A proposal for the development of an integrated visible and UV CMOS detector polarimeter based on a nano-WGP

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Polarimetry applications

Imaging polarimetry is dedicated to mapping the state of polarization across a scene of interest.

Two possible scenarios:

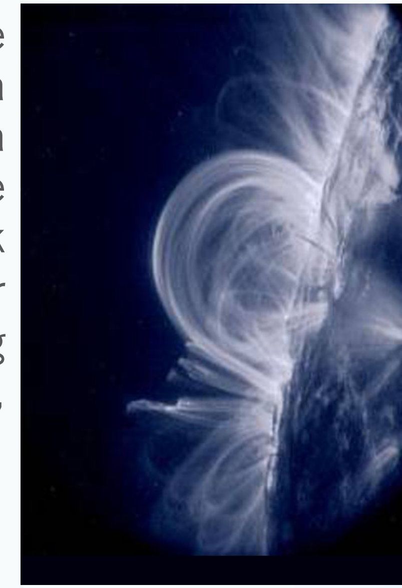
① there is a difference between the polarization properties of light coming from the background and the light coming from a target. In such cases, significant **contrast enhancement** can be obtained.

② The process that we are interested in studying emits polarized radiation

Polarizing imagers have shown applicability in a number of research fields:

- they are widely used in mitigating the effects of **random media**.
- in **robotics** as autonomous agent navigation using the variations in the degree of skylight polarization
- **medicine** as skin cancer detection tool.
- Polarization is greatly diffused in **lidar** remote sensing where it is used, for example, to determine:
  - characteristics of clouds and atmosphere (presence of ice in clouds or non-spherically shaped dust particles).
  - backscattered light in studies of forests and Earth-surface properties
  - detection of fishes.

Polarimetry in Astronomy



Solar Physics:. the spectropolarimetry is the only tool that enables the study of the magnetic field from the photosphere to the hot corona through the Hanle and the Zeeman effect. The *magnetic field* plays a fundamental role in basically all the physical phenomena that are observed in the chromosphere, transition region and corona. The lack of reliable measurements of the magnetic field vector in the outer solar atmosphere represents one of the most serious limitations in solving basic but enduring problems in solar physics, such as *coronal heating*, triggering *of coronal mass ejections* (CMEs), *and solar wind acceleration*.

Exoplanets - Polarimetry is also a powerful differential technique for future investigations of scattered light from extrasolar planets The huge variety of polarimetric properties observed on the solar system bodies suggests that polarimetry will play an important role for the incoming *characterization* of extrasolar planets.

