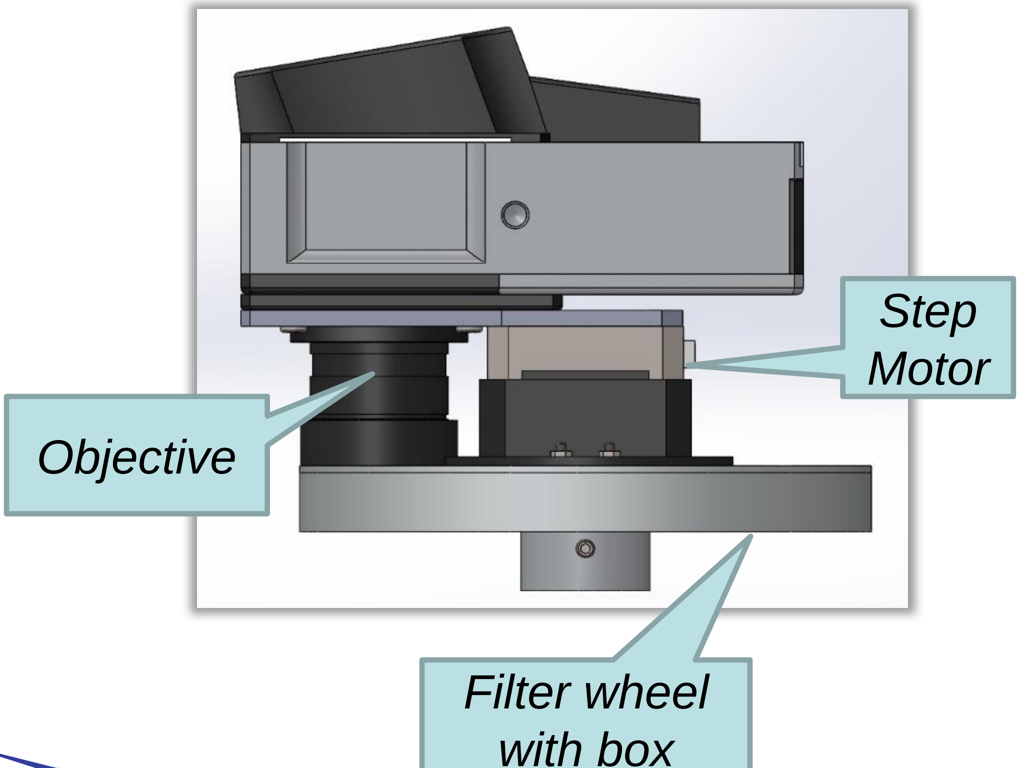
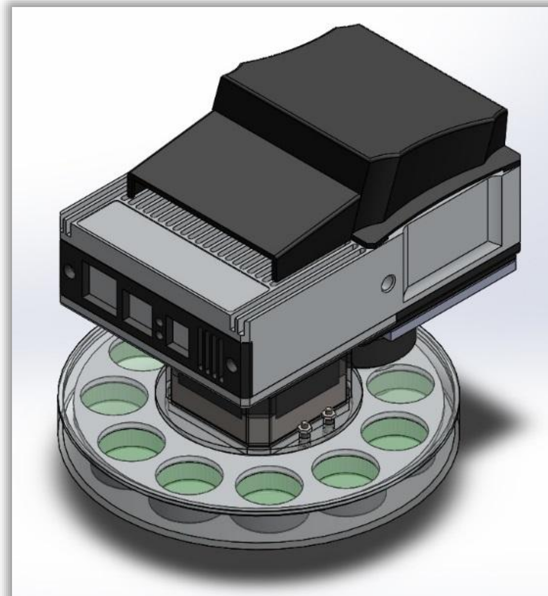
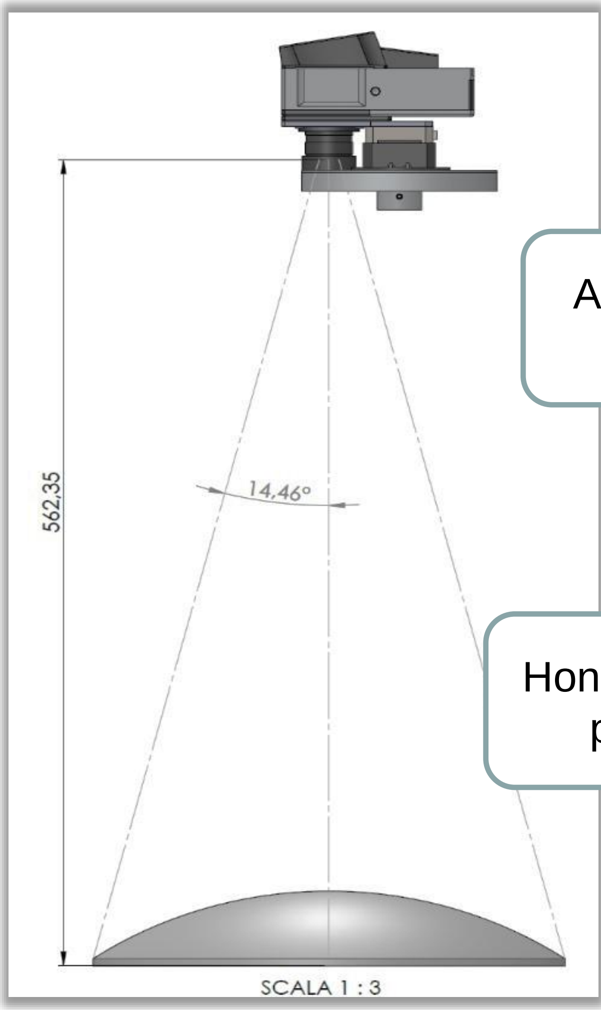
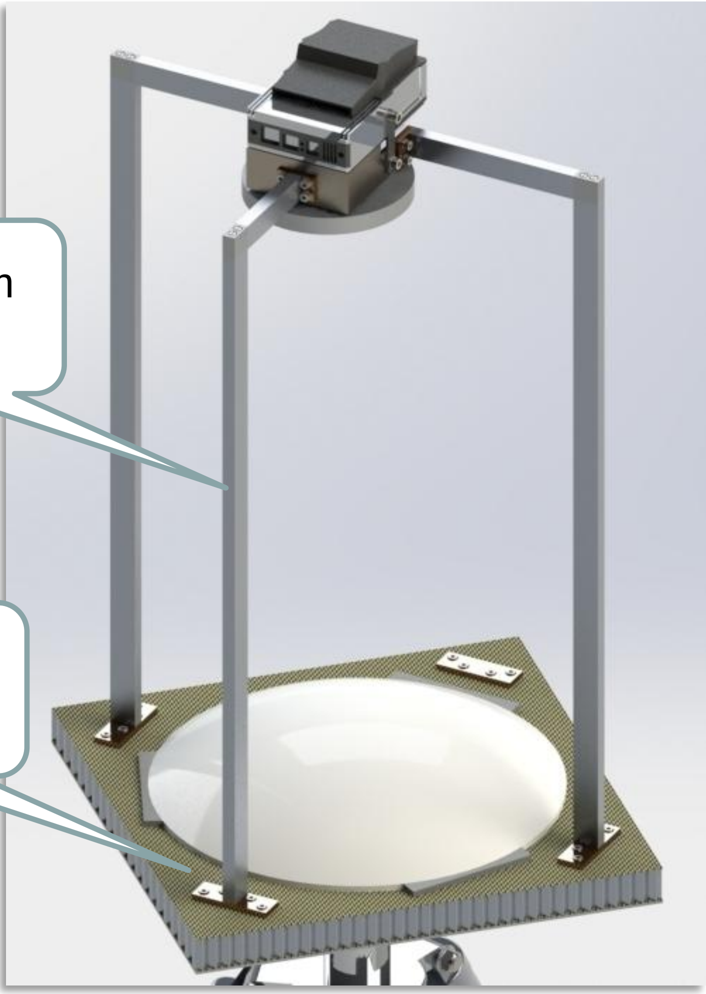
Integration of the filter wheel





