LyNaCoPo: the observation of the magnetic field of the solar corona through a nano-wire polarizer

Federico Landini[a], Marco Romoli[b], Maurizio Pancrazzi[a], Cristian Baccani[b], Mauro Focardi[a]

a INAF - Arcetri

UNIVERSITÀ DEGLI STUDI FIRENZE | Dipartimento di Fisica e Astronomia b

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Outline

- Investigation of the Solar Corona magnetism through the HI Lyα linear polarization measurement
- PeNCIL: explorative project for a compact coronagraph optimized for the Lyα
  - Optical design and performance
  - The nano-wire polarimeter
- SCOUT: the facility to calibrate the polarimeter

Magnetic field in corona

- The magnetic field is the driver of the structure, dynamics and the energetics of the solar corona
- But it is measured mainly at the solar surface and is poorly known in the corona itself
- In fact it is not trivial to infer the magnetic field in corona: different observing techniques and a lot of modeling to interpret the results and remove LOS effects are needed

The Hanle effect (resonant lines)

Key parameter:

$$\Omega = \omega_L \cdot \tau \quad \propto \quad \mathbf{B}$$

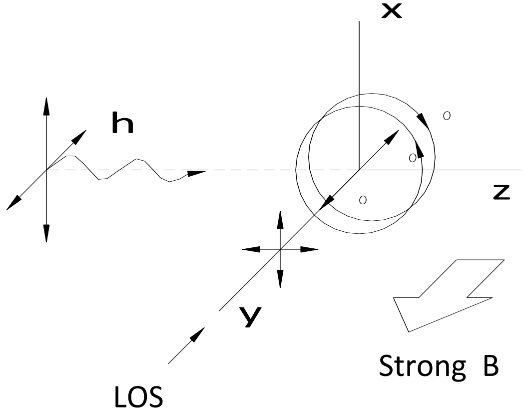
($\tau = 1/A$ transition mean lifetime)

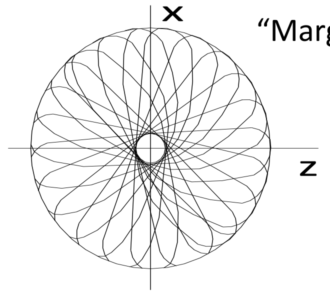
Regimes

$\Omega >> 1$ strong field

$\Omega << 1$ weak field

$\Omega \approx 1$ H.E. maximum sesitivity

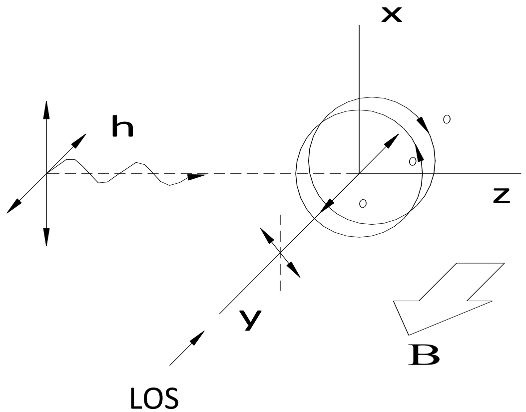


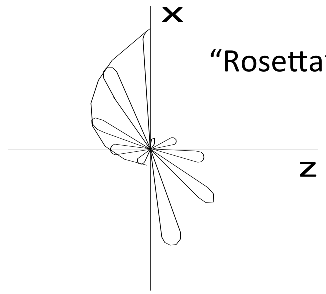


For **B** directed toward the observer and for 90° scattering (Breit,1925):

$$\frac{p}{p_0} = \frac{1}{\sqrt{1+4\Omega^2}}$$

$$\varphi = \frac{1}{2} \cdot \arctan(2\Omega)$$

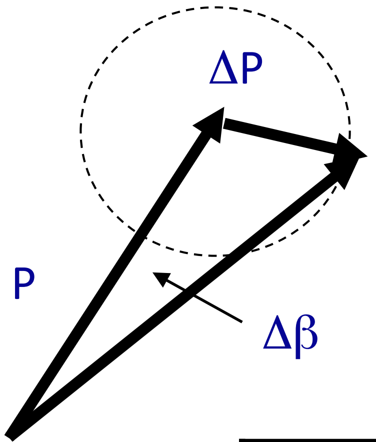




Strong magnetic field ($\Omega >> 1$) with the relative polarization pattern (“margherita”)

Intermediate magnetic field ($\Omega \approx 1$) with the relative polarization pattern (“rosetta”).

Hanle effect sensitivity



(Min. Detectable Rot. Angle) $\Delta\beta \sim \Delta P/P$

ΔP (Min. detectable Polariz.) ~ 1/signal-to-noise ratio

$P \sim P_0/(1+Coll/Rad)$ $\Delta\beta\ [rad] \sim 0.88 \cdot g_J \cdot B_{min}/A$