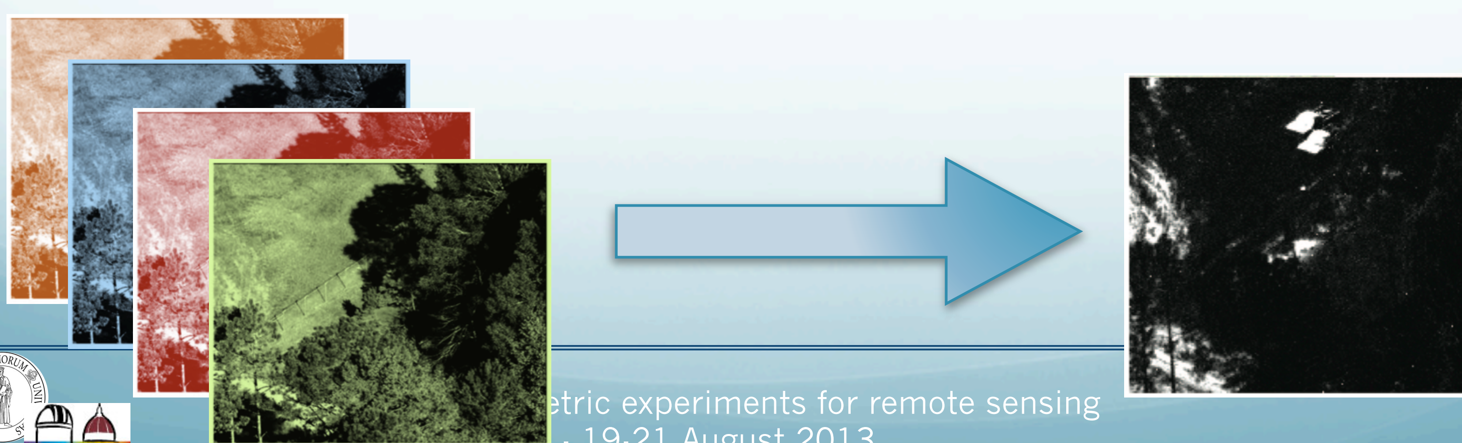
Observing methods

The polarization state of radiation is represented in terms of the Stokes vector (I, Q, U, V).

Multiple information are required to even partially characterize the polarization state of a scene.

Traditional methods collect these data acquiring multiple frames:

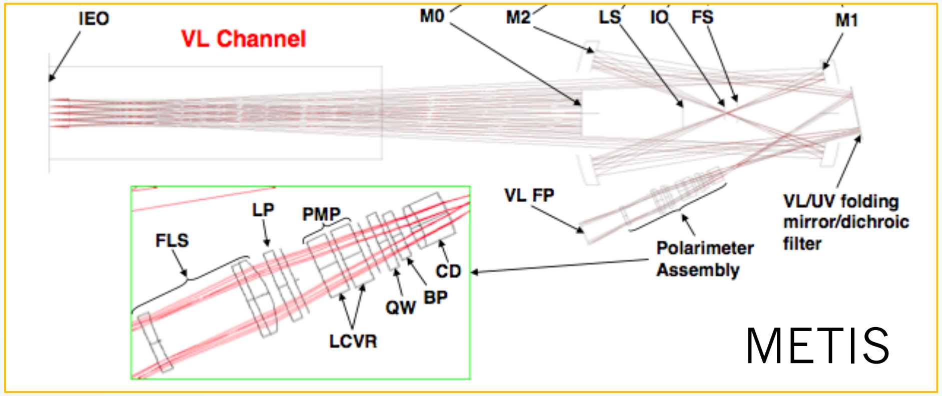
- simultaneously by using separate cameras
- sequentially with a single detector.

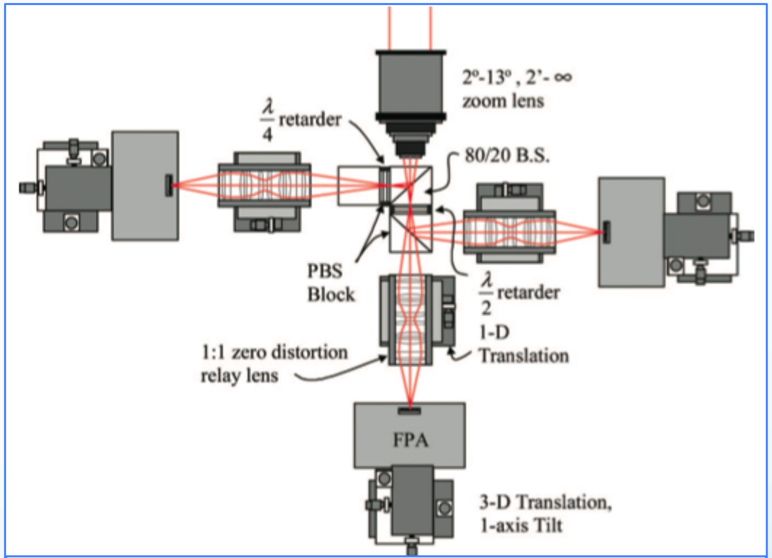


Observing methods

Sequential Acquisition

Any motion of the scene or spatial mismatch in the pixel results in artifacts that have the potential to mask the true polarization signature.





C. A. Farlow, et al.,, Proc. SPIE 4819, 118–125 (2001)

Simultaneous acquisition

Mechanical and optical alignment is a tricky point. Further, the many degrees of freedom in the relay lens sets result in different aberrations in each channel. The volume and the weight of the system might become extremely large.

