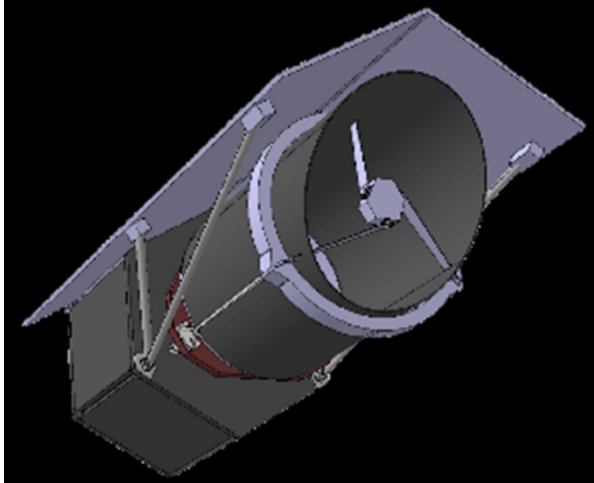
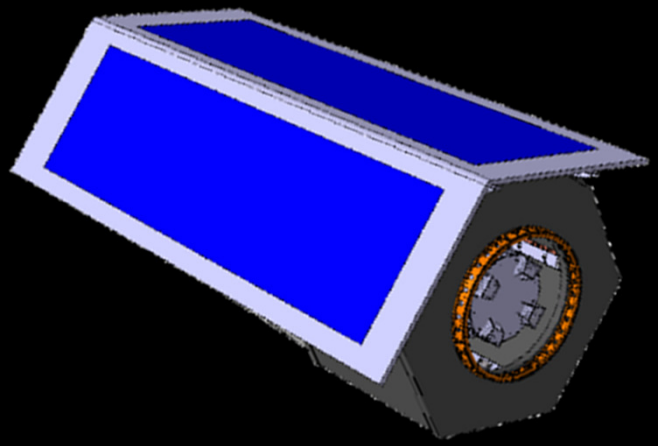
Arago : stellar UV and visible spectropolarimetry from space





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Brussels, 22nd October 2015

l'Observatoire de Paris | LESIA

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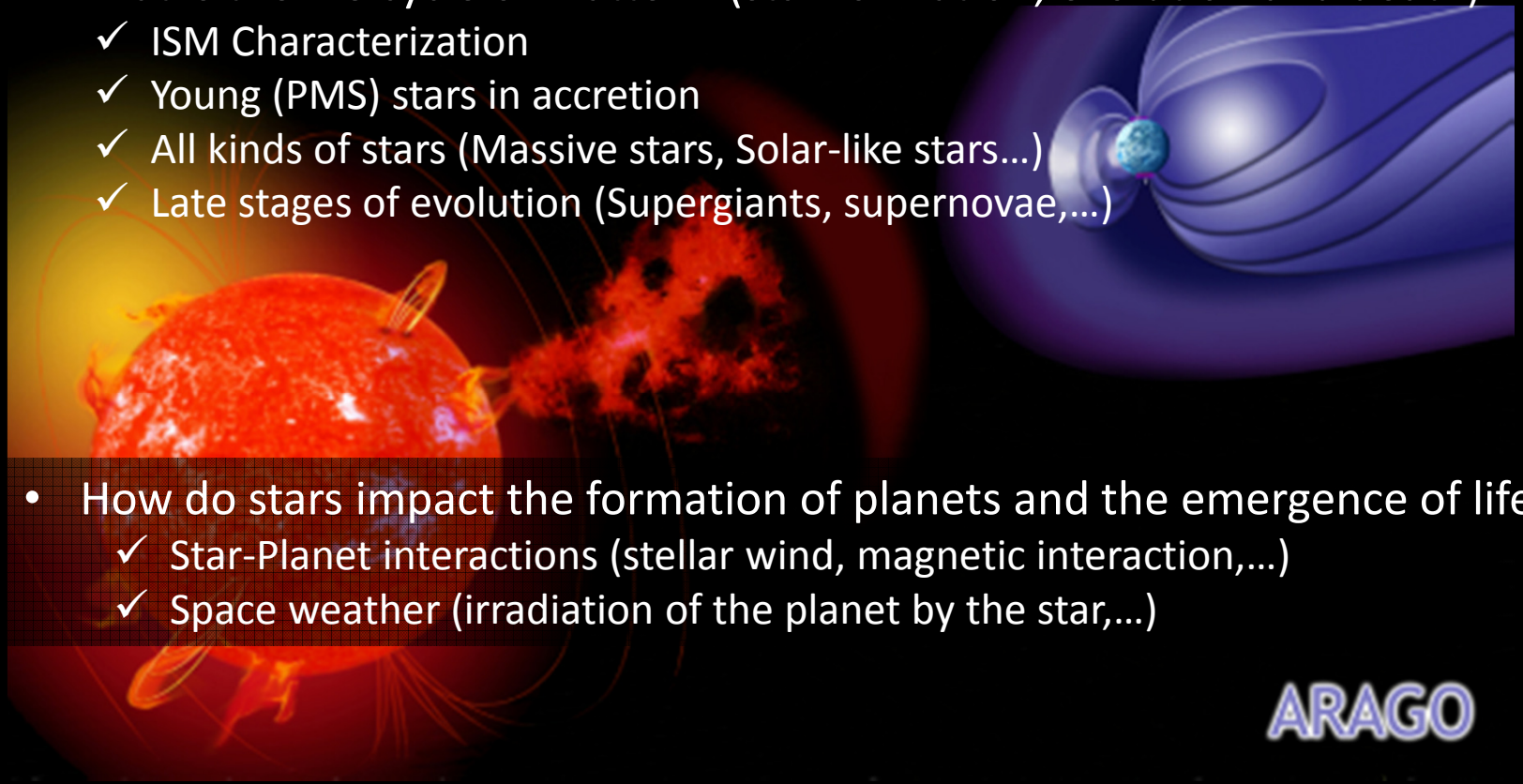
Scientific goals

- What is the life cycle of matter ? (star formation, evolution and death)
  - ✓ ISM Characterization
  - ✓ Young (PMS) stars in accretion
  - ✓ All kinds of stars (Massive stars, Solar-like stars…)
  - ✓ Late stages of evolution (Supergiants, supernovae,…)



- How do stars impact the formation of planets and the emergence of life?
  - ✓ Star-Planet interactions (stellar wind, magnetic interaction,…)
  - ✓ Space weather (irradiation of the planet by the star,…)

➡ High-resolution UV and Visible spectropolarimetry

Specifications

Preparation for ESA M5 call (deadline April 2016)

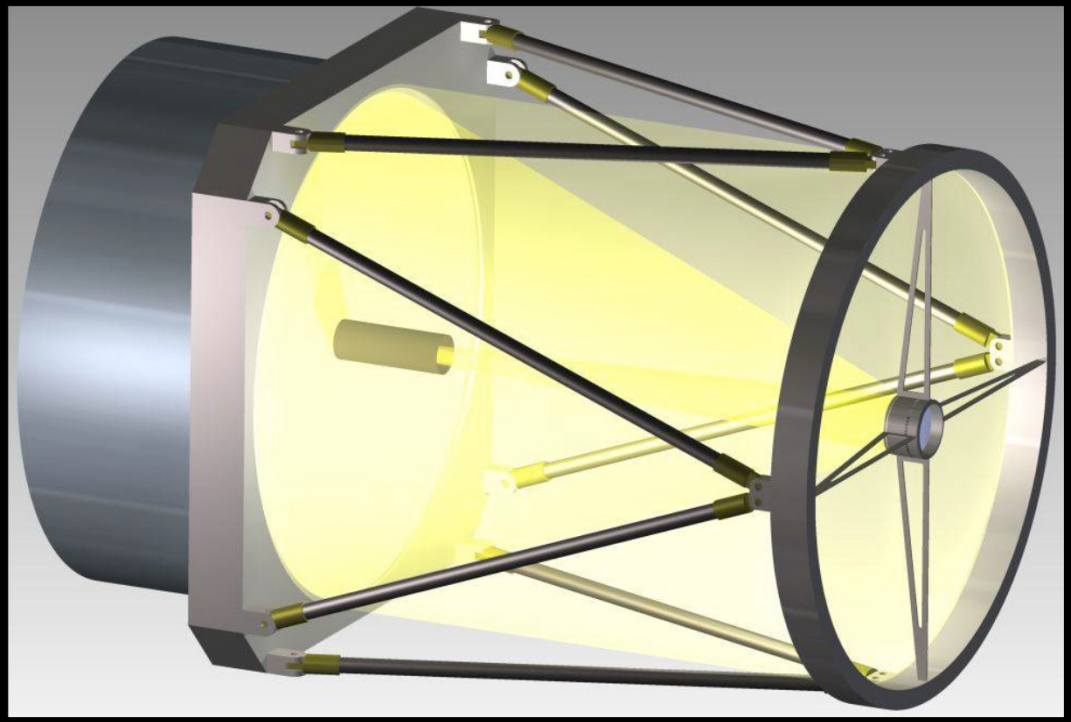
Specification	Requirement
Spectral range	[119 nm ; 888 nm] for the spectra [123 nm ; 888 nm] for the polarization
UV Resolution	25 000
Visible Resolution	35 000
S/N	100
Typical exp. time	30 min (OBA stars, V=7) 1h (FGK stars, V=7)
Target Magnitude	V=3-10
V_{rad} accuracy	1 $km.s^{-1}$ (in absolute) 0.1 $km.s^{-1}$ (for magnetic fields measurement)