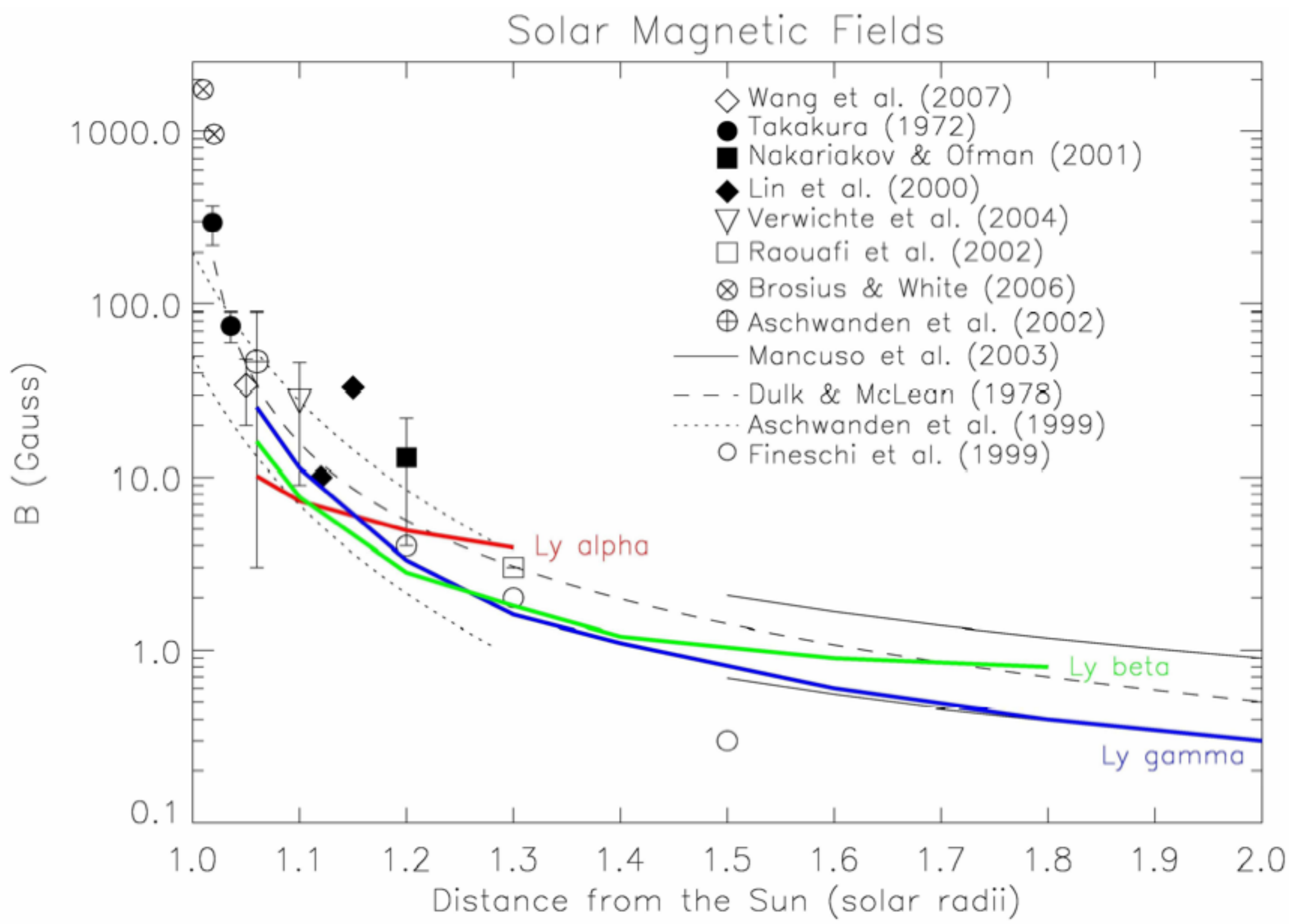
Fineschi et al, Proc. SPIE, 1999

Spectral line	λ (nm)	***A*** (10^7 Hz)	g_j	***B*** (Gauss)
H I Lyα	121.6	62.65	4/3	10 ÷ 70
H I Lyβ	102.5	16.72	4/3	2 ÷ 20
H I Lyγ	97.2	6.82	4/3	1 ÷ 7
O VI	103.2	41.60	4/3	6 ÷ 50

$$B_{min} = \frac{A \cdot [1 + Coll / Rad]}{P_0 \cdot SNR}$$

Courtesy of S. Fineschi

Hanle effect sensitivity



The resonantly scattered Lyα is a great candidate to infer the component along the LOS of the coronal magnetic field through the Hanle effect.

Courtesy of S. Fineschi

Constraints (i.e., what is needed?)

- A space-borne coronagraph (Lyα is absorbed by the Earth atmosphere) with FOV aimed at the inner corona
- A polarimeter working at 121.6 nm, suitable and reliable for a space mission (limit the use of mechanisms and motors)
- Good image quality: better to work on axis
- Weak signal: the minimum possible amount of optics
- Costs: keep everything compact (length 1 m) and light-weighted

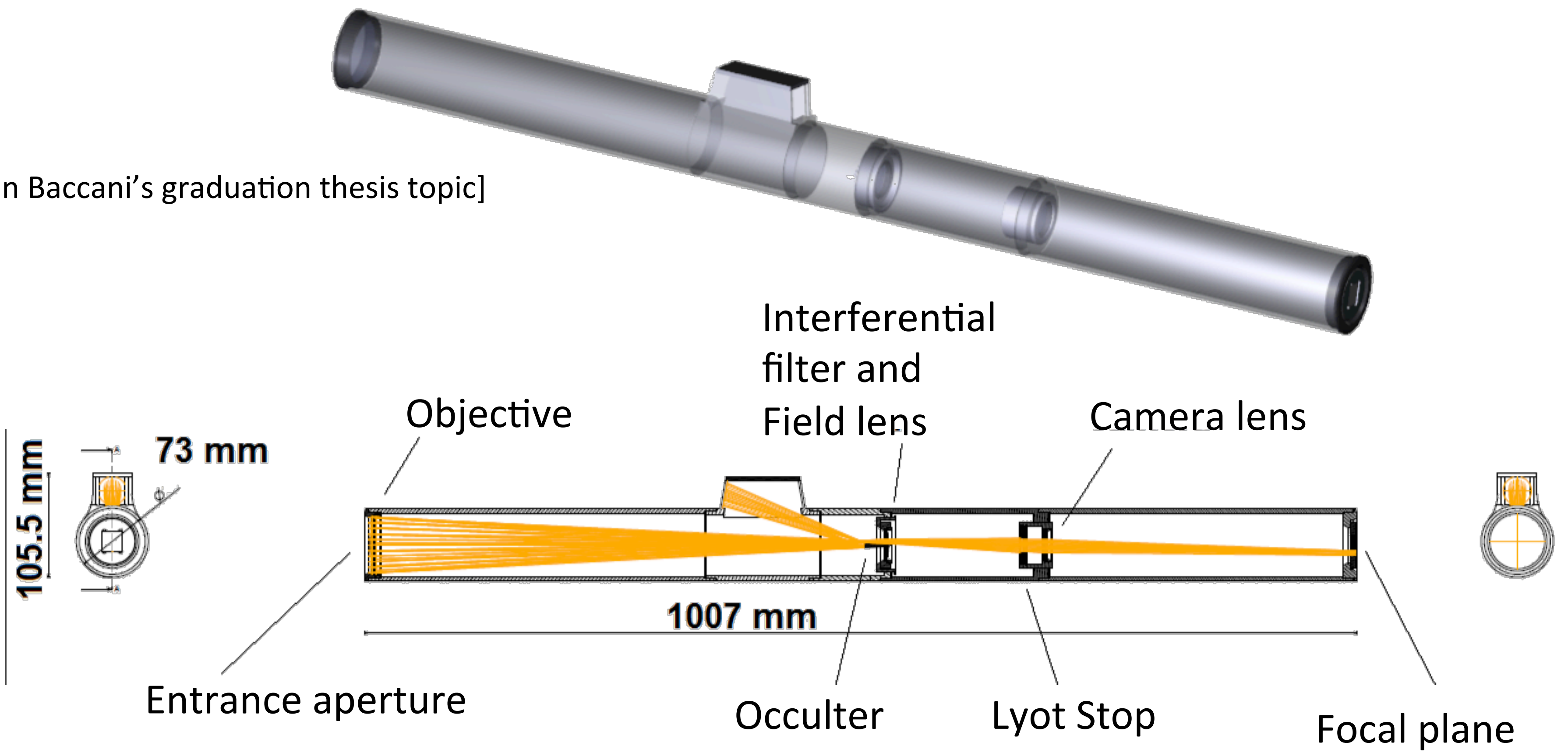
An answer: PeNCIL

- PeNCIL: **P**olarim**e**try with **N**anowires for **C**oronal **I**maging of **L**yα
- Explorative project of a compact coronagraph integrated to a polarimeter to measure the linear polarization of the Lyα 121.6 nm
  - Internally occulted refractive coronagraph optimized for the 121.6 nm emission line
  - Polarimeter based on a nano-wires polarizer and a piezo-electric modulated MgF_2 retarder