The Ideal Polarization Analyser

Registration of multiple images is therefore complicated by the need to **correct** either for **temporal variation** of the scene or, in case of simultaneous acquisition, for both **mechanical misalignment** as well as **optical "misalignment"**.

An ideal polarization analyser shall be able to acquire <u>simultaneously</u> the required information in order to freeze, in a single snapshot, the polarization state of the target.

Furthermore the entire system should be as <u>small</u> as possible (in volume and weight)

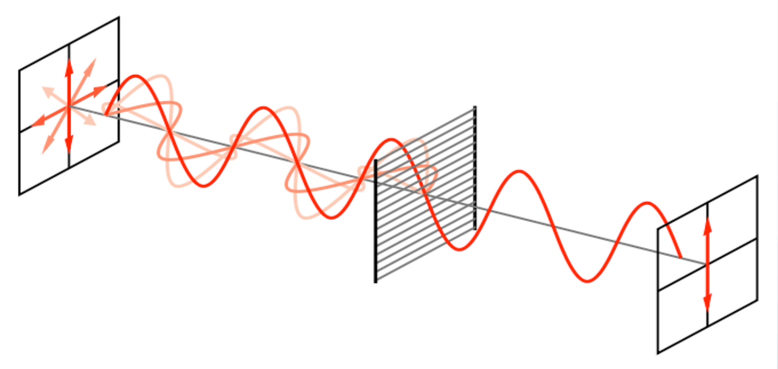
designing and developing a first prototype of an integrated polarimeter based on a CMOS detector and nano-Wire Grid Polarizers (WGPs)

Wire Grid Polarizers

WGP consists of a regular array of fine parallel metallic wires, placed in a plane perpendicular to the incident beam.

The component of the electromagnetic waves with electric field aligned parallel to the wires is **reflected** by the WGP whereas the other component (electric field perpendicular to the wires) **is transmitted**.

The transmitted wave has an electric field purely in the direction perpendicular to the wires, and is thus linearly polarized.