Telescope

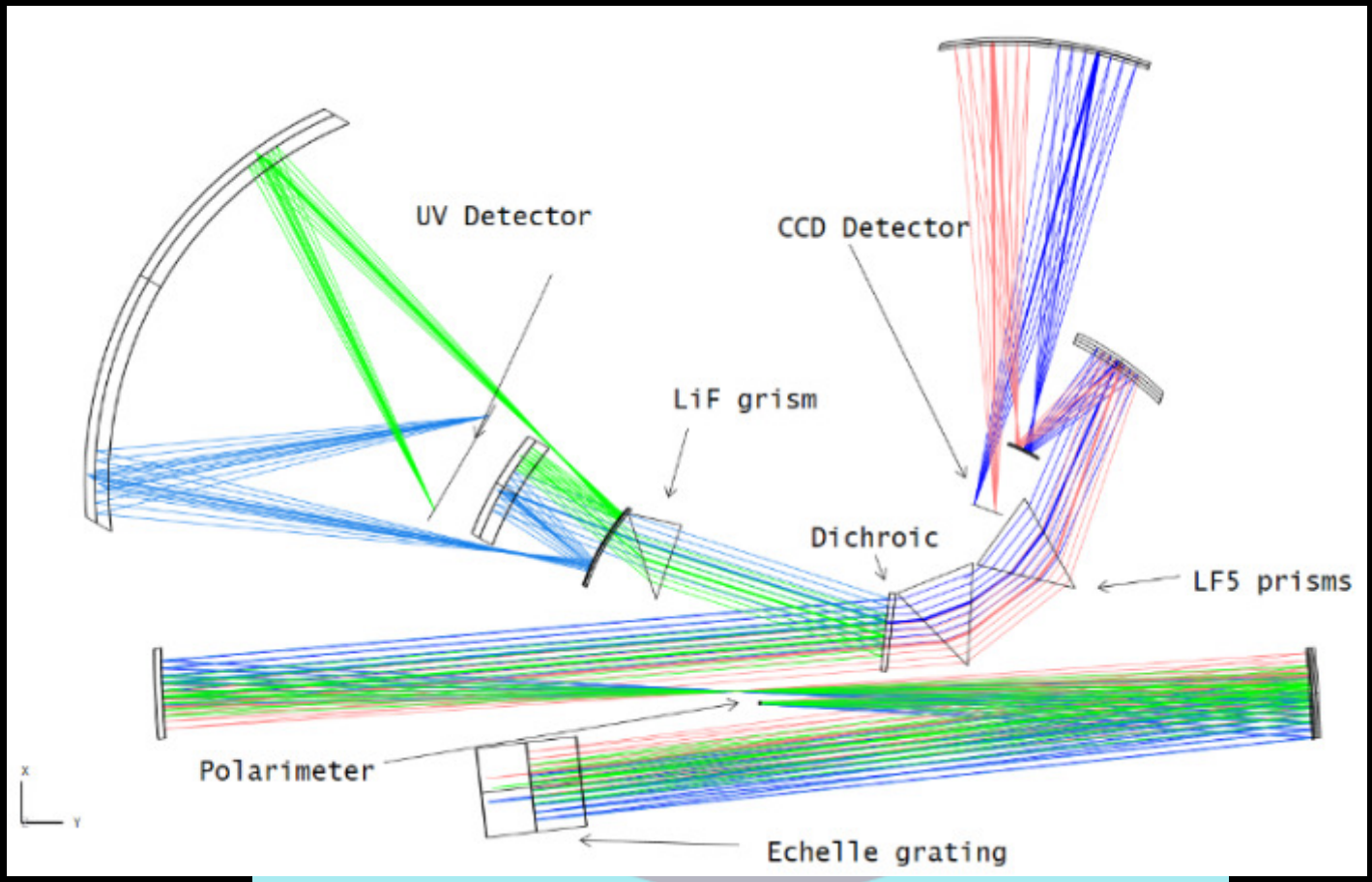
Spec. :

- SNR 100
- V=7 Star
- 30 min exposure time

⇒ 1.3m diameter
Cassegrain telescope
F/13

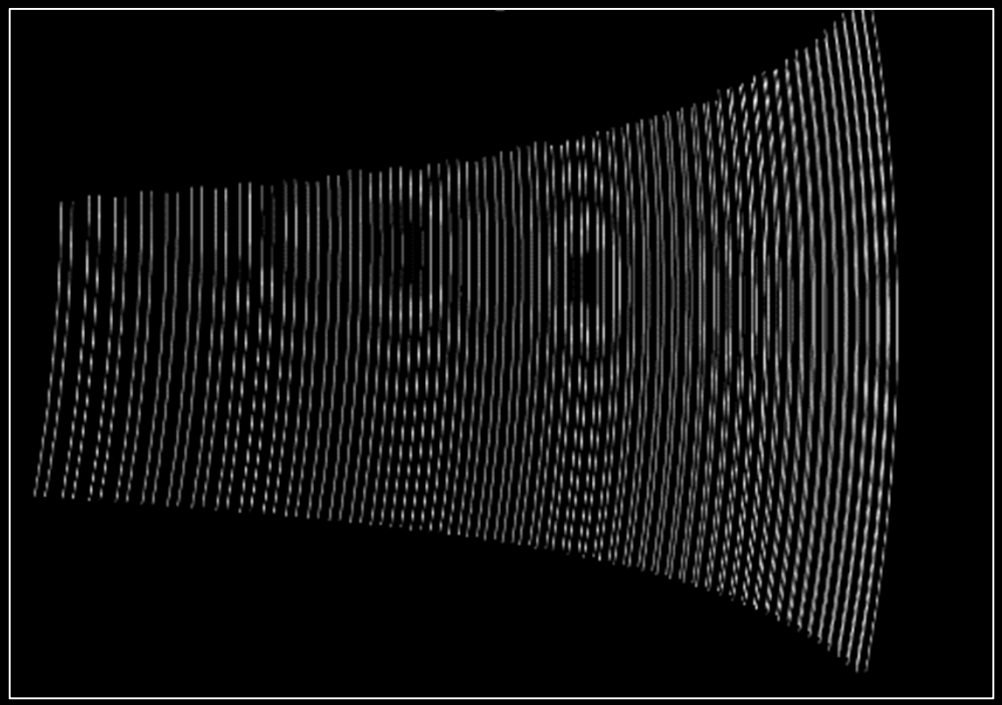


Spectrograph



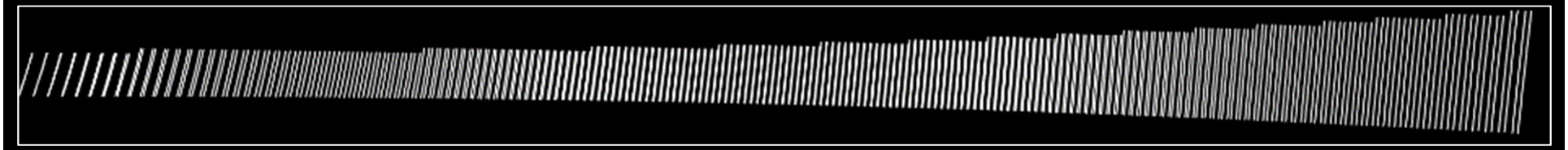
Instrument design for M4, will be redesigned for M5

Focal planes



Visible (for M4):