First step: the coronagraph

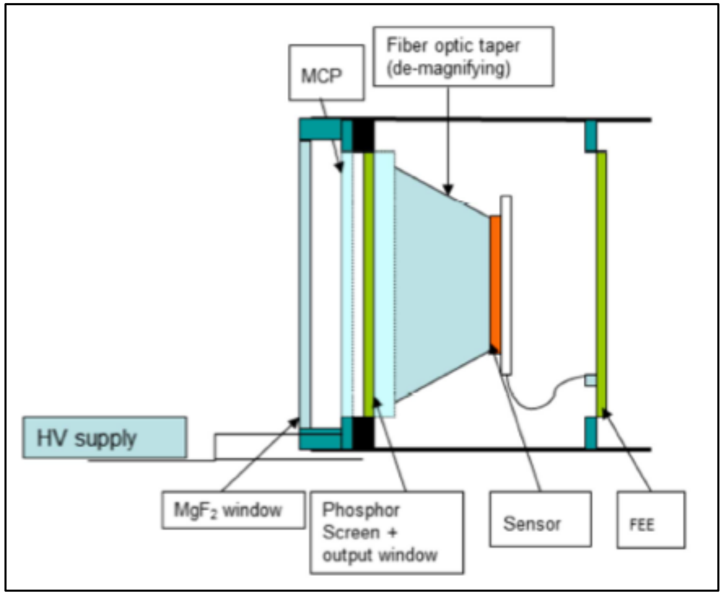
- Classical Lyot coronagraph, with MgF_2 lenses

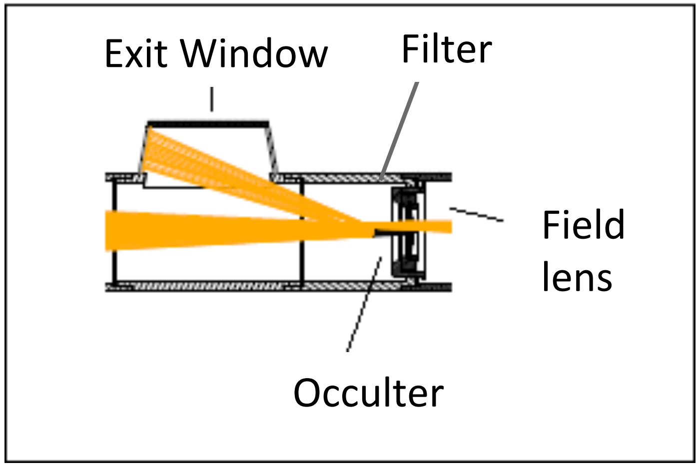
[Cristian Baccani's graduation thesis topic]

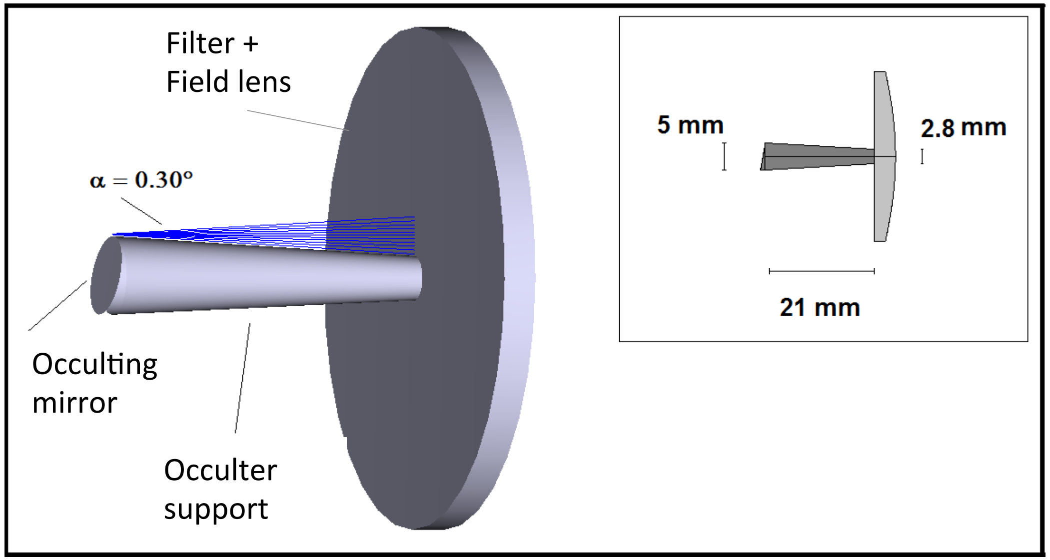


Coronagraph characteristics

Description	Value
Focal length	1.09 m
FOV	1.1÷ 2 $R_\odot$ @ 1 AU
F/number	f/19.5
Entrance aperture	56 mm⌀
Resolution	3.78 arcsec
Total length	1 m