Assembled system



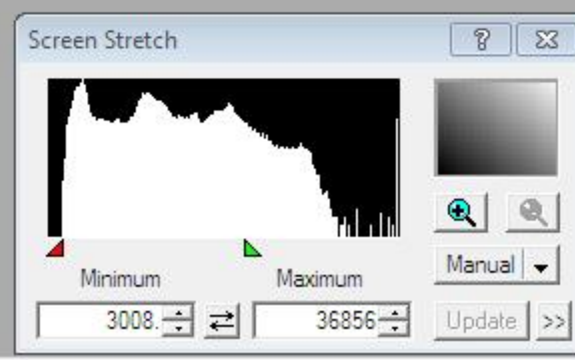


Resolution and sensitivity test

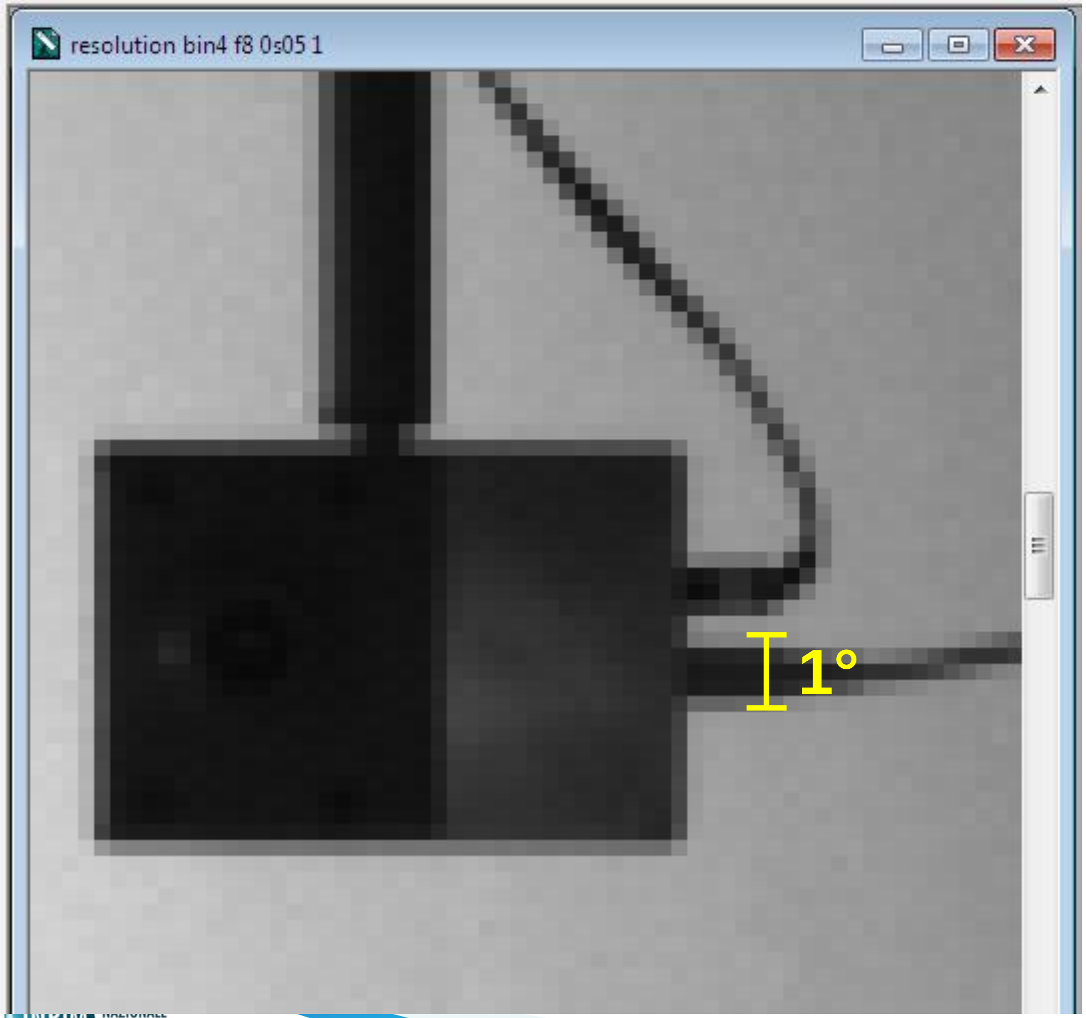
Camera set:

4x4 binning = 512x512 pixel image

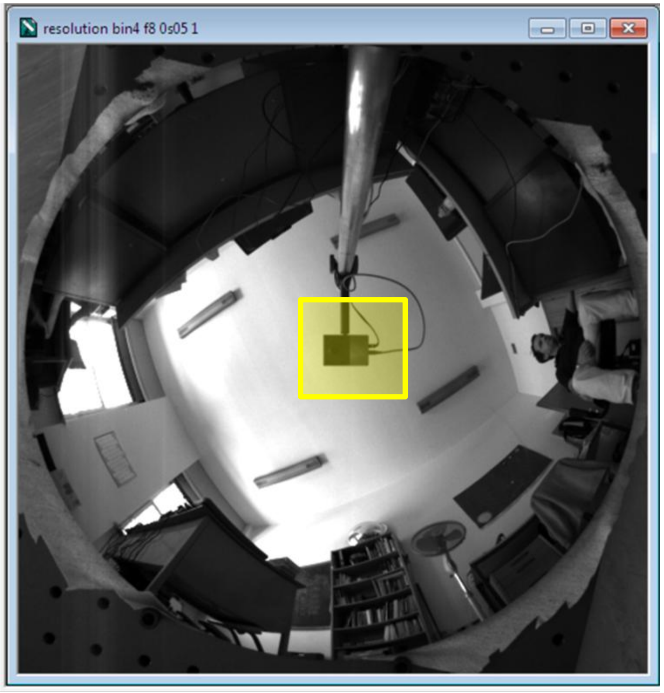
Objective aperture f=8



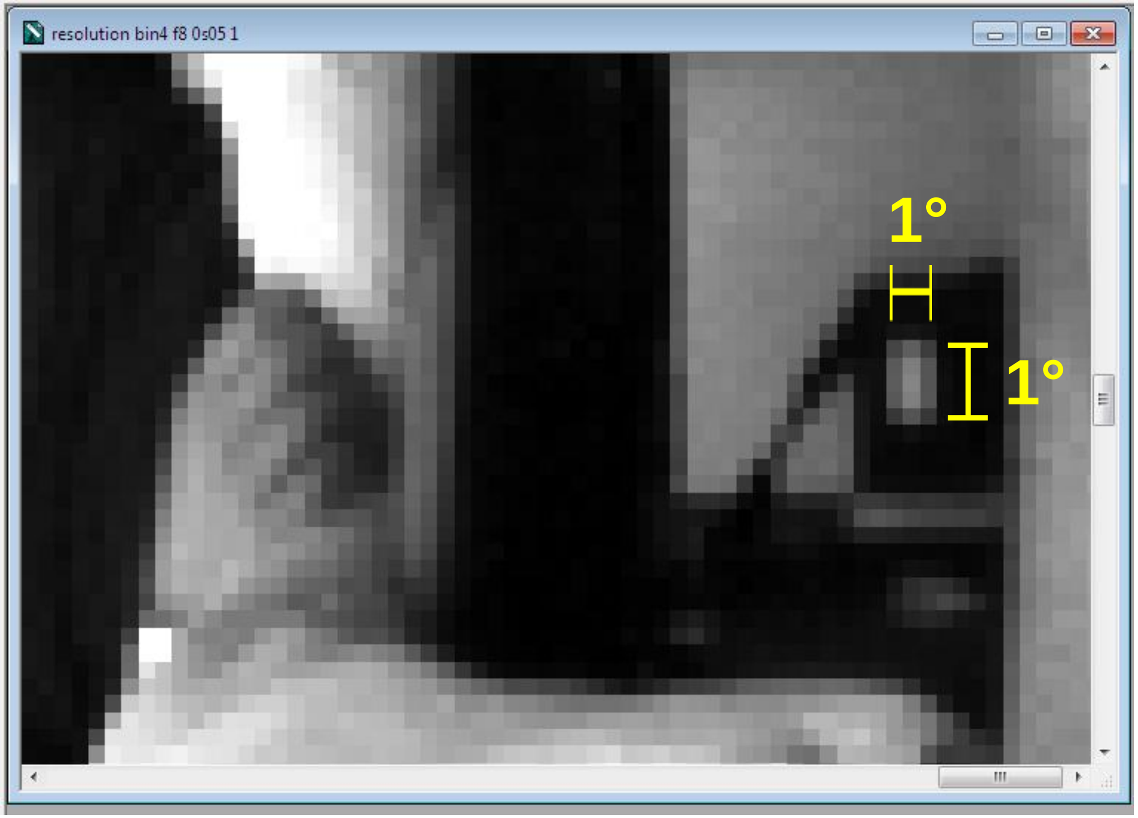
Resolution at zenith



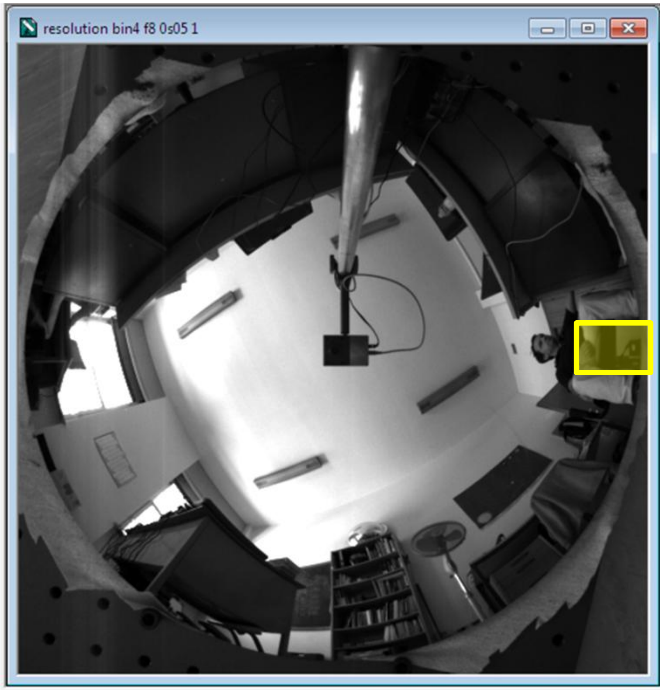
- Angular resolution << 1°
- Angular sensitivity
  ≈ 4.4 pixel/deg