Frame size 30 x 30 mm



UV (for M4): Frame size 120 x 14 mm

Challenge

~~Achromatic plates~~

~~Liquid crystal~~

Optimized rotating plates

Create an efficient polarimeter from FUV to NIR for a space mission

Spatial modulation

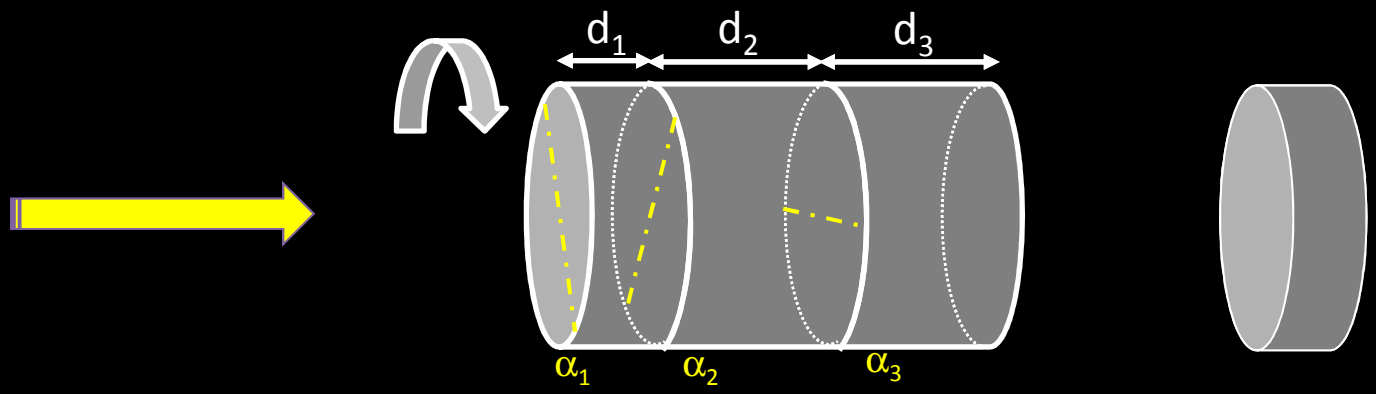
Polarimeter : baseline

Aim : create a polychromatic polarimetric modulator

- 3 MgF_2 stacked wave plates with fast-axis angle and thicknesses:

  (α_1,d_1), (α_2,d_2),(α_3,d_3)
- Optimization on these 6 variables

- The stack of the 3 plates takes 6 different angular positions (0°,30°,60°,90°,120° et 150°)



Polarimeter: baseline

Aim : create a polychromatic polarimetric modulator

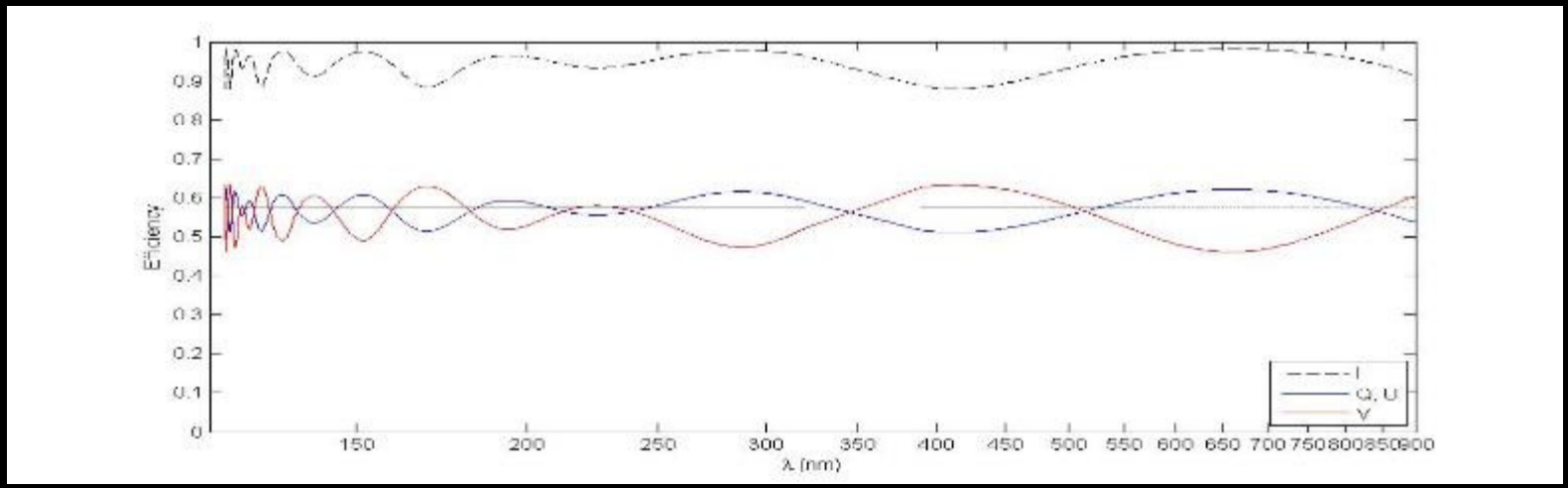
- Definition of a **demodulation matrix** D such as: $S_{in}=D.I_{out}$
- The extraction efficiencies of the Stokes parameters *:

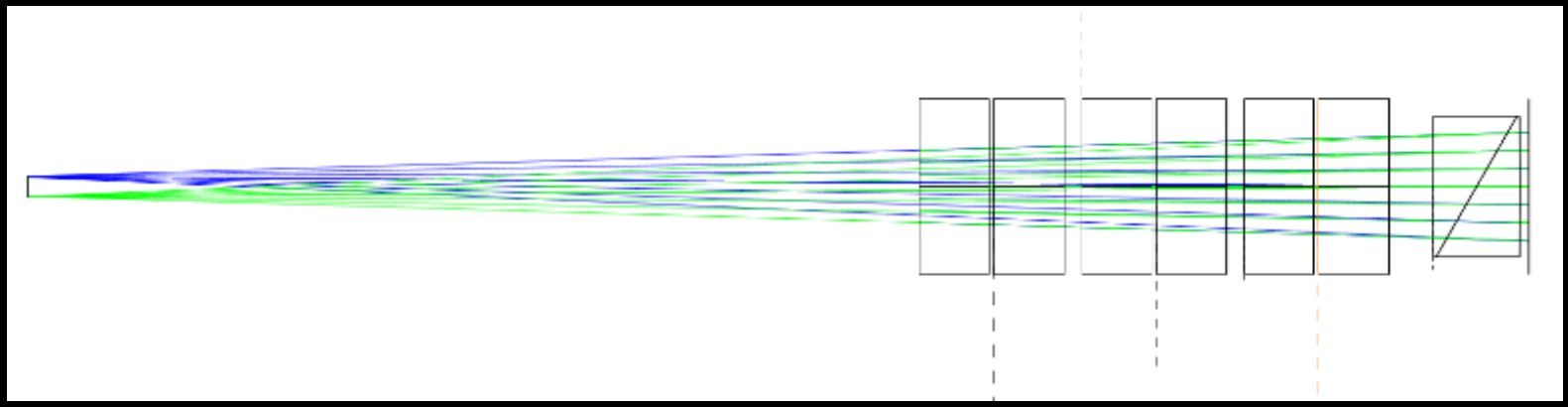
$$\epsilon_i = \left(n \sum_{j=1}^{n} D_{ij}^2 \right)^{-1/2}$$

- The optimal efficiency for Q, U and V is $1/\sqrt{3}$ ≈57.7%
- **The extraction is achromatized and not the retardance of the plates!**

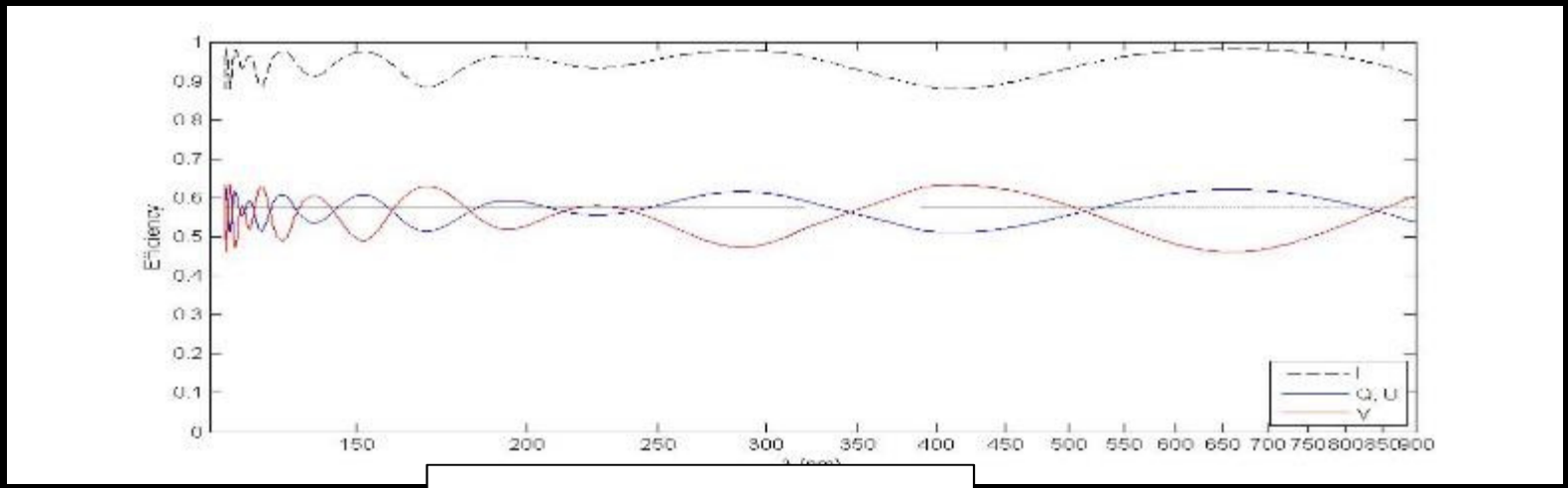
** Optimum modulation and demodulation matrices for solar polarimetry,* JC del Toro Inista and Collados (2000)