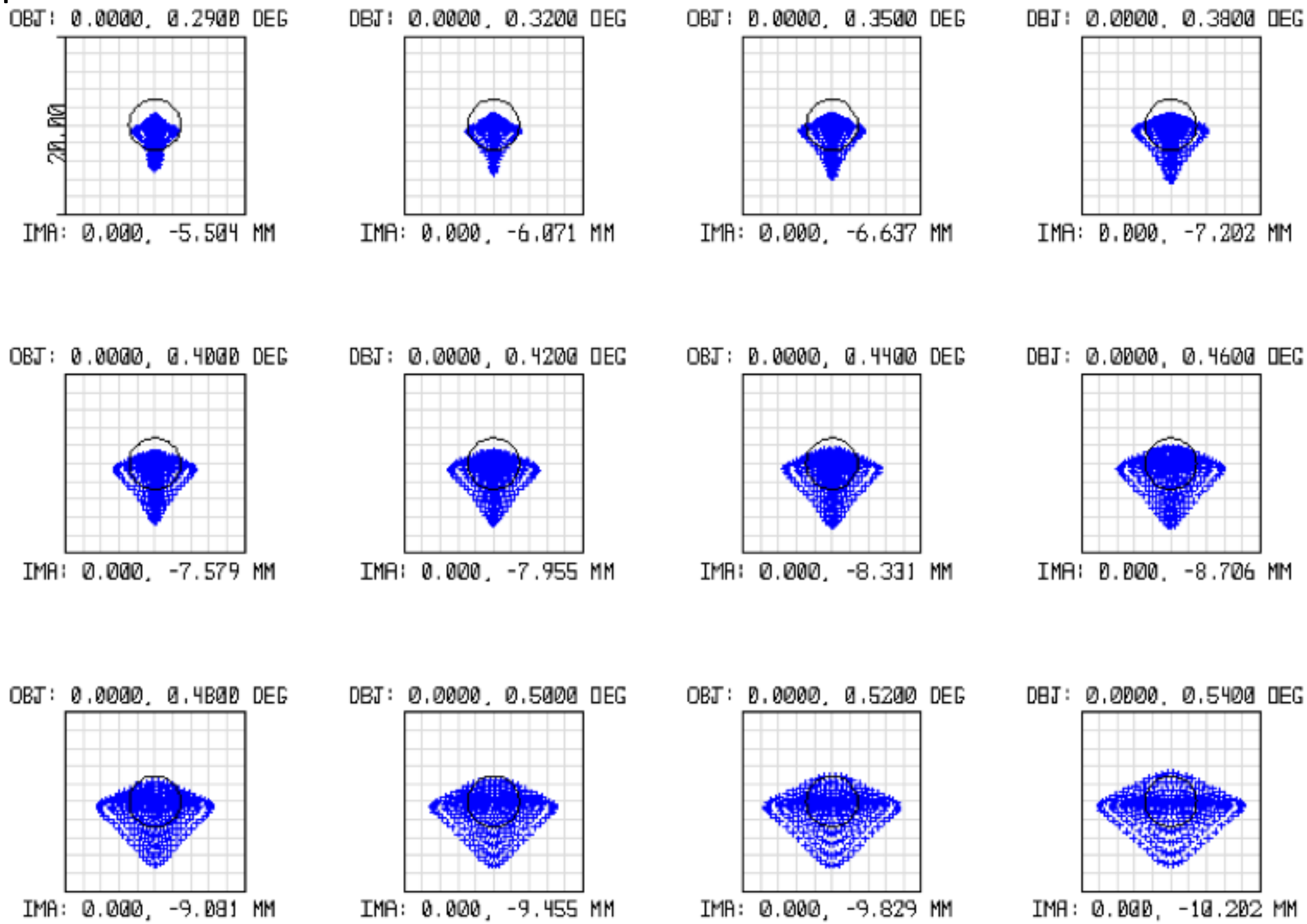






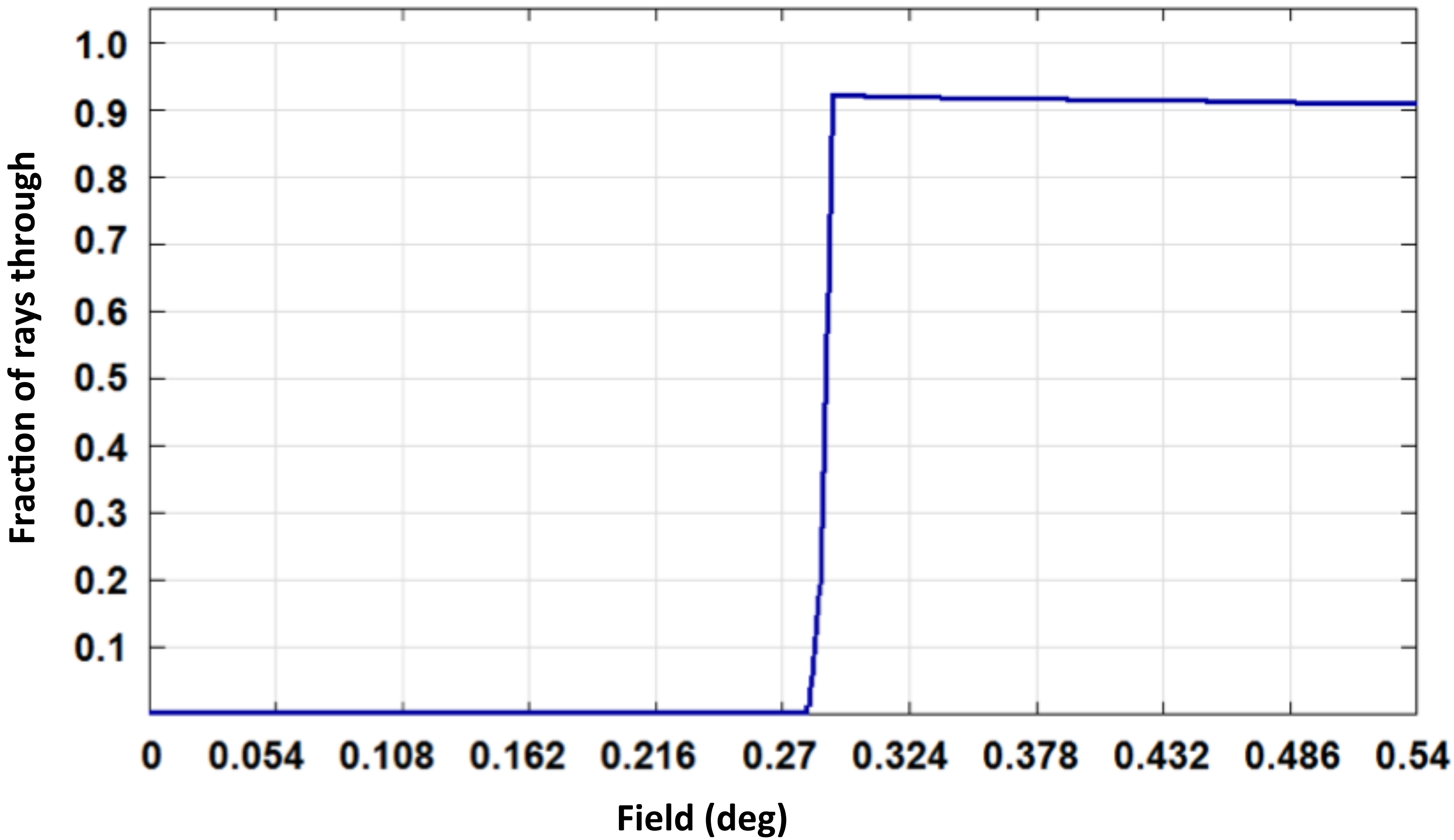
Coronagraph performance

Spot diagram



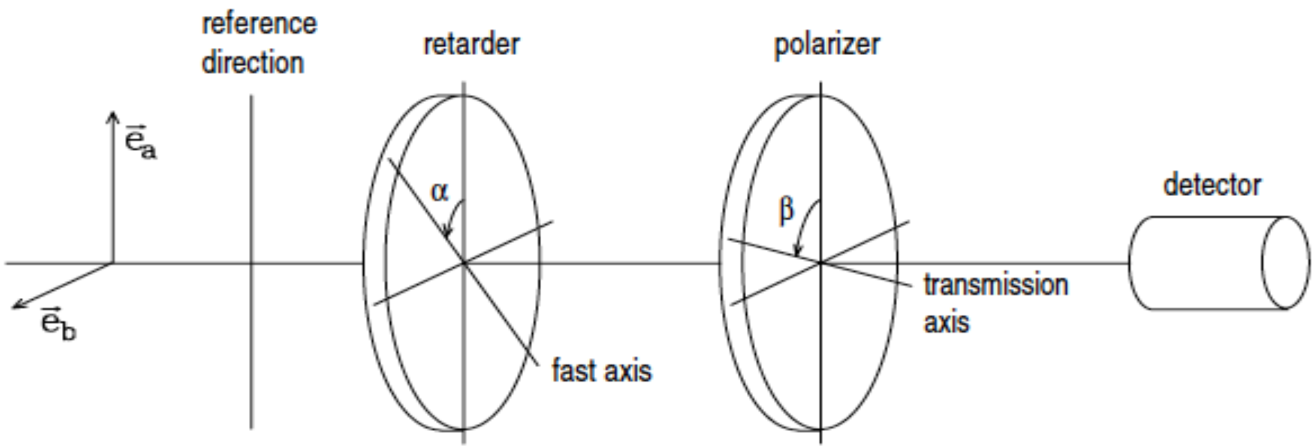
Coronagraph performance

Vignetting function



Second step: the polarimeter

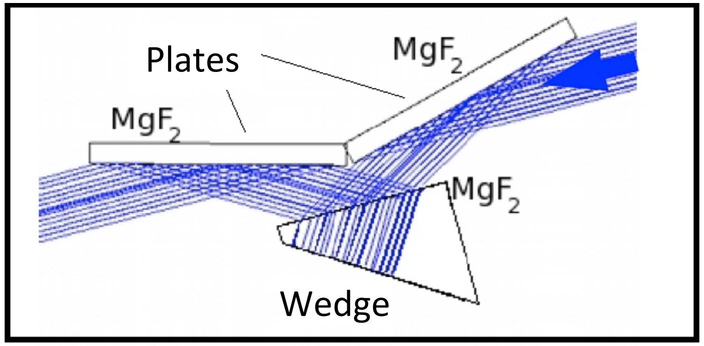
- The same constraints hold good for the polarimeter as well
  - Work possibly on axis
  - Reduce the use of motors and mechanisms