Resolution close to the horizon



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



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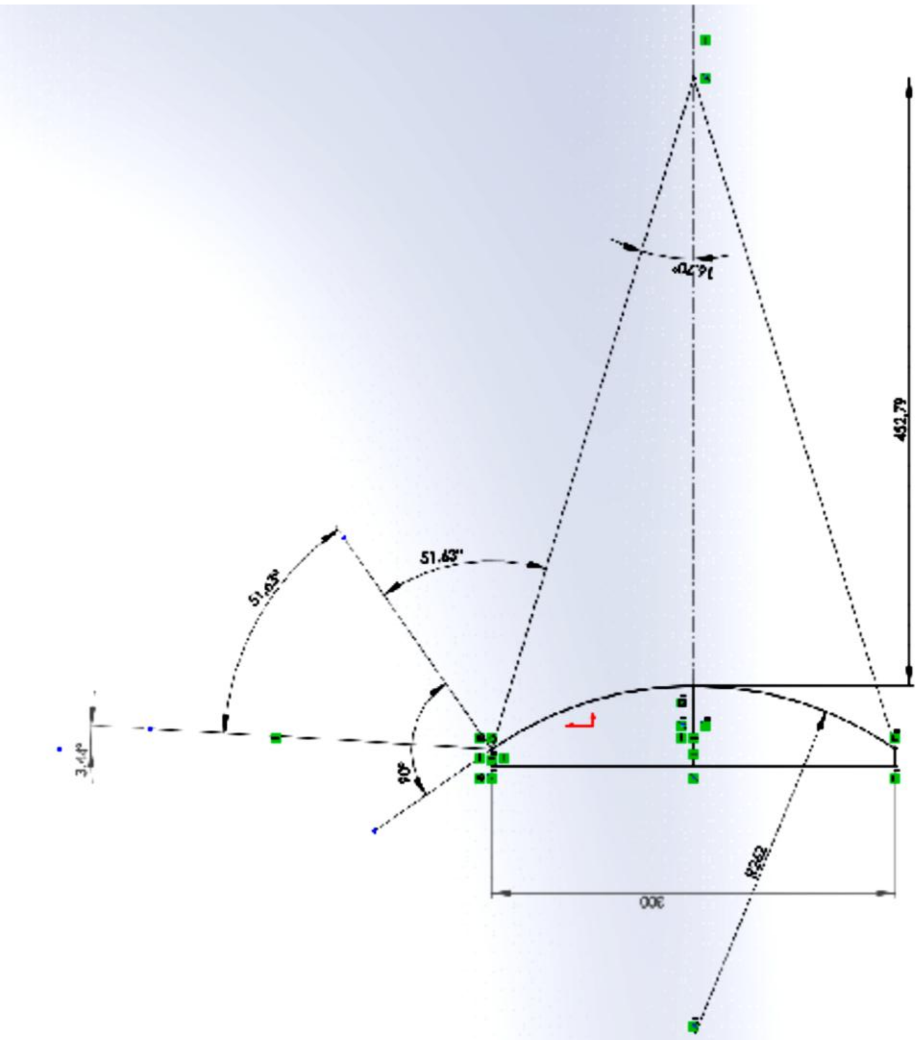
Angle of view

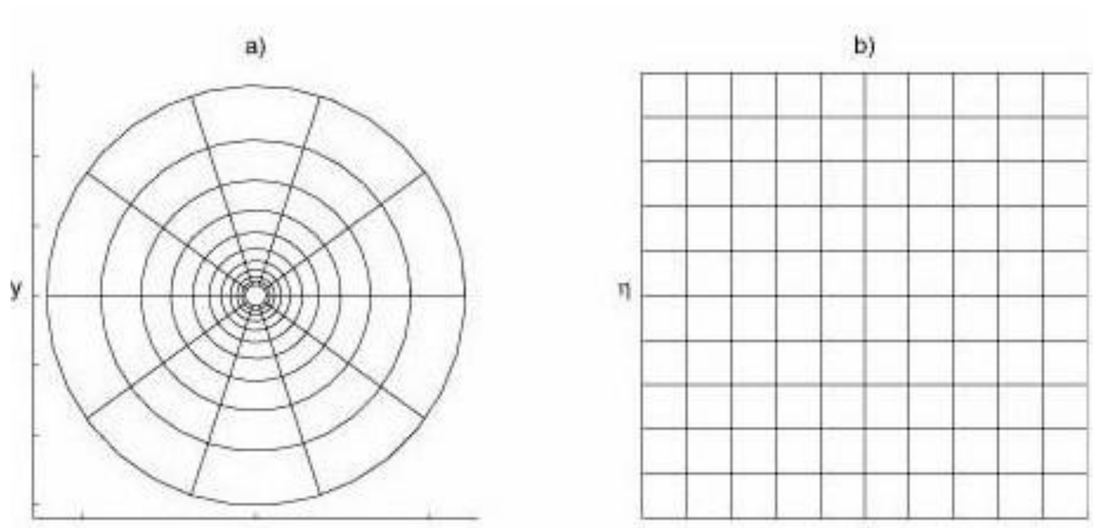
The angle of view has been evaluated theoretically and verified experimentally. Sky coverage exceeds ± 80° as required.



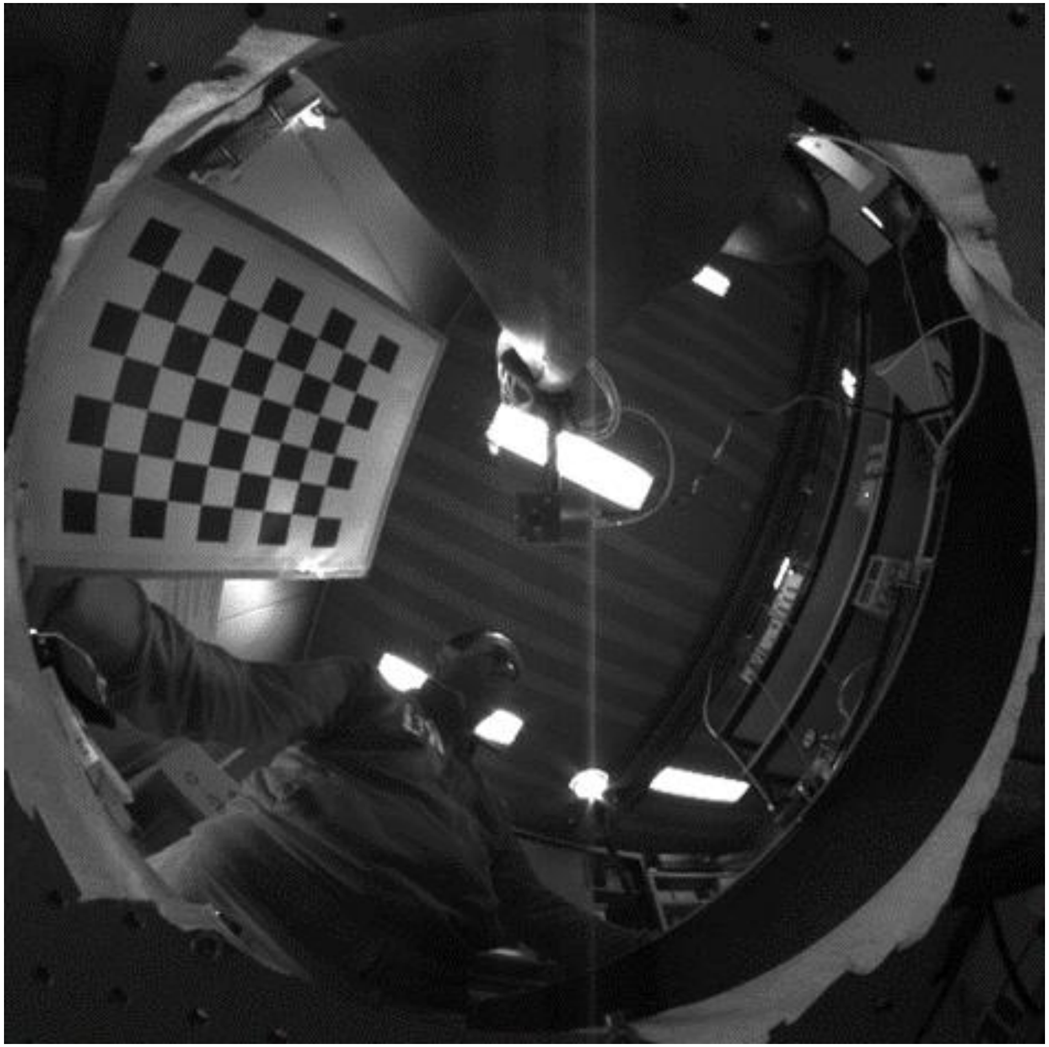
Edge of the mirror ≈ 6.5° above the horizon