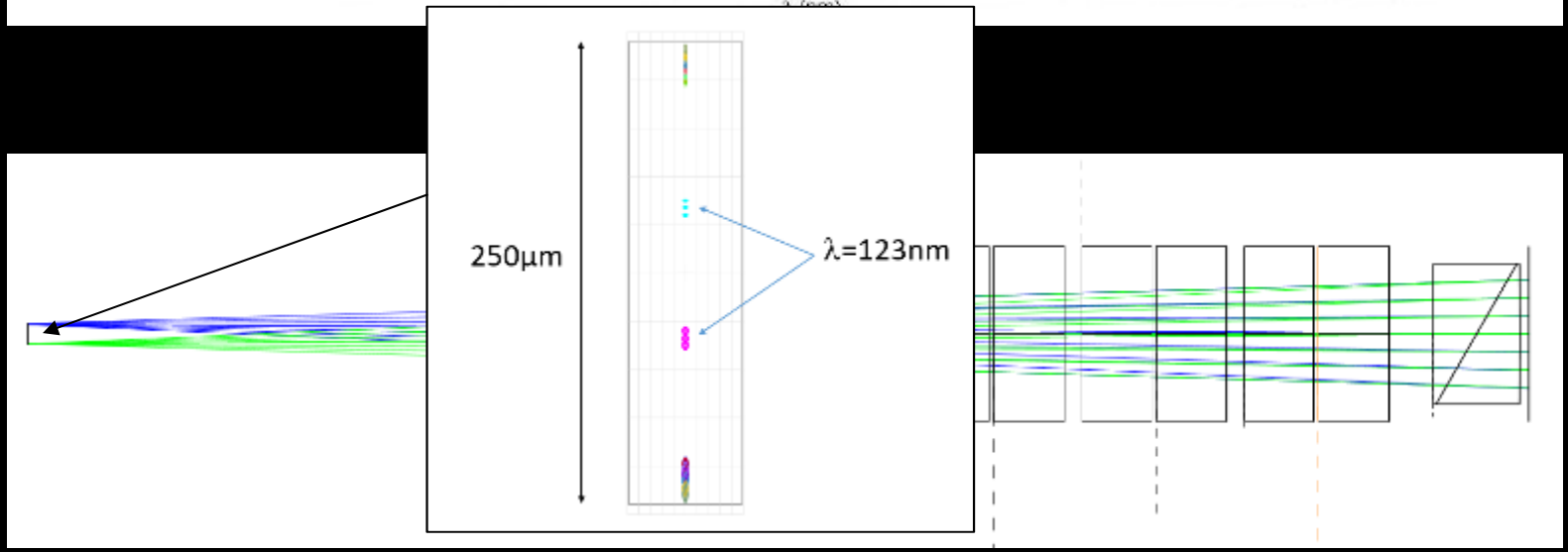
Polarimeter: baseline





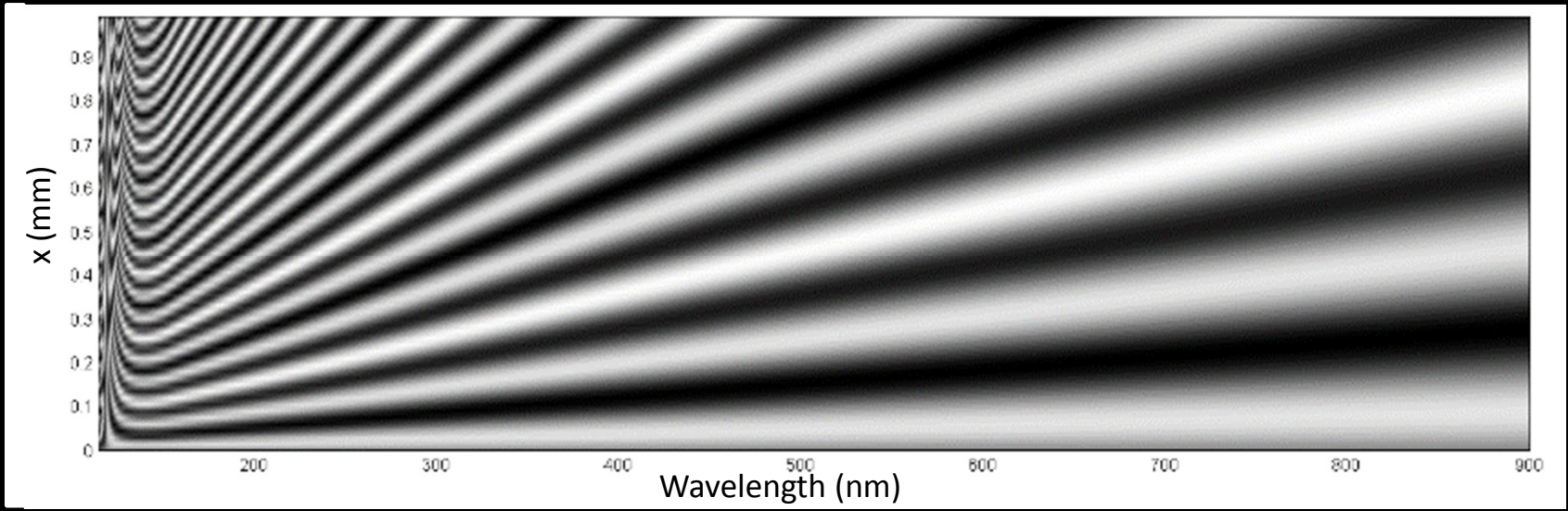
Polarimeter: baseline



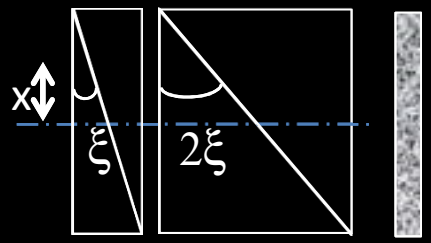


Polarimeter:
R&D on a new concept

Concept



$$x = \frac{\Phi}{4\pi \tan(\xi)} \cdot \frac{\lambda}{\Delta n(\lambda)}$$

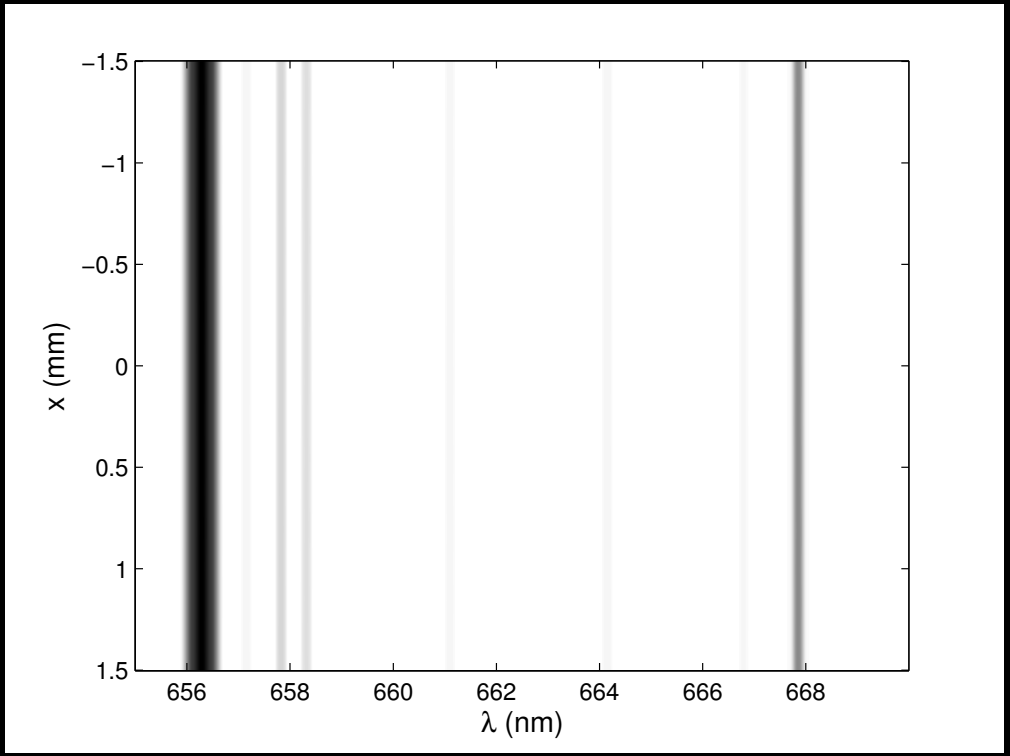


Polarizer