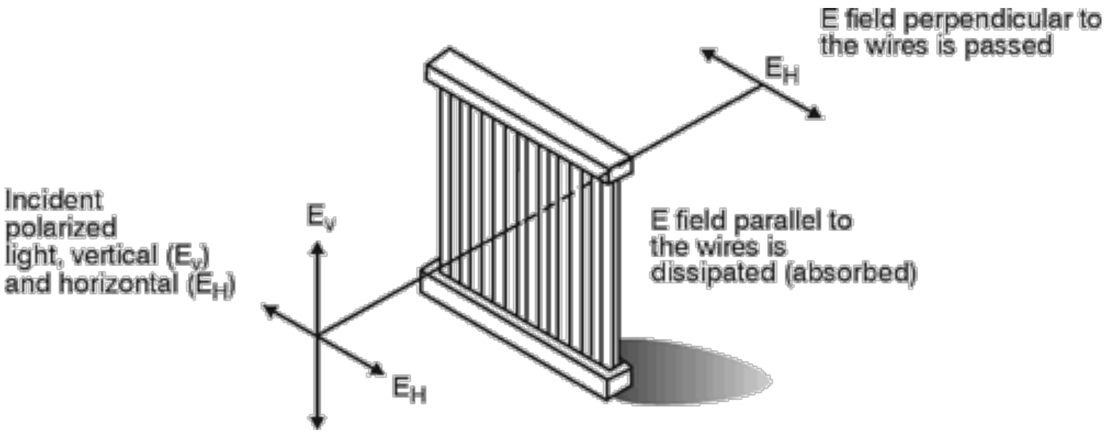
Courtesy:
Landi Degl'Innocenti, Landolfi
"Polarization in Spectral Lines", Kluwer, 2004

The polarizer

- On axis:
  - Three reflection polarizer
    - Hard to align
    - Efficiency loss (3 reflections)



  - Wire grid polarizer
    - Easy to align
    - Good efficiency



Courtesy: The Center for Occupational Research and Development, USA

Wire grid polarizer

- Light has been polarized using metal wire grids for over a century (mainly in the radio, IR and Visible)
- Example:

(to polarize microwaves)

Courtesy: Harvard Lecture Demonstration Services, USA

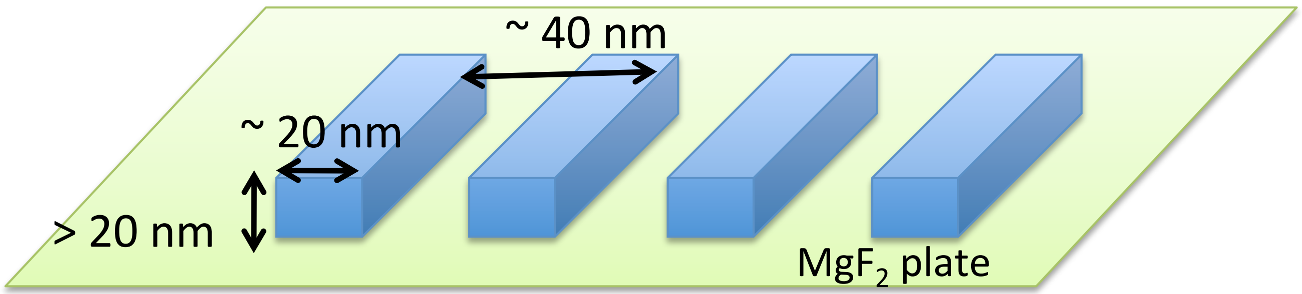
Wire grid polarizer

- "As a general rule of thumb, the shortest operating wavelength of a WGP can work efficiently as a polarizer is about three times of the pitch." (Jian Jim Wang et al., Applied Physics Letters 90, 2007)
- In order to be effective at 121.6 nm a wire grid polarizer shall have a pitch of **40 nm**: NOT TRIVIAL AT ALL!
- Nanotechnologies are needed