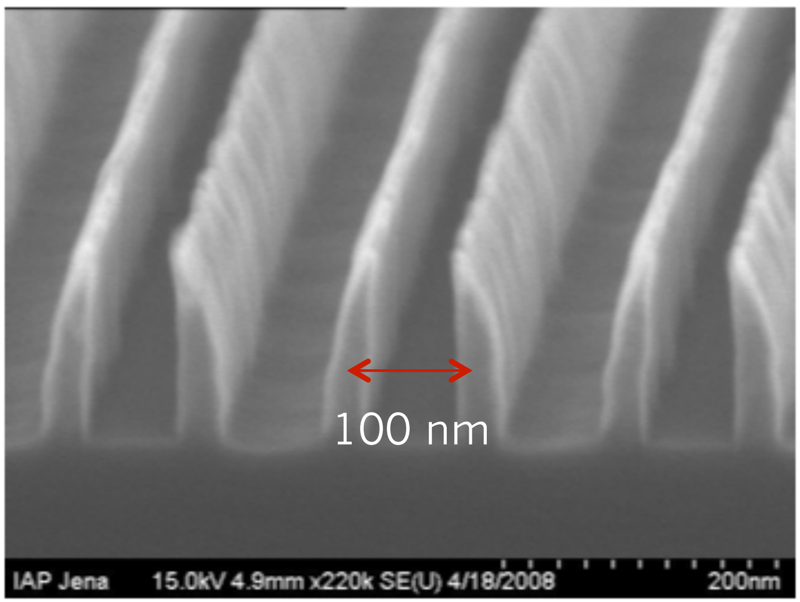


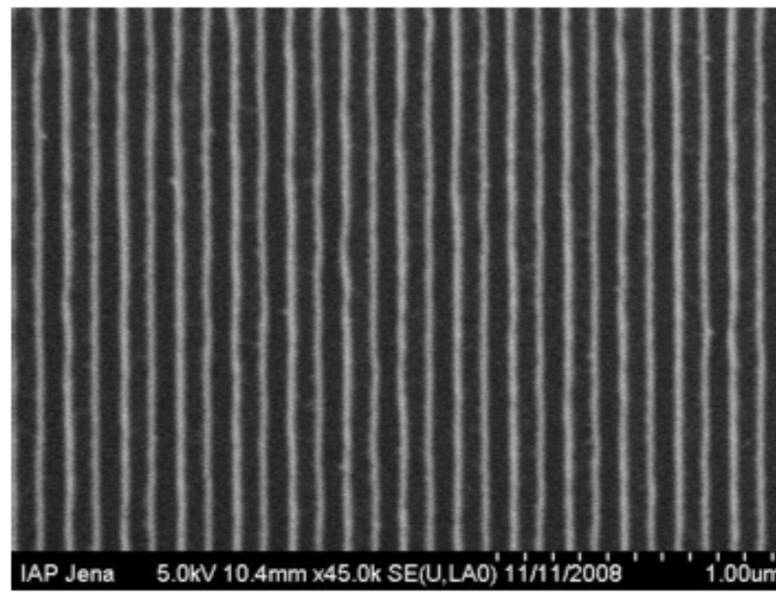
WGP is efficient for $\lambda \geq 3\ L_{pitch}$.

Wire-grid based polarizers have been extensively used in the past for application in the infrared and sometime in the visible region.

nano - WGP

Recently, the remarkable improvement in nano pattern generation made by lithography techniques, brought the wire grid polarizers to have the potential to generate a broadband polarizer even in the UV range.



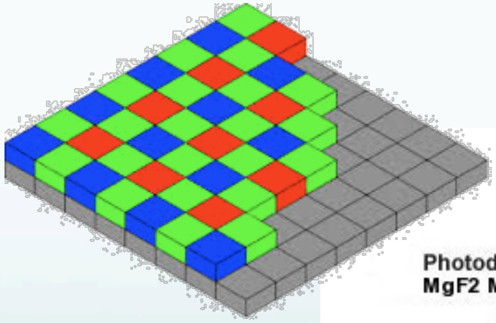


Weber T., et al, “Wire-Grid Polarizer fir the UV spectral region”, Proc. SPIE 7205, (2009)

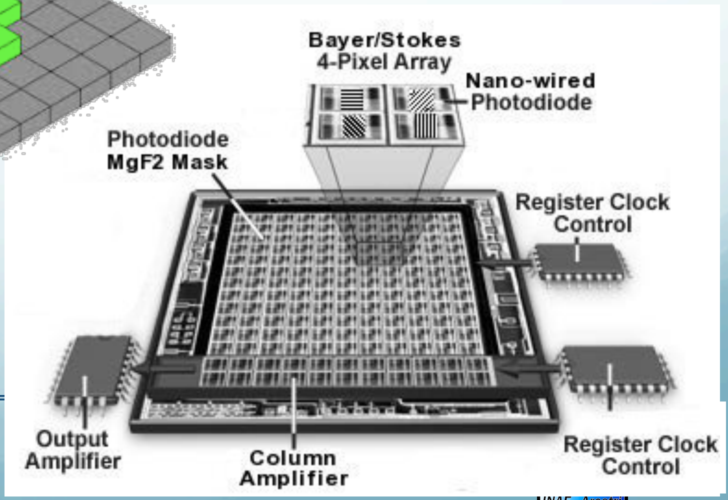
nano-WGP Mask

Borrowing the color-filter Bayer matrix concept, we aim at realizing an array of differently oriented (0°, 45°, 90°, 135°) nanowires WGPs matching the pixel array of a CMOS detector.

We want to develop a mask organized in 2x2 pixels sub-array hosting 4 different nanowires WGPs. The 4 neighbouring pixels, having different polarizing masks, enable the redundant collection of the 3 basic information (I, U, Q), necessary to obtain the linear polarization



As first prototype a matrix of 4x4 px (4 sub-arrays) shall be produced to demonstrate the design feasibility and the alignment procedure.