$$I_{out} = 0{,}5(I + Q(\cos\Phi cos2\theta - sin\Phi \sin2\Phi \sin2\theta) + U\cos2\Phi\sin2\theta + V(\cos\Phi\sin2\Phi\sin2\theta + \sin\Phi\cos2\theta))$$

Sparks et al. (2012)
Pertenais et al. (2015)

Star simulation

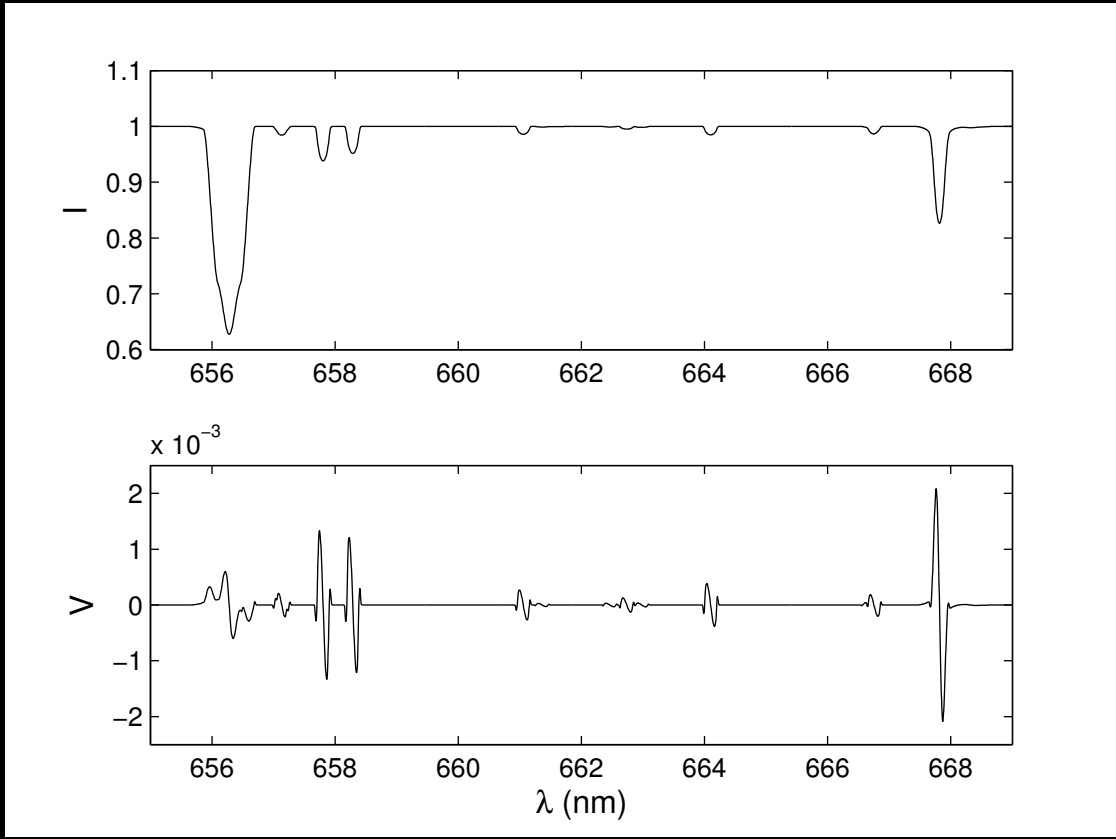


Simulation of the image obtained with a synthetic spectrum

- Teff= 30 000K
- Log g = 4.0
- 1000 G dipolar magnectic field

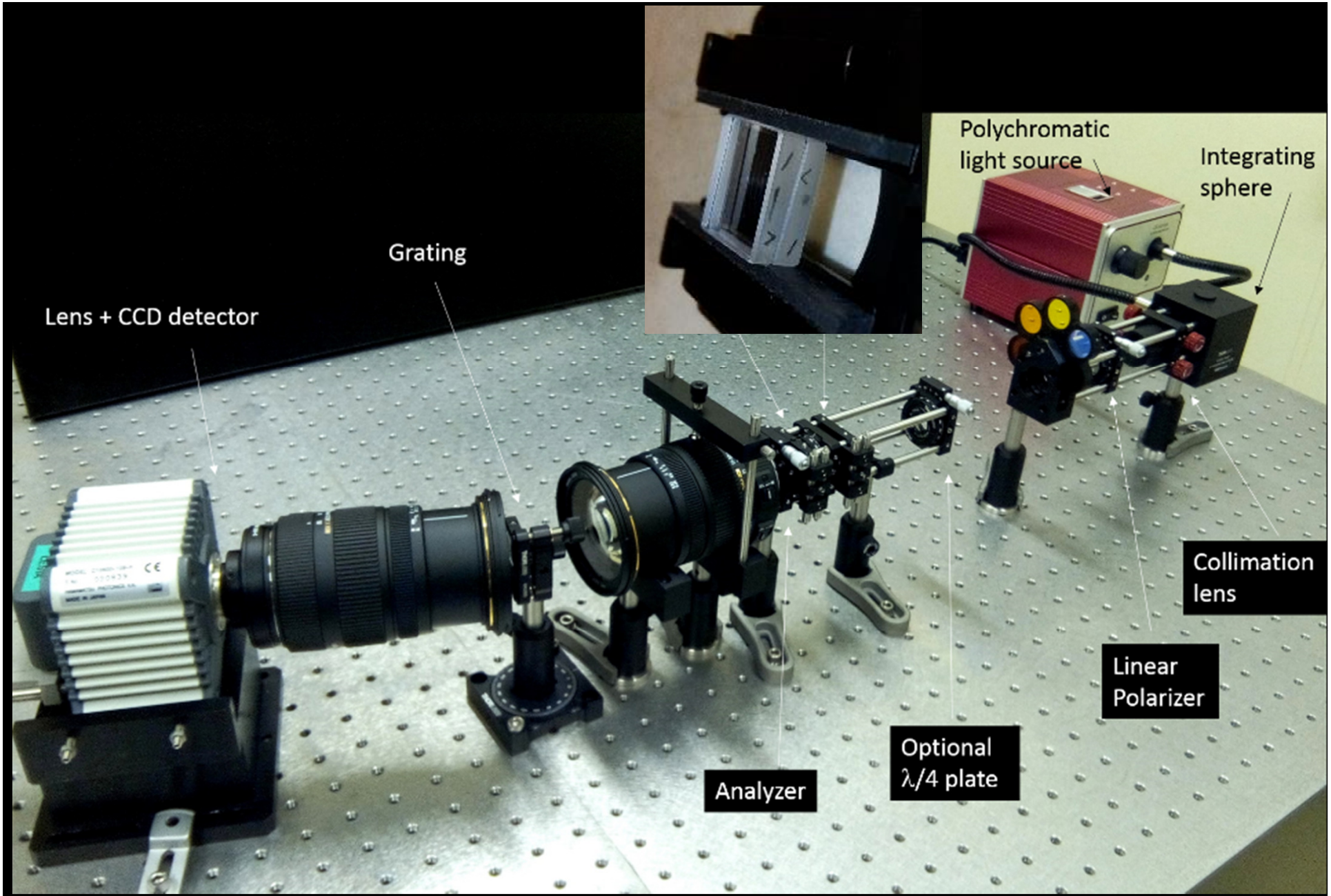
Pertenais et al. (2015)