Resolution and mapping

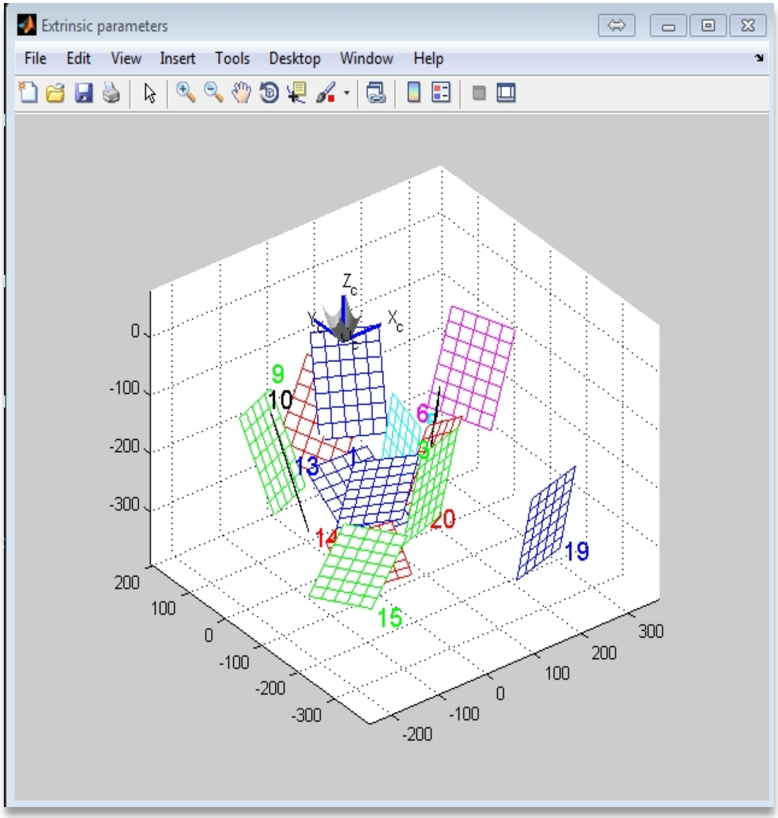
- With 4x4 binning the resolution exceeds 2pix/deg (worst case), the image dimension is 512x512x16bit
- A complete mapping of the angular coordinate of each pixel must be obtained experimentally

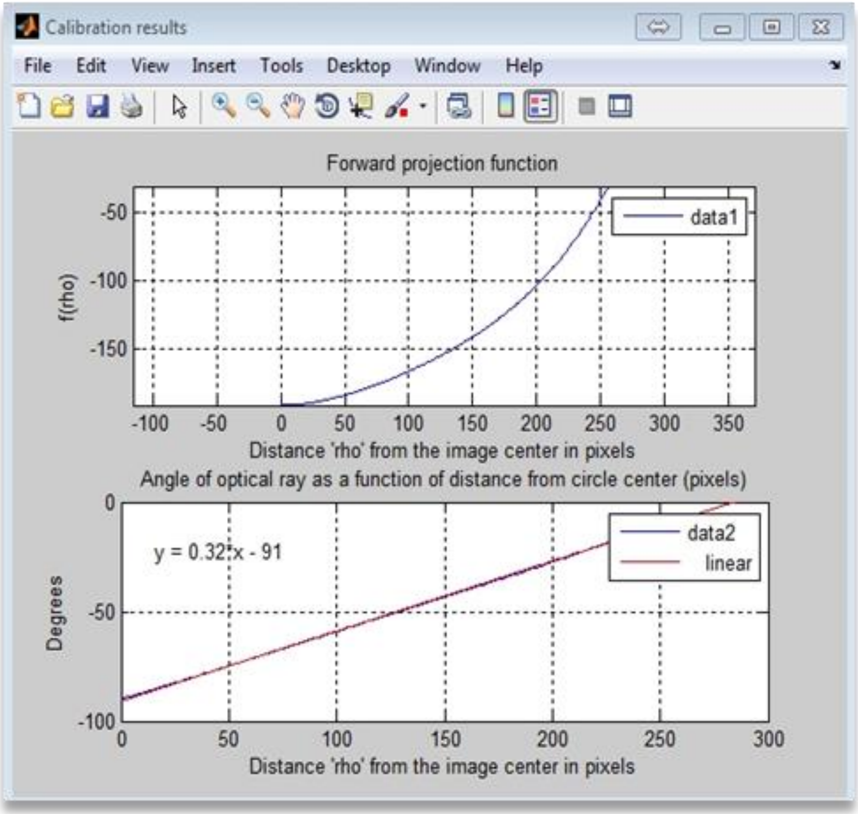


Angle-Pixel calibration



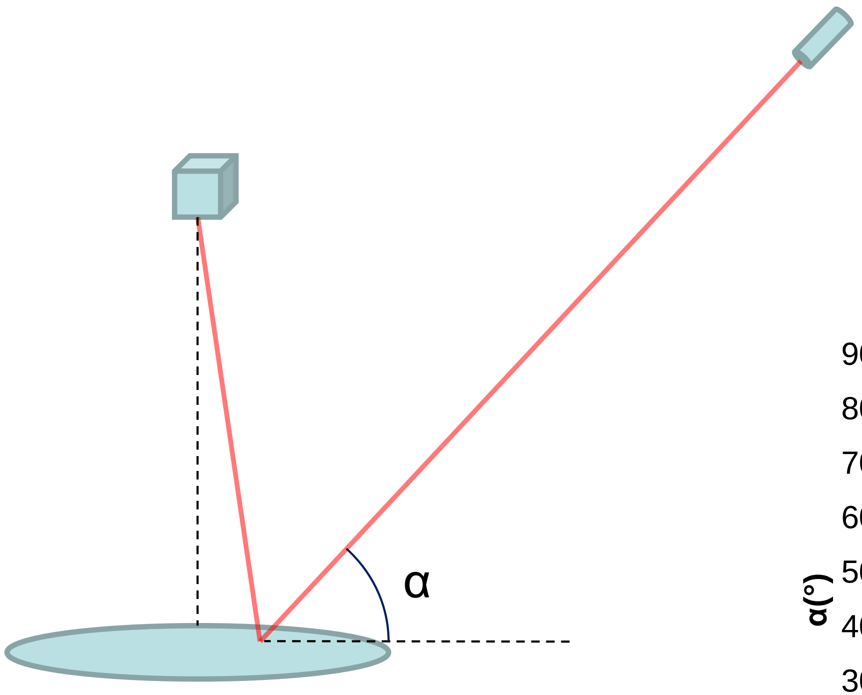
Method to calibrate Central Catadioptric Systems