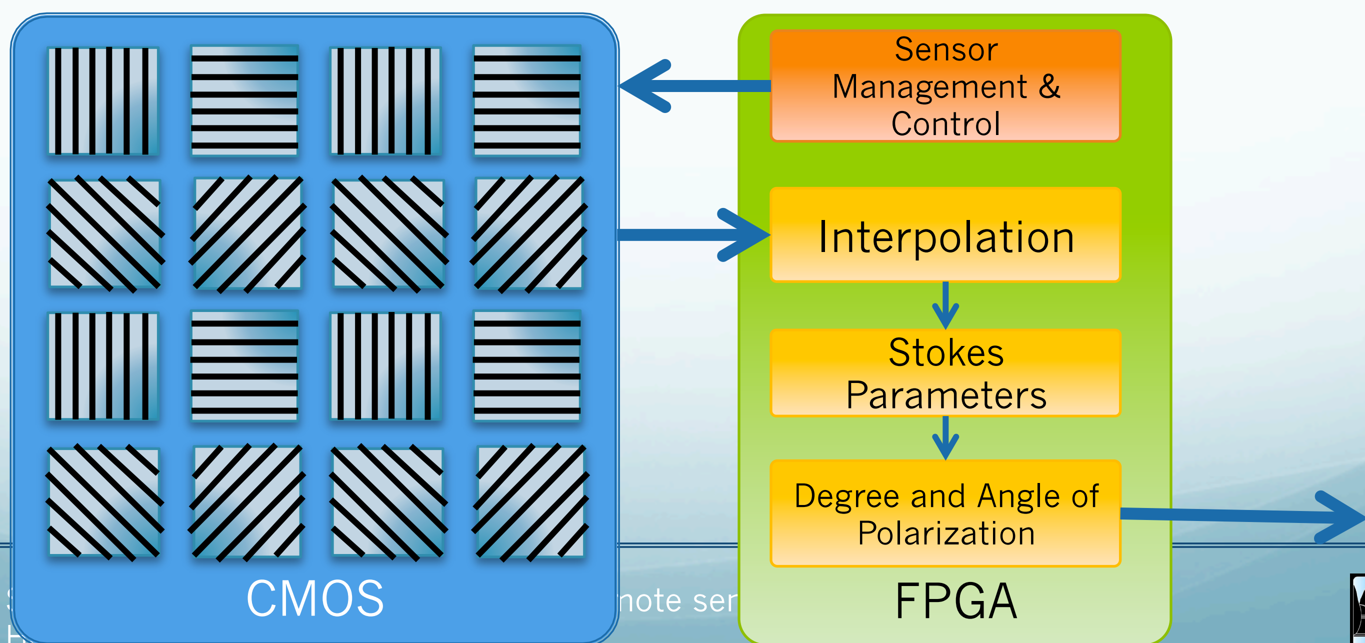


CMOS Integrated Polarimeter

The Bayer matrix shall be digitally elaborated by the proximity electronics to directly extract the polarized signal.

This solution will allow to efficiently acquire the Bayer matrix and to perform, at the same time, some preliminary signal processing aboard the HW device, before downloading it to a hosting PC, to directly determine the polarization p or to compute on chip the polarized brightness pB.

Functional scheme



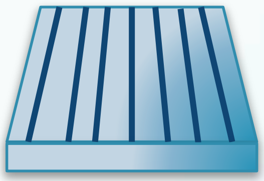
The step of the project - 1

The project is organized in 3 years and should provide intermediate results.

First year

In collaboration with ICFO Nanophotonics Laboratory in Barcelona, Spain

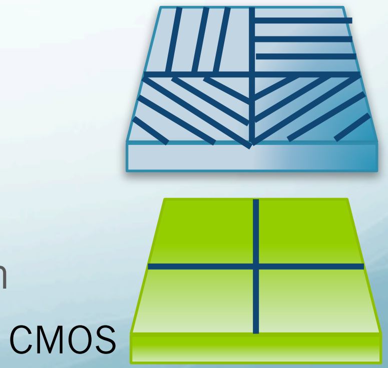
1) Realization and characterization of a single nano-WGP working in the visible
   - Efficiency vs λ
   - Extinction Ratio vs λ



2) Realization of a nano WGP pixelated mask hosting 4 differently oriented arrays of wires with a pitch of ~150 nm

3) Matching the mask to a a commercial UV-enhanced back-illuminated CMOS detector (e.g. a 128x128 array)

4) Development of the data reduction algorithms for the extraction of the linear polarization information



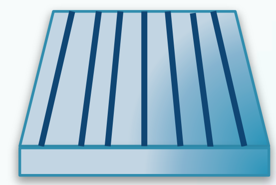
The step of the project - 2

The project is organized in 3 years and should provide intermediate results.