Star simulation



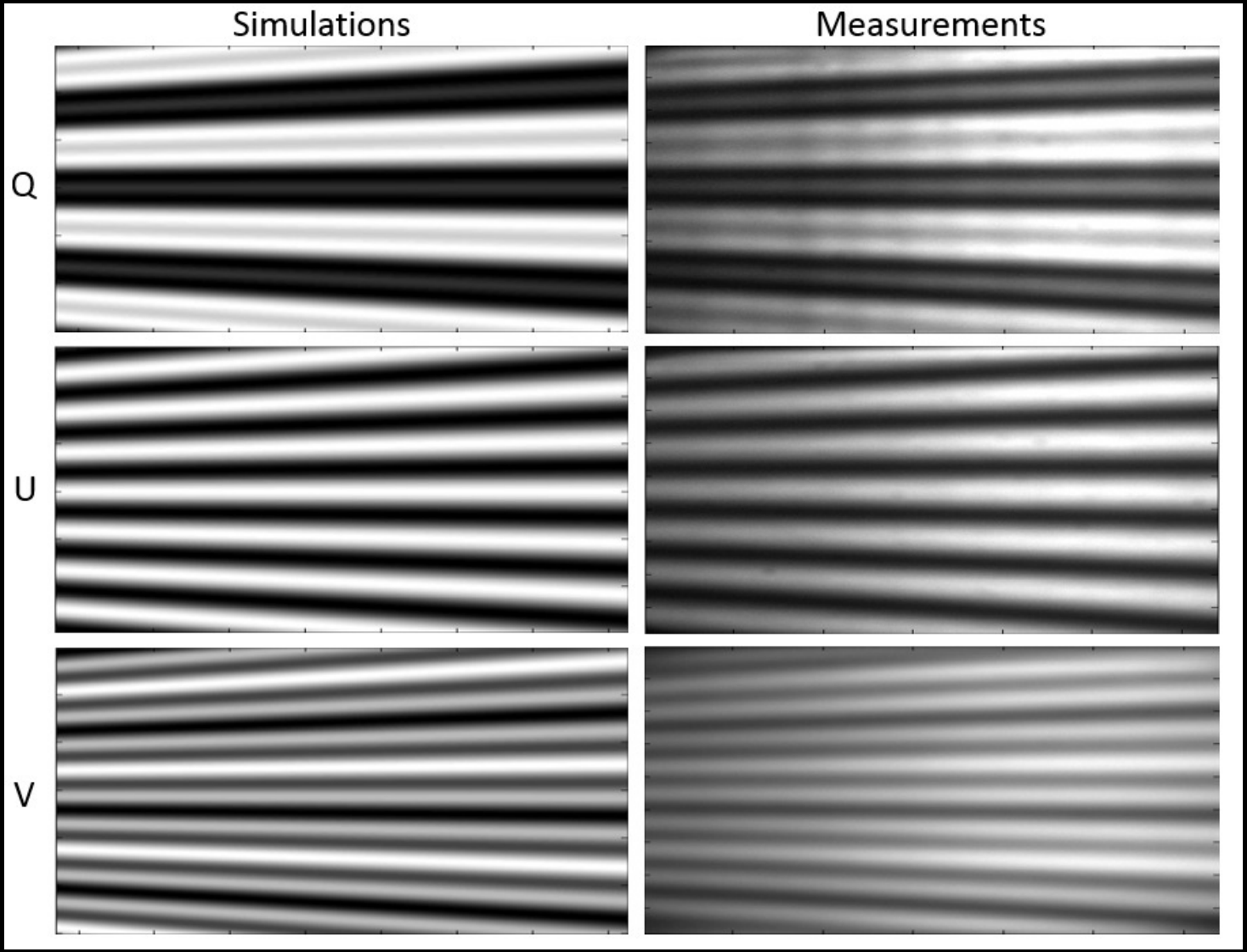
Retrieved Stokes I and V

Pertenais et al. (2015)



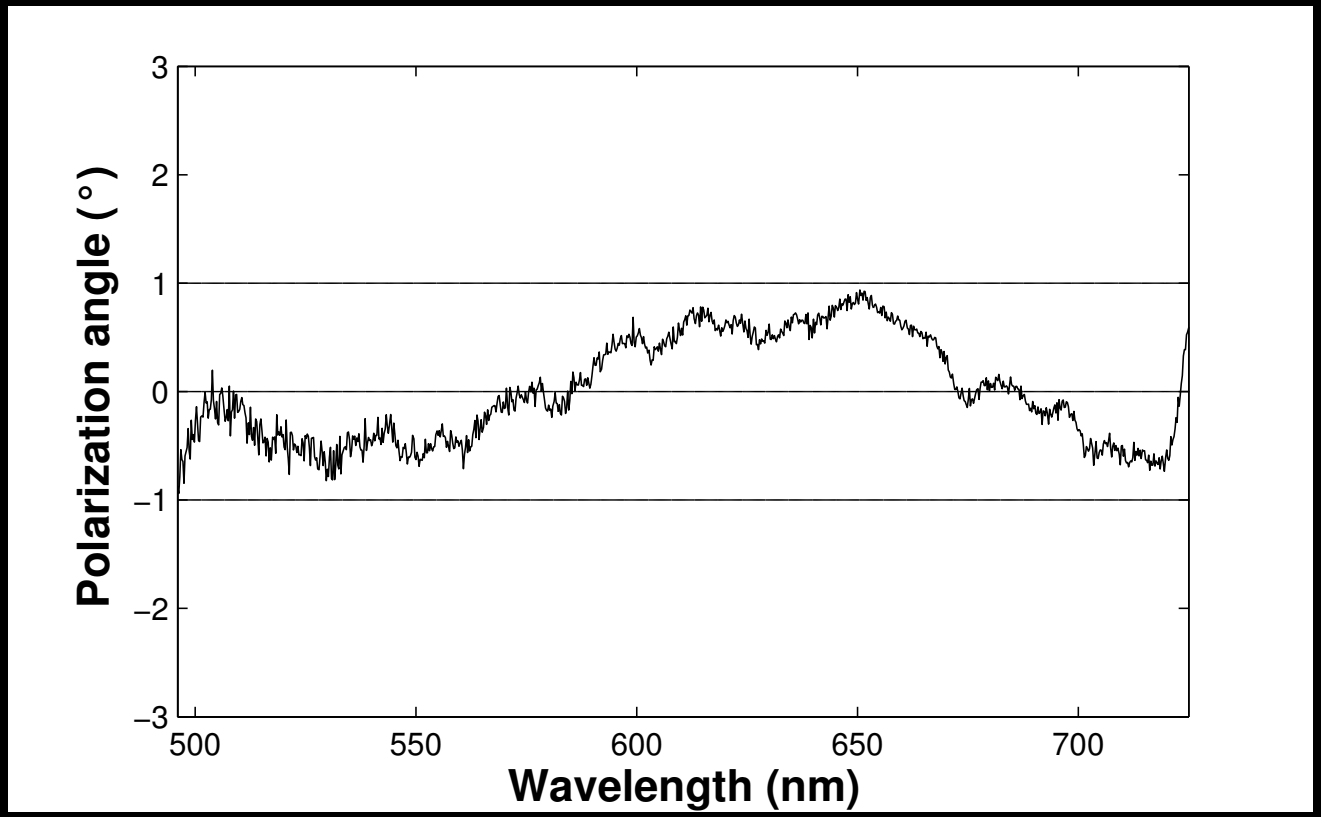
Pertenais et al. (2015)