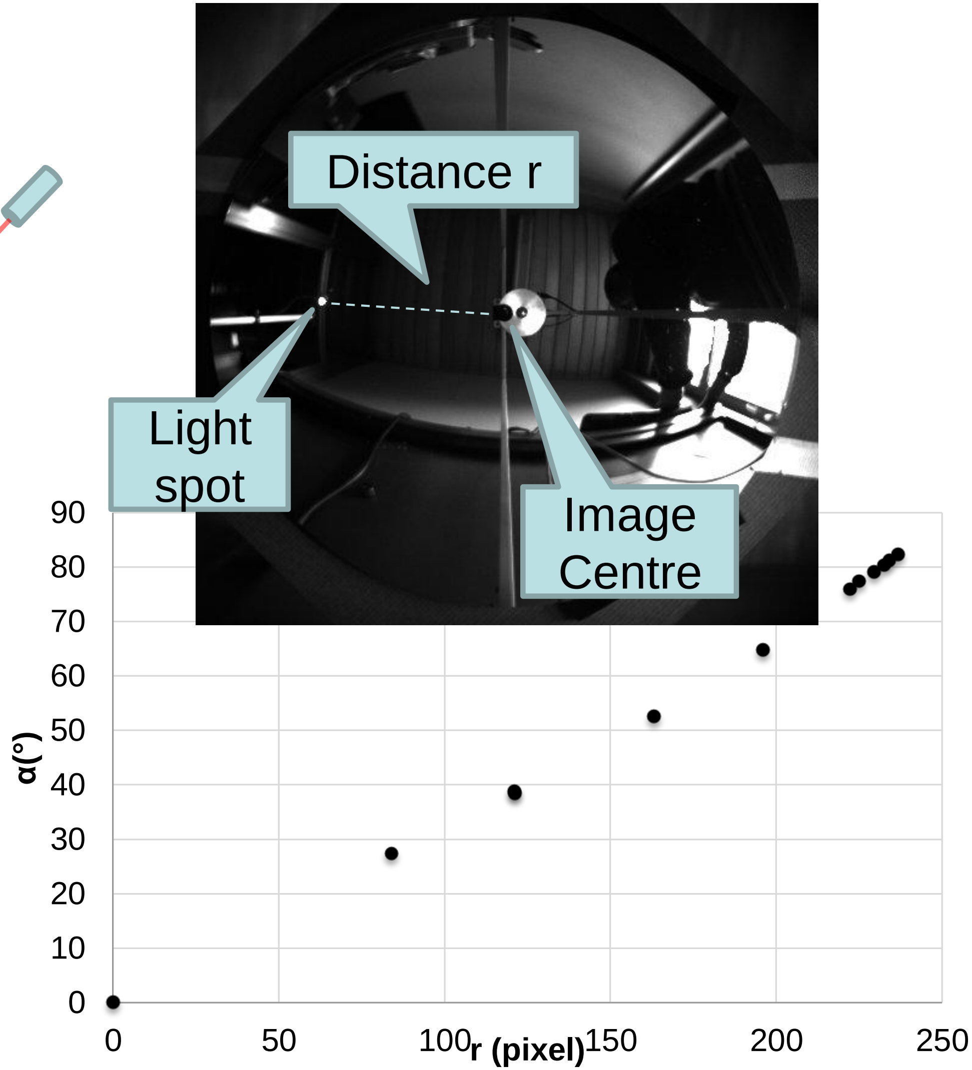




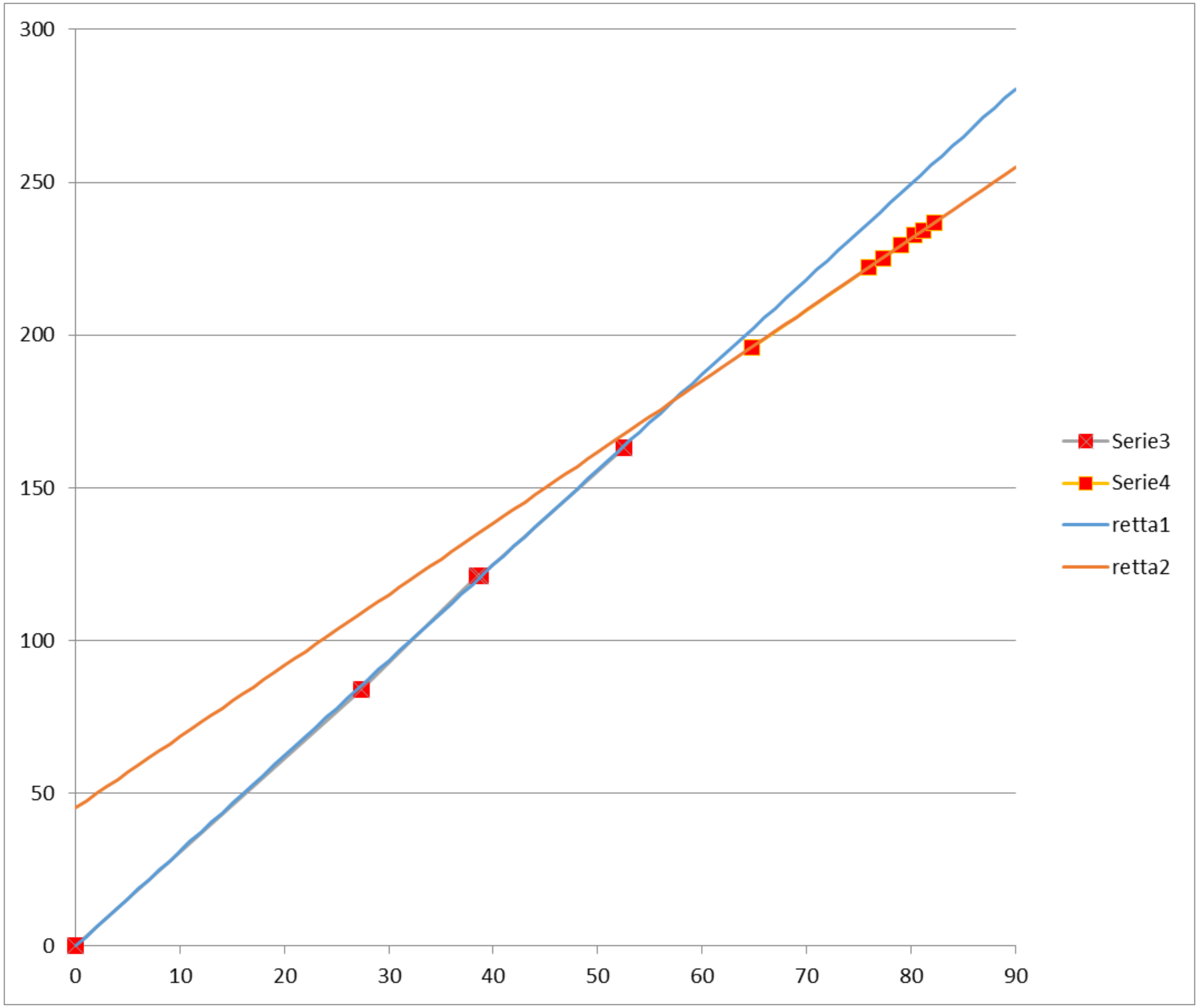
http://www-sop.inria.fr/icare/personnel/Christopher.Mei