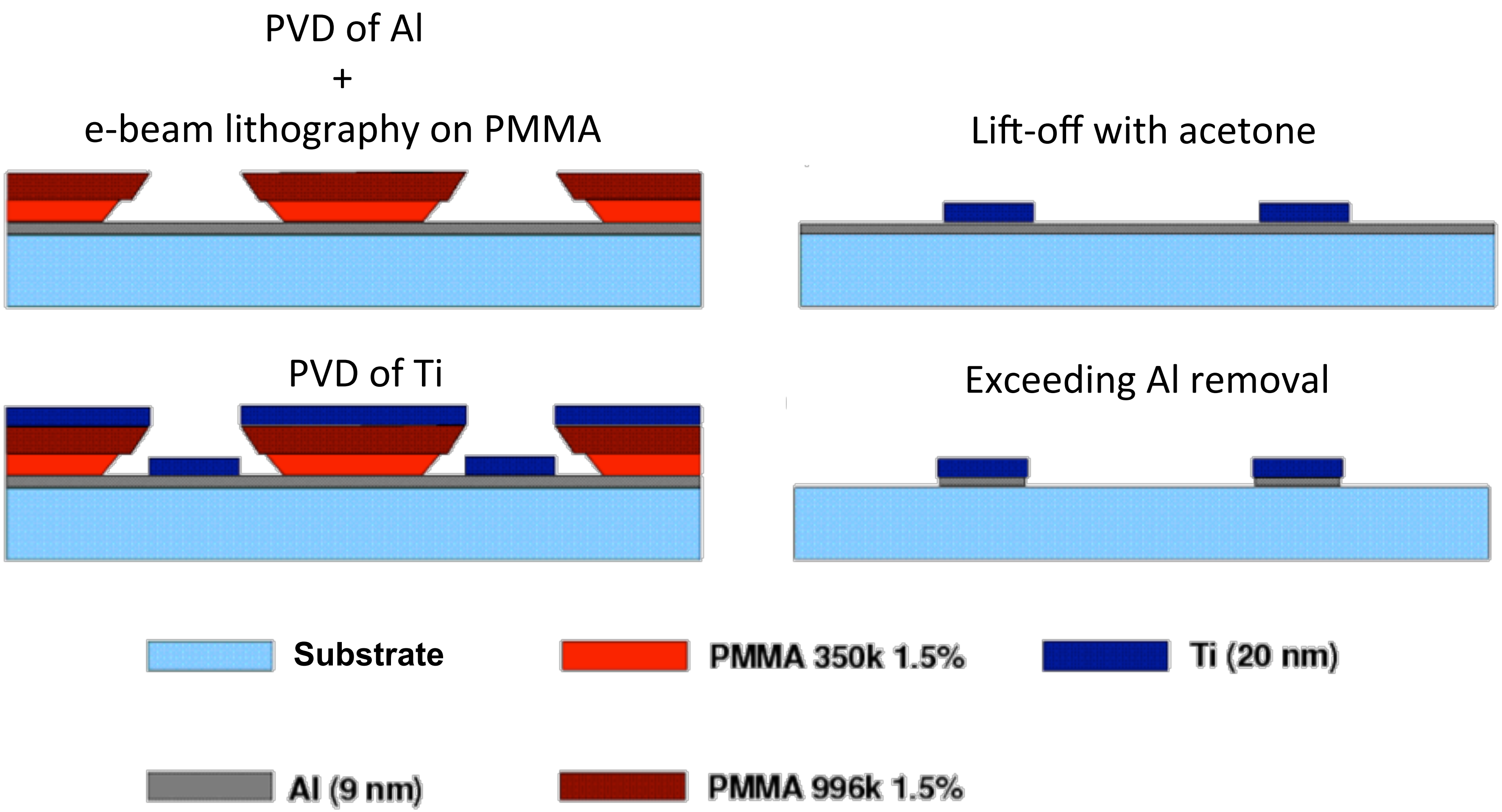
Wire grid polarizer

- The NANOPol project was funded by Regione Toscana (Italy) in order to retrieve such polarizers.

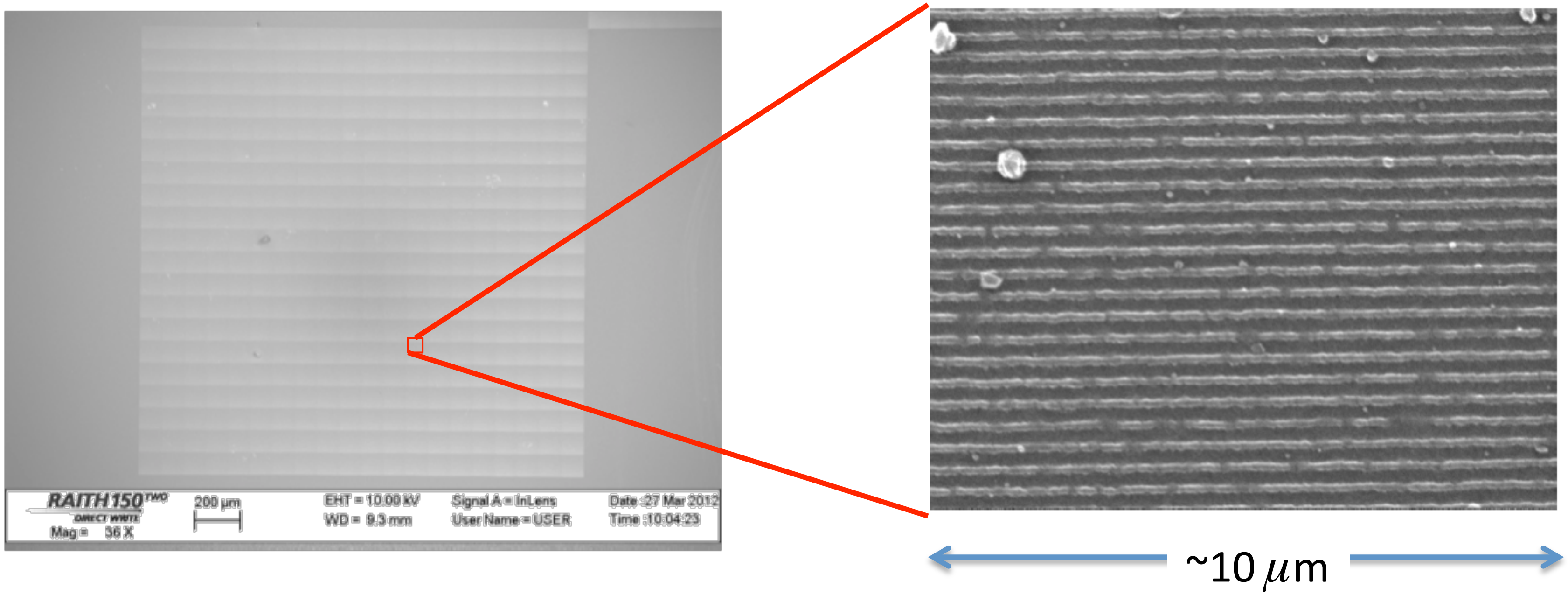
@121.6 nm	n	k	Penetration depth	T @ 10 nm	T @ 20 nm	T @ 25 nm
Au	1.265	0.967	10.0 nm	37%	14%	8%
Al	0.0419	1.13	8.6 nm	31%	10%	5%
Ti	0.86	0.85	11.4 nm	42%	17%	11%
Ni	0.948	0.833	11.6 nm	42%	18%	12%

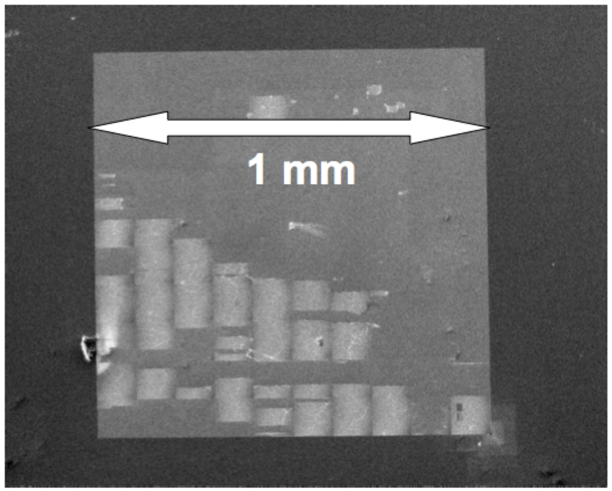


Wire grid polarizer



Wire grid polarizer





Good lithography and deposition

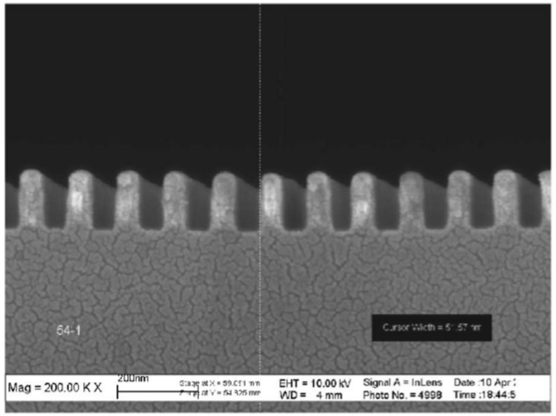
Dramatic Lift-off!

A different technique is needed.

Wire grid polarizer: alternatives

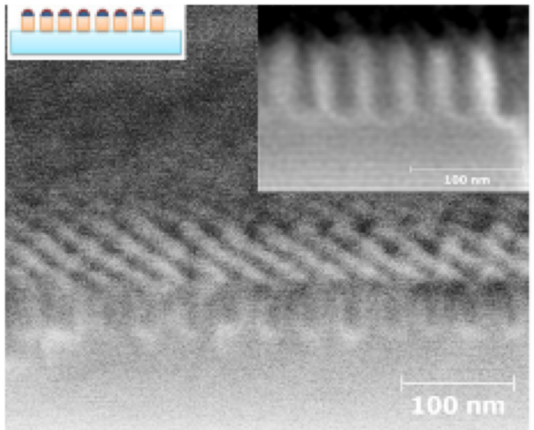
- Reactive Ion Etching: it is a top-down technique, opposite to the bottom-up that have been used.