First results



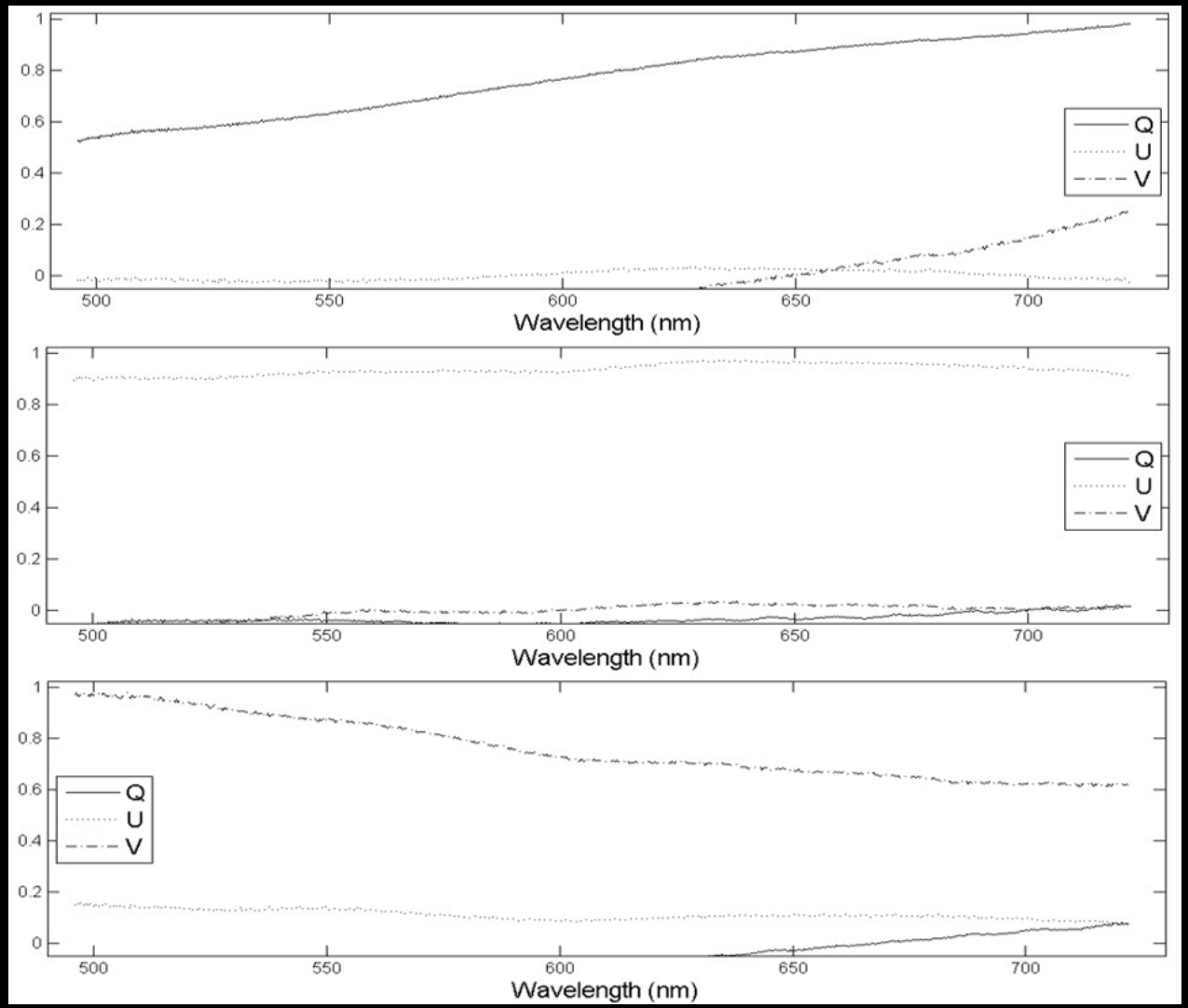
Pertenais et al. (2015)

Lab results



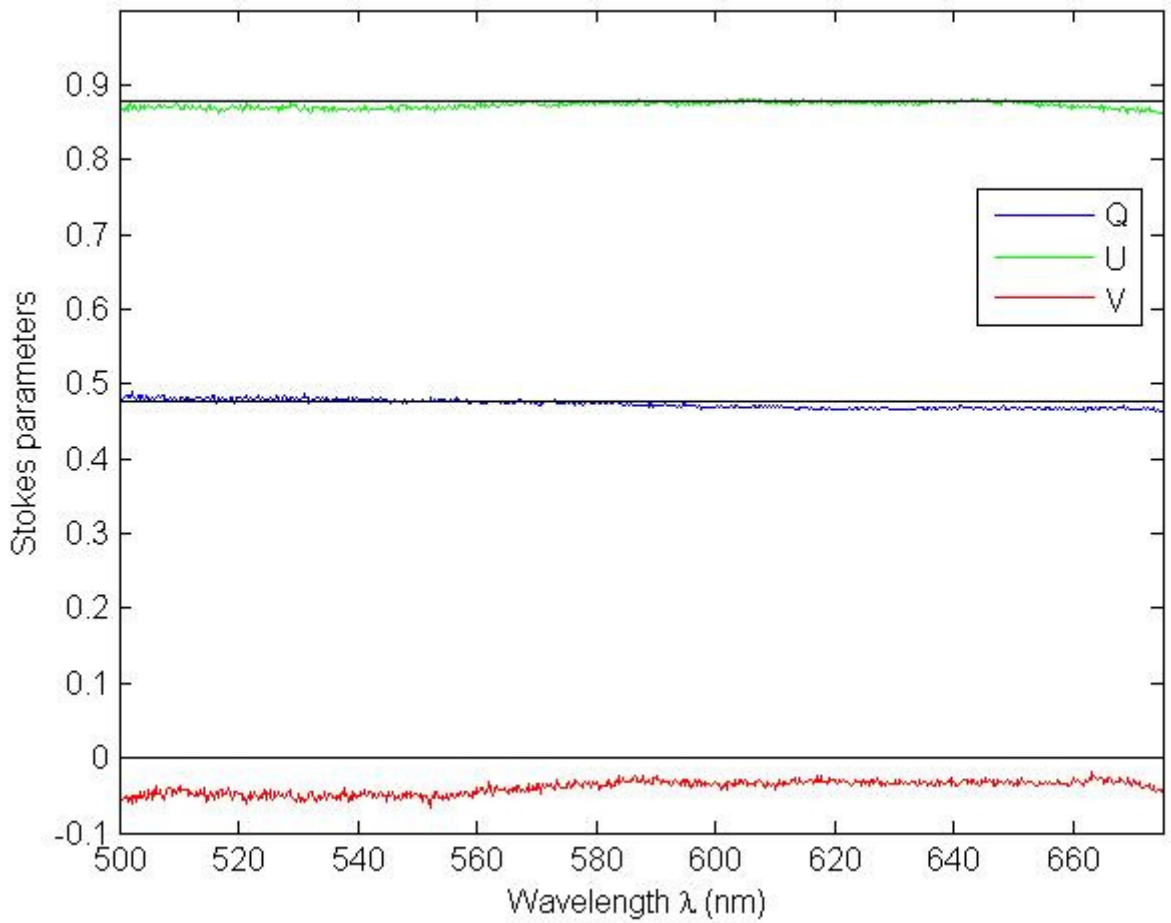
Pertenais et al. (2015)

Lab results



Pertenais et al. (2015)

Lab results



± 3.10^{-2} accuracy

Conclusions

- High-resolution spectropolarimetry
- Precise Full Stokes (IQUV) measurement
  - Baseline: polychromatic rotating modulator
  - R&D on innovative polarimeter concept
- From FUV (119 nm) to NIR (888 nm)
- Exciting science !

Thank you for your attention !

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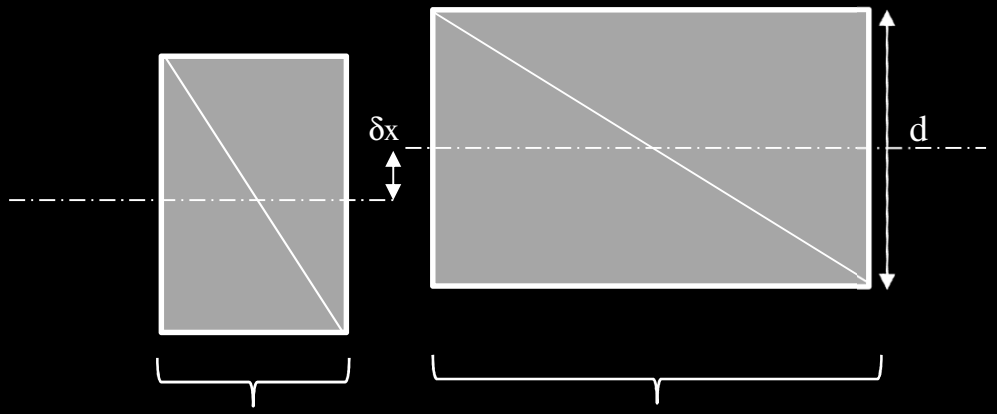
Acknowledgment : COST Action MP1104