Calibration using a laser



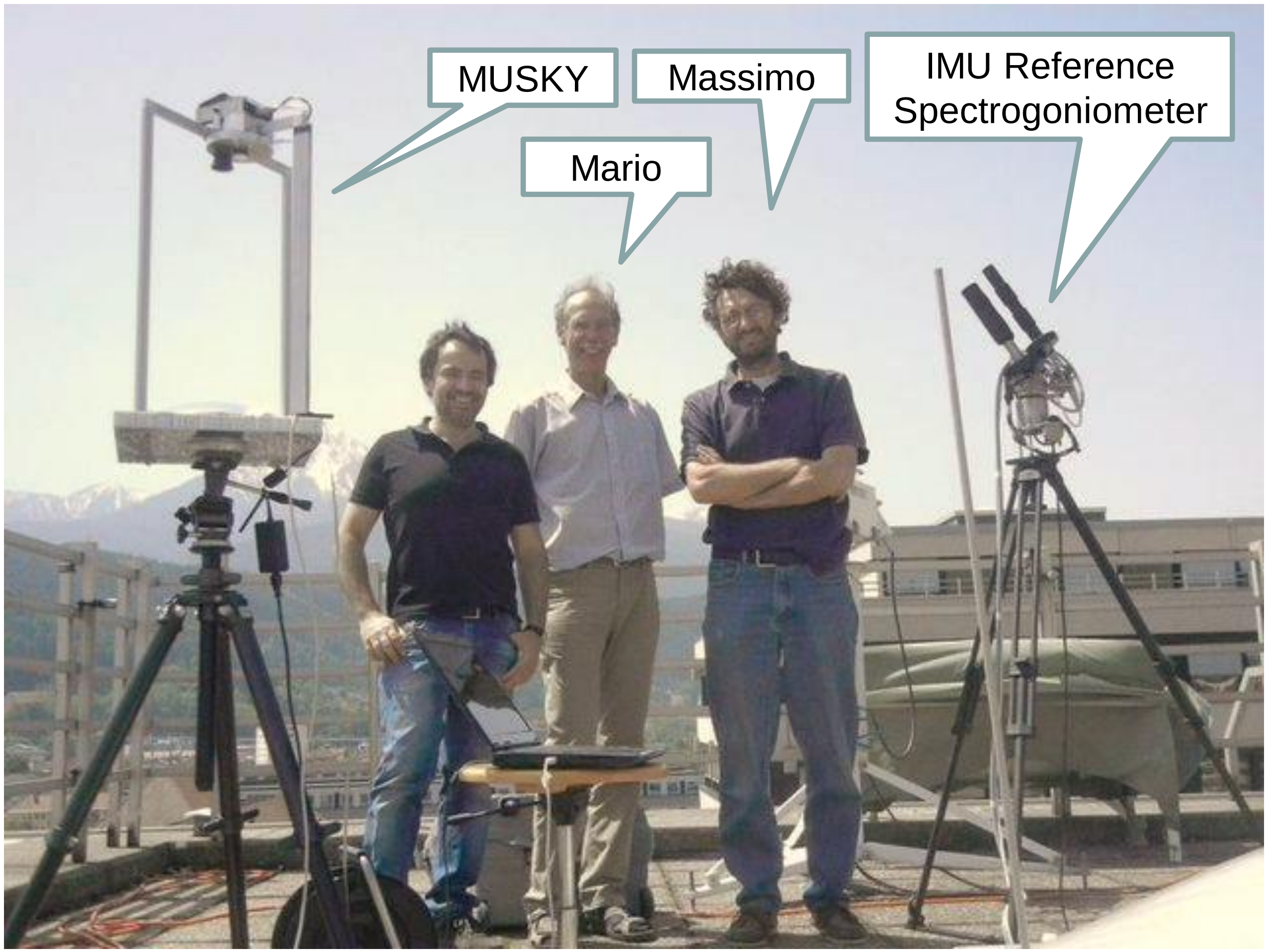


Zenith Angle-Pixel calibration



UVNet Workshop, Davos 16 July 2014

Responsivity calibration at IMU



Calibration at IMU (with strong wind!)

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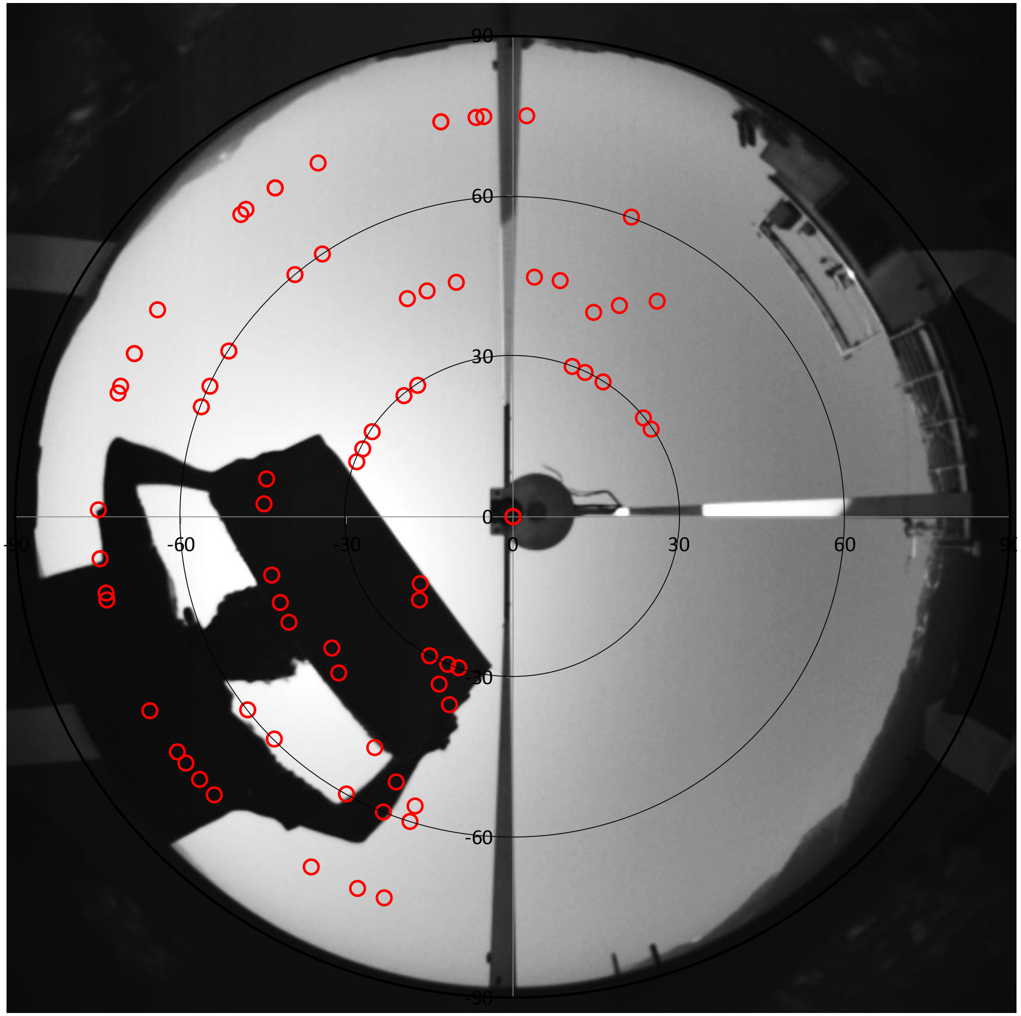
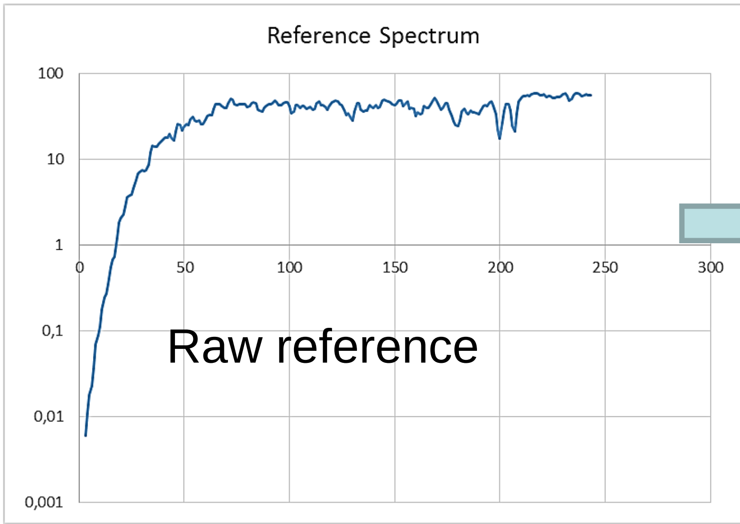
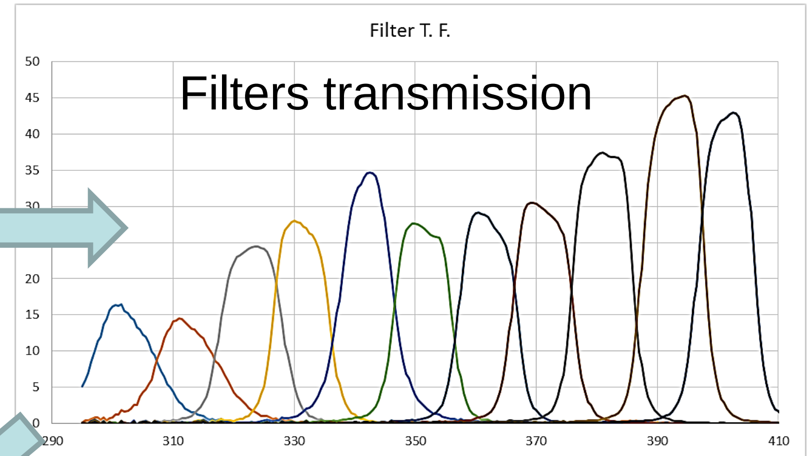
Calibration Procedure

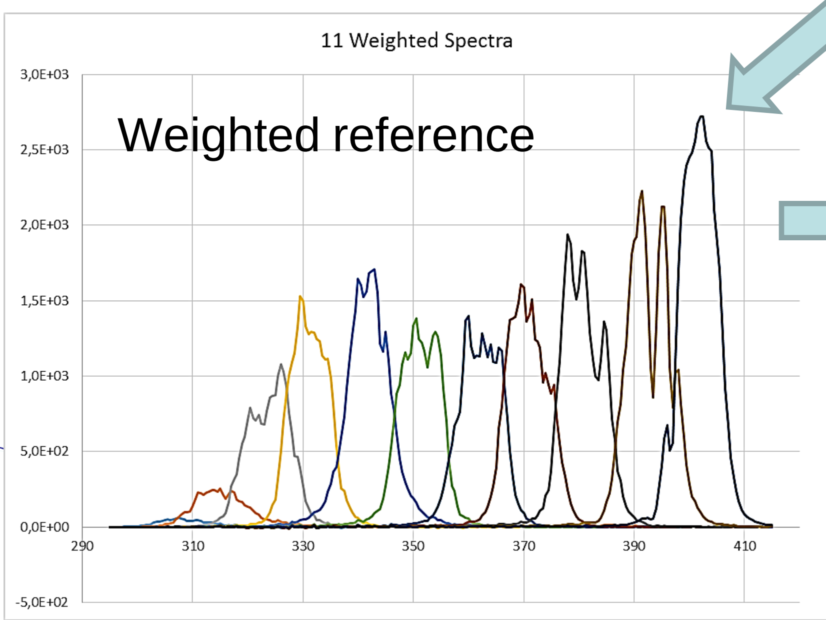
- We have compared the reference specta with the spectra from Musky image taken in the same coordinate at about the same time