  Wang (2007) obtained a ~70 nm pitch aluminum nanowire grid plate with full-wafer immersion interference lithography



- Block copolymers comprise two or more different monomer units, strung together in long sequences rather than randomly distributed

  R. Register group (Princeton, USA) is achieving polystyrene-poly (ferrocenylisopropylmethylsilane) templates with 35 nm pitch… but it is not conductive



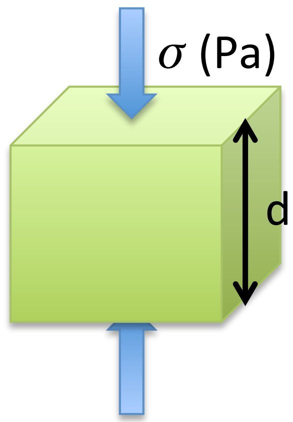
Wire grid polarizer: alternatives

- On-going cooperations:
  - ICFO (Barcelona, Spain): they try to push the limits of their technique (Focused Ion Beam Milling) to reach 40 nm pitch
  - ASRL (Washington University, St. Louis, USA): with RIE they can routinely achieve a pitch of 160 nm, even directly on a detector pixelated mask. They try to push the limit down to the UV. Italian ministry funding on hold.

Third step: the retarder

- A piezo-electric modulated MgF_2 plate can work as a variable retarder.
- No experiment done so far on MgF_2 (some are planned in the first half of 2015), but "a block of a few cm in side length of common BK7 glass can be stressed enough by hand such as to introduce a quarter-wave retardation" (Christoph U. Keller, Utrecht University).
- Retardation (in waves): $$\delta = \frac{1}{\lambda} K \cdot d \cdot \sigma$$