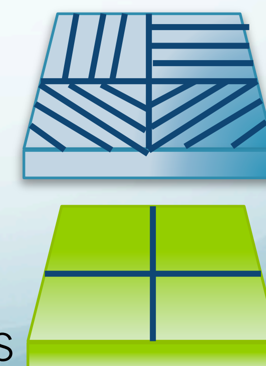
Second year

In collaboration with ICFO Nanophotonics Laboratory in Barcelona, Spain

1) CMOS characterization in the UV band to assess the 10% QE UV cut-off wavelengt



2) Realization and characterization of a single nano-WGP working in the UV (pitch < *100 nm*)
   - Efficiency vs λ
   - Extinction Ratio vs λ



CMOS

3) Realization of a nano WGP pixelated mask hosting 4 differently oriented arrays of wires with a pitch of < 100 nm

4) Matching the mask to a a commercial UV-enhanced back-illuminated CMOS detector (e.g. a 128x128 array)

The step of the project - 3

The project is organized in 3 years and should provide intermediate results.

Third year

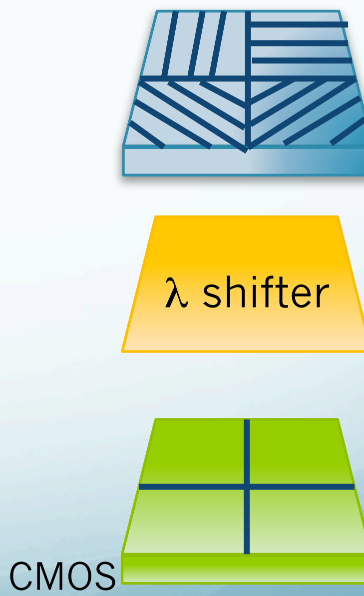
Extension of the nanoWGP+CMOS operability down to VUV (121 nm).

1) Investigation/procurement of the lambda-shifter coating material (tetraphenyl-butadiene -TPB- or metachrome) to improve the detector efficiency at shorter wavelengths;

2) Calibration of the lambda shifter + CMOS assembly in the VUV range;

3) Deposition of TPB or metachrome on the backside of VUV-pitch WGP facing the detector or directly on the CMOS device (if possible);

4) Test and calibration of the VUV CMOS-WGP assembly;



SCOUT: Small Chamber for Optical Uv Tests

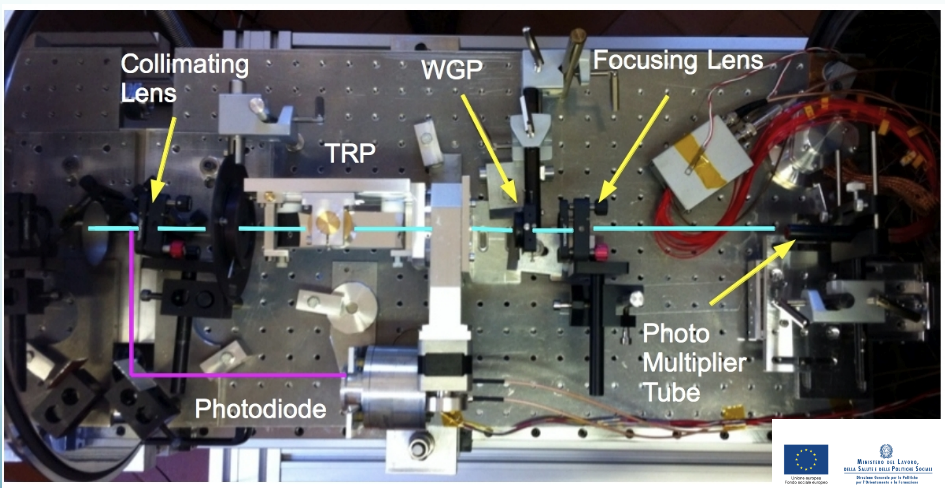
A vacuum chamber has been developed @UniFi laboratories in Florence in order to perform practical and fast measurements on compact (within 1 m) experiments that need vacuum (e.g. UV tests). The chamber is a 120 cm long stainless steel tube with the following characteristics:

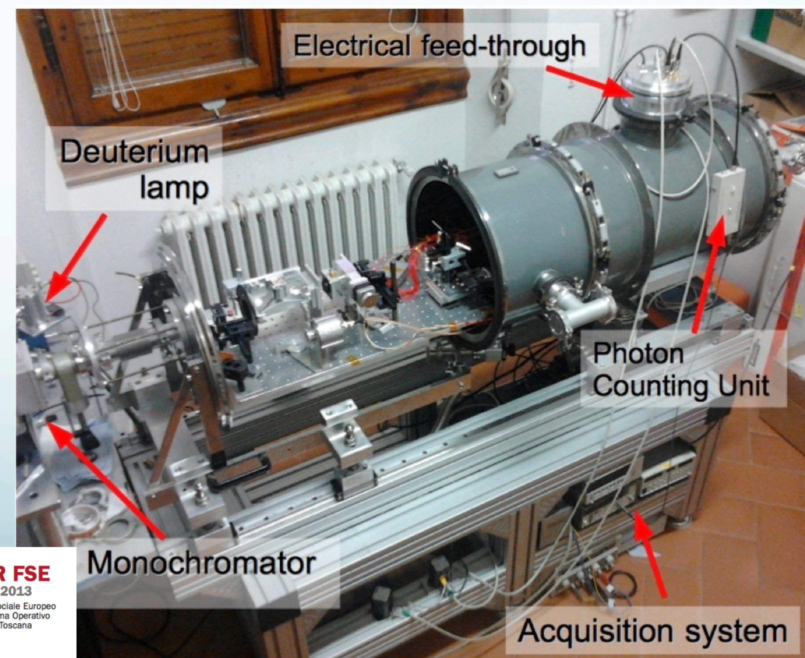
- Two movable sections;
- Internal optical bench (65x35 cm);
- Electrical feedthrough;
- Compact and powerful pumping vacuum system (1.0 E^{-4} mbar in 10 min, 3-4 E^{-5} in 1 hour);
- Translation and rotation vacuum stages;
- Numerous vacuum standard I/F fitting different sources (D_2 lamp, monochromator, Hollow cathode);

SCOUT @ work

The functionality and the capabilities of SCOUT have been extensively tested in the measurement campaign to characterize a first prototype of wire-grid polarizer (WGP) optimized to work in transmission in the UV band developed for the NANOPol project.

Some nominally identical nano-wire grid polarizers have been produced, in order to compare them and check whether the manufacturing procedure is reliable and repeatable. A first set of nano-wires with a pitch of 100 nm (suitable to polarize light at λ>250÷300 nm) has been realized and their characterization has been carried out using a set-up accommodated inside SCOUT as shown in the pictures below.





Applications of a nano-WGP CMOS polarization analyser

Conclusions:

This project has been submitted on February 2013; it passed a first selection obtaining a good judgment (9.67/10) by the 3 referees who examined the proposals. A more detalied proposal has been submitted the last June. The final selection should be in Autumn.

There are several Astronomy fields that would take advantage from the development of a CMOS sensor with an integrated polarimeter.

Such a device would be particularly suitable to be hosted in space instrumentation where mass, volume and power budget are restrictive constraint to deal with.

A CMOS integrated polarimeter could be profitably used to study fast evolving astrophysical processes such as plasma diagnostic or Sun-Earth weather relationships based on coronal plasma observations

We really hope to get this project funded!!

Thanks

to the COST and to the local organizers for the great opportunity of attending this interesting meeting and presenting this work.

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