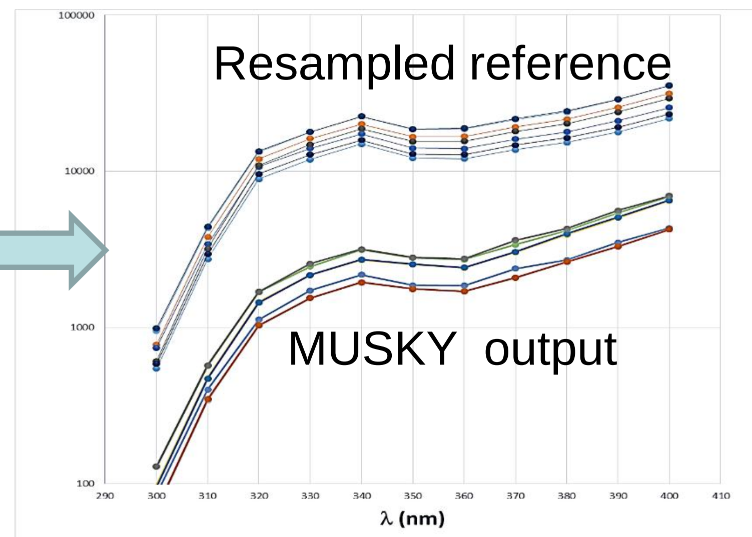


Calibration Procedure









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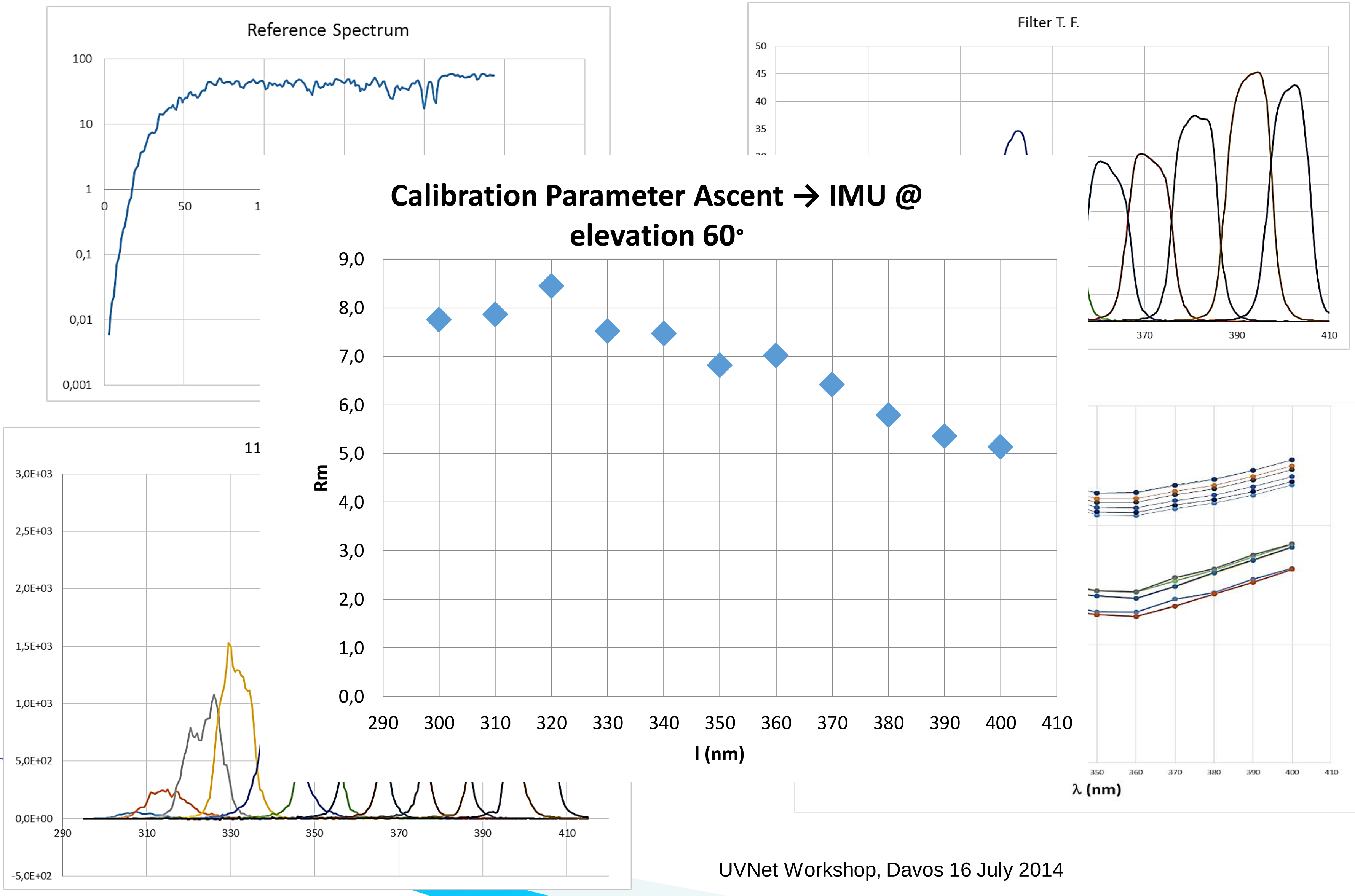
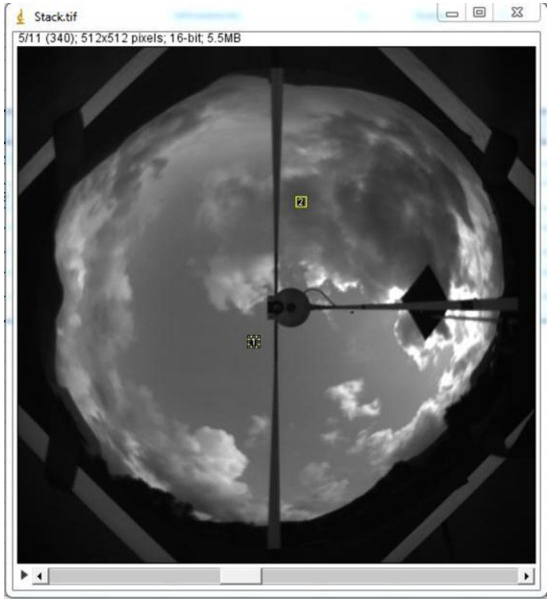
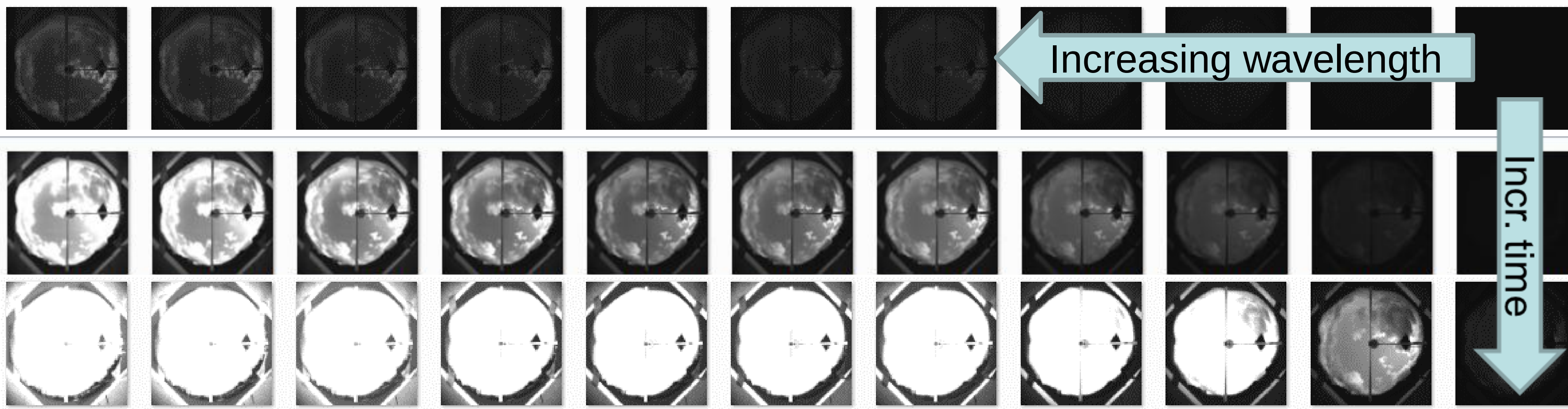
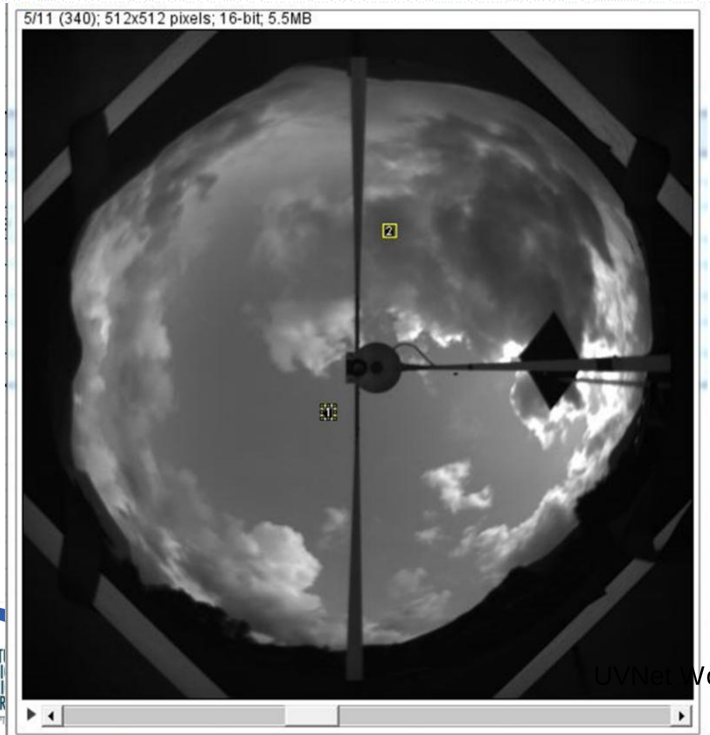