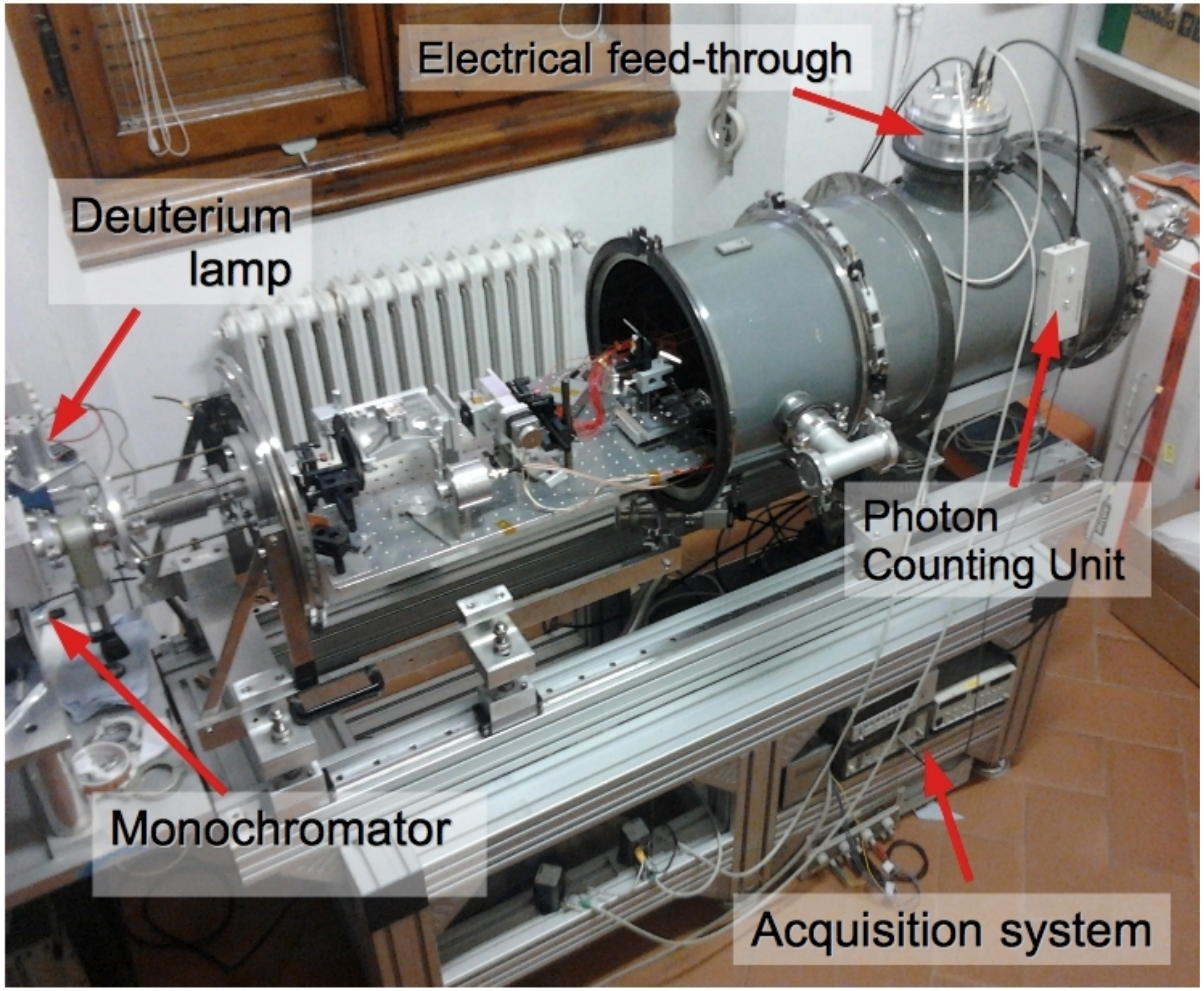
  K (1/Pa): stress optical coefficient



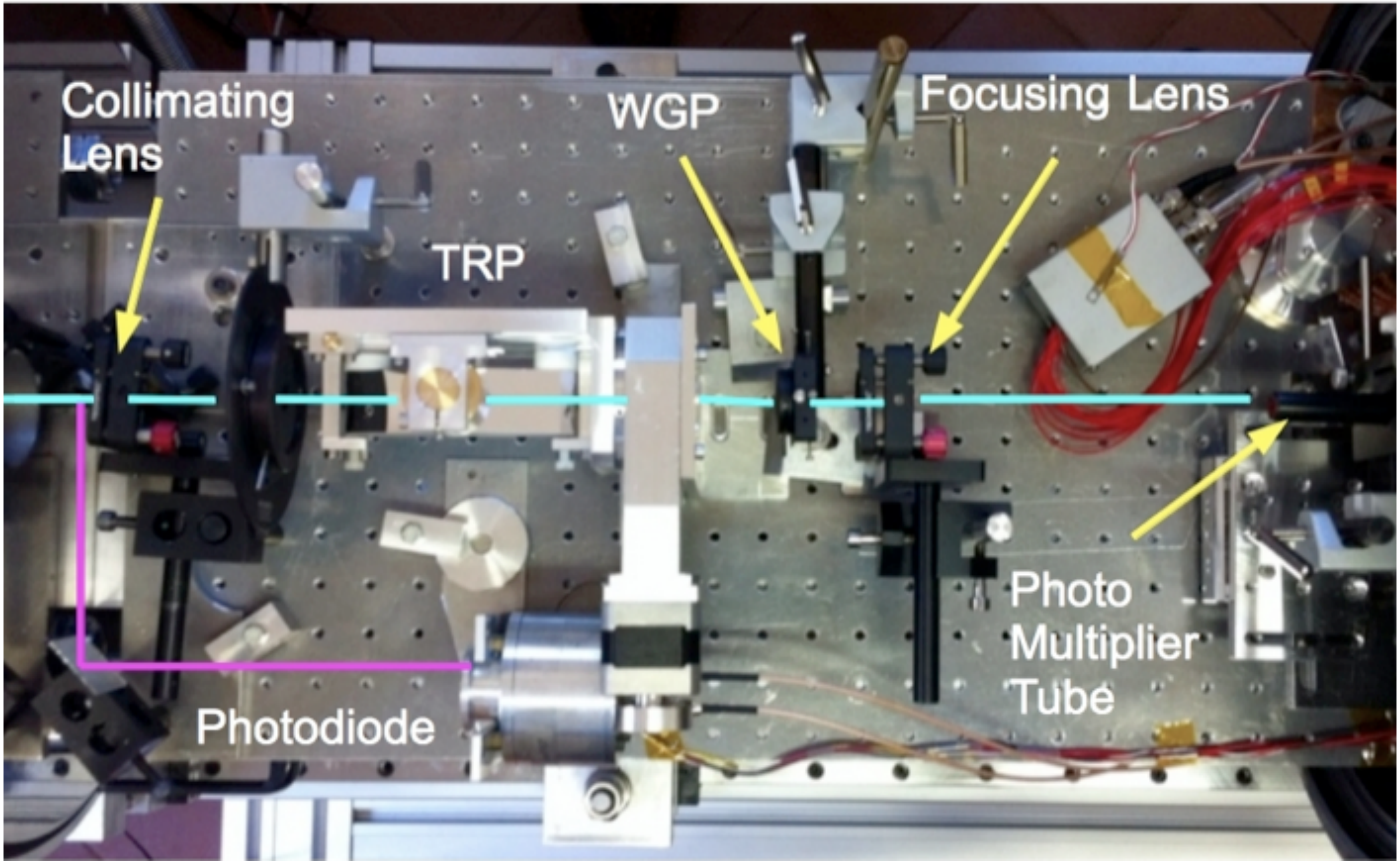
- K of MgF_2 and BK7 is of the same order of magnitude.

Test and calibration set-up

- SCOUT: Small Chamber for Optical UV Tests

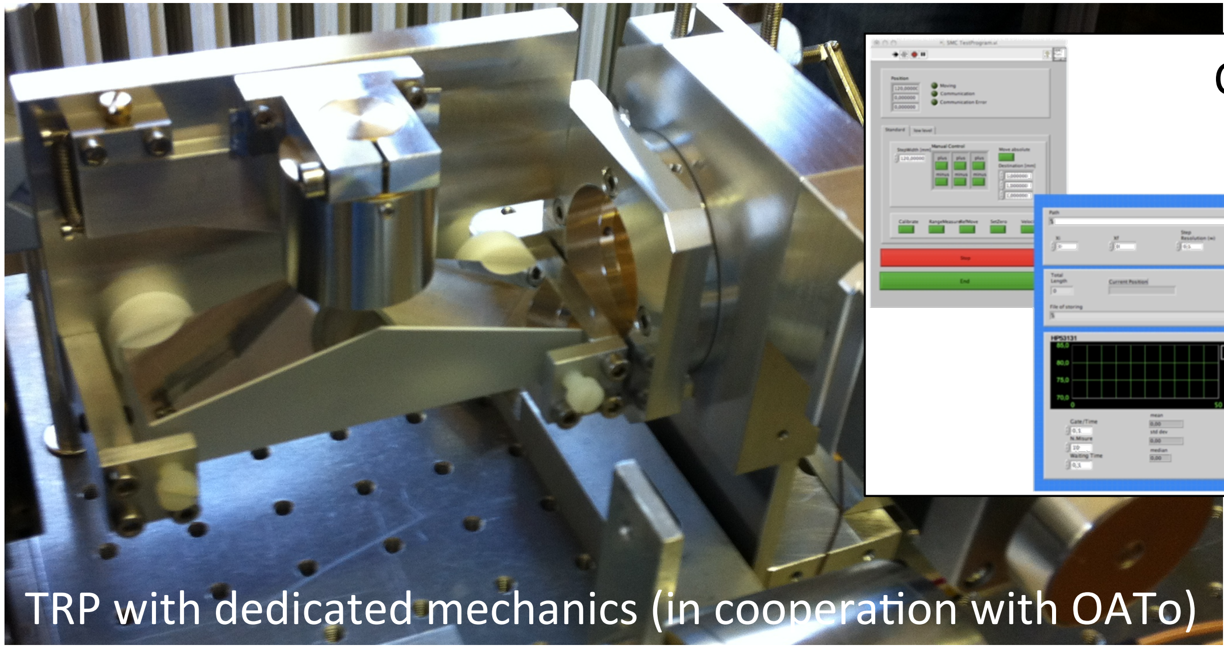


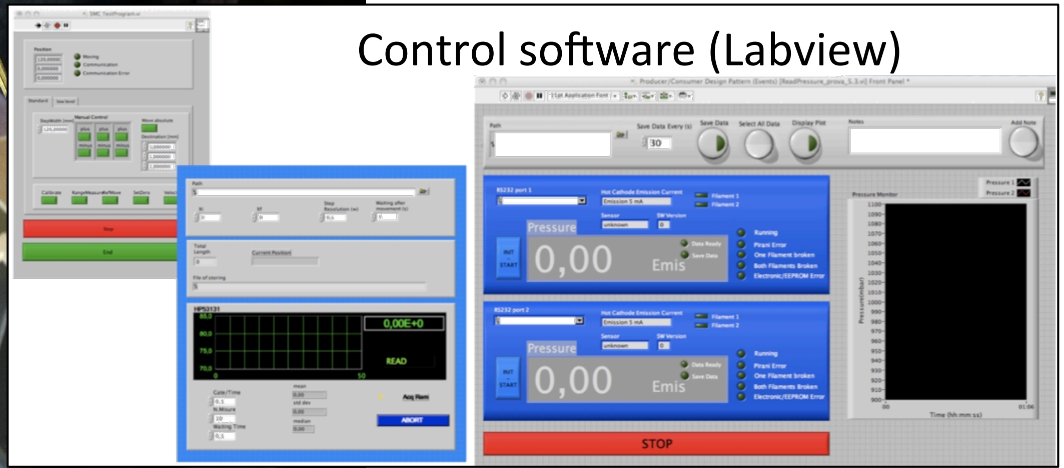
SCOUT



Collimating Lens
WGP
Focusing Lens
TRP
Photo Multiplier Tube
Photodiode

SCOUT





M. Pancrazzi et al., Proc. ICSO, 2012

<u>Characteristics and performance</u>

- Modular chamber (possible lenghts: 300, 600, 900 mm)
- Diameter: 400 mm
- Vacuum: 1.e-4 mbar from atmospheric pressure in less than 30 min (max dimension)
- Complete remote control (motors, pressure, temperature, cooling of PMT electronics, detectors, wavelength selection)

Suggestions?
Comments?

Curses?

… thank you