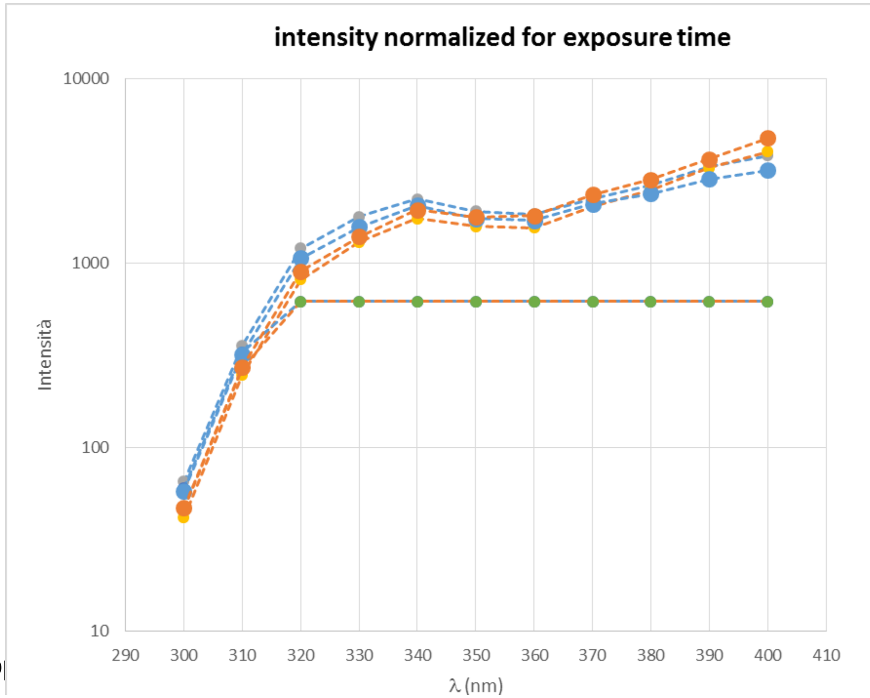
Sky measurements in Davos



Sky measurements in Davos

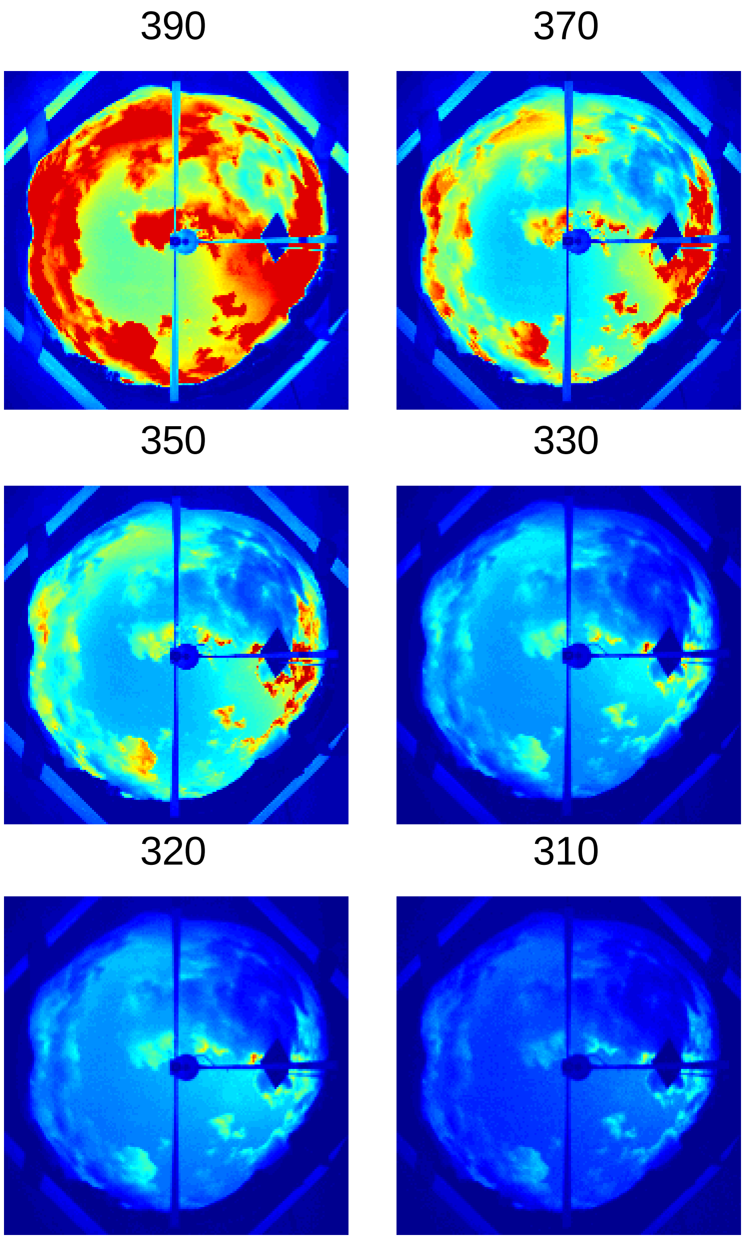




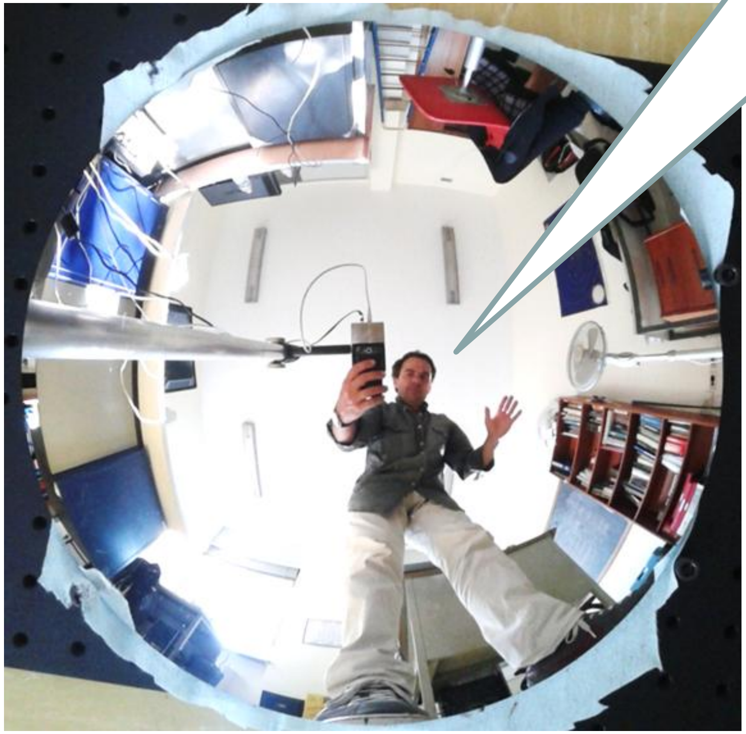


Conclusions

- A Multispectral Fish-eye camera in the UV has been built and tested
- Spectral resolution: 11 bands in the 300-400 nm range
- Angular resolution < 1° up to 83° Zenith angle
- An UV Hyperspectral device has been realized obtaining good preliminary results



Thank you!



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