Back-up slides

Tolerancing

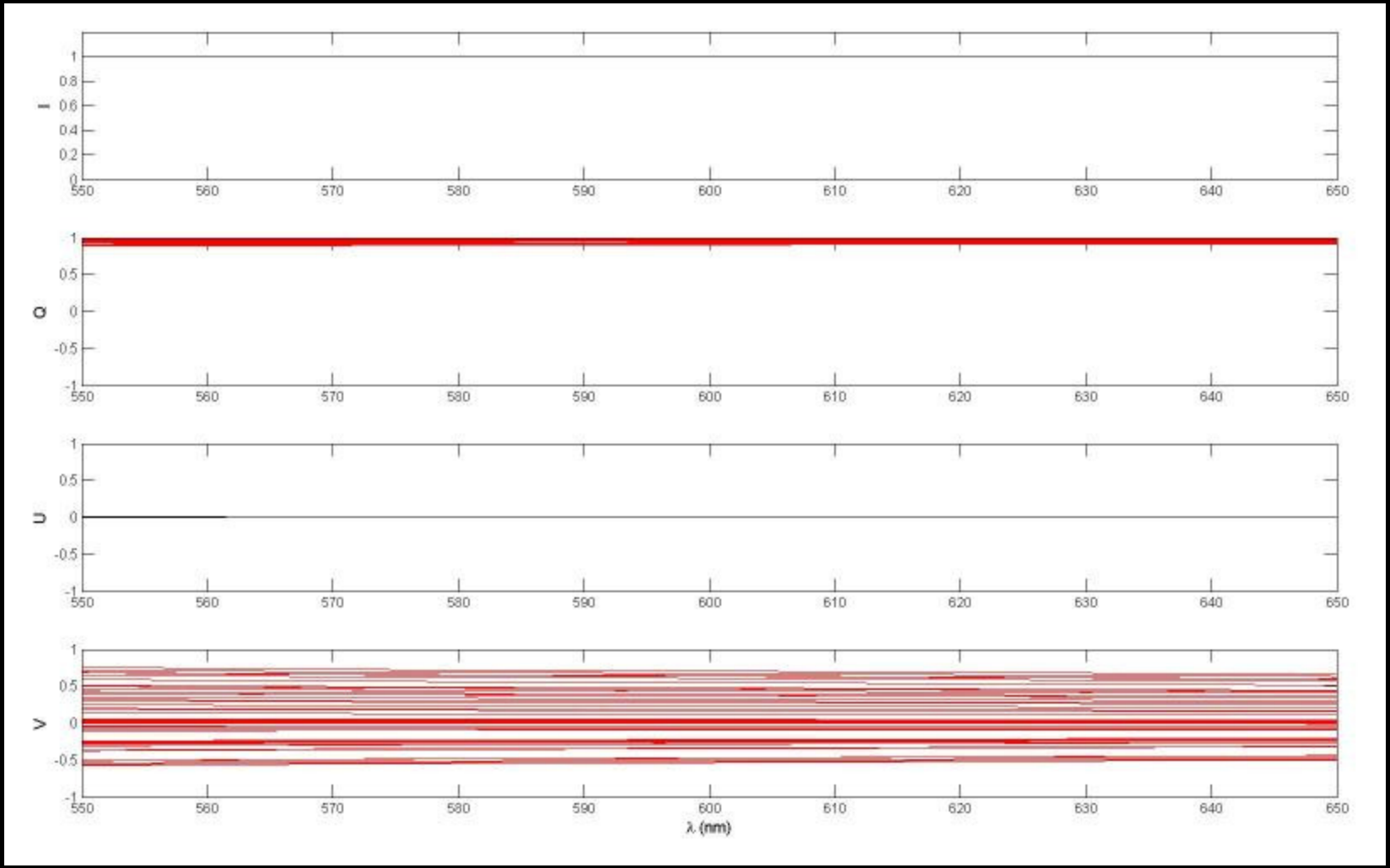
- Relative decenter



$$\delta\Phi = \frac{8\pi}{\lambda}\tan\xi\,\Delta n(\lambda)\delta x$$

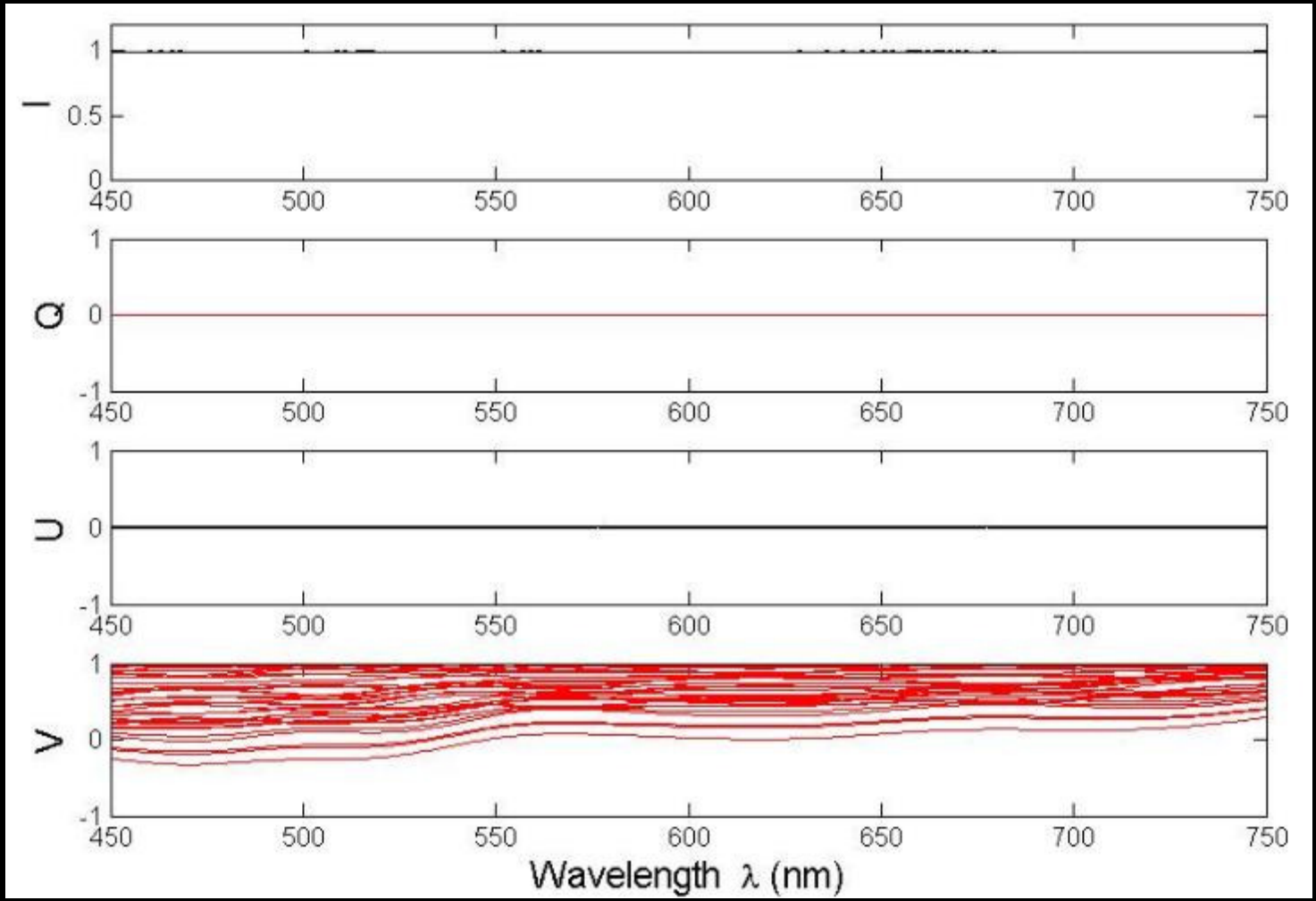
- Birefringence uncertainty
- Apex angle uncertainty

Tolerancing



Decenter δx=±0.05 mm
I=1, Q=1, U=0, V=0

Tolerancing

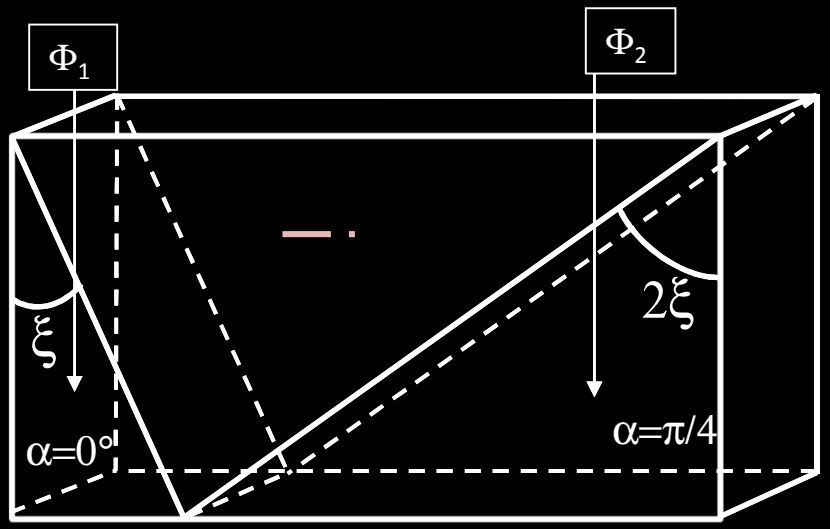


Apex angle ξ=1.5° ± 0.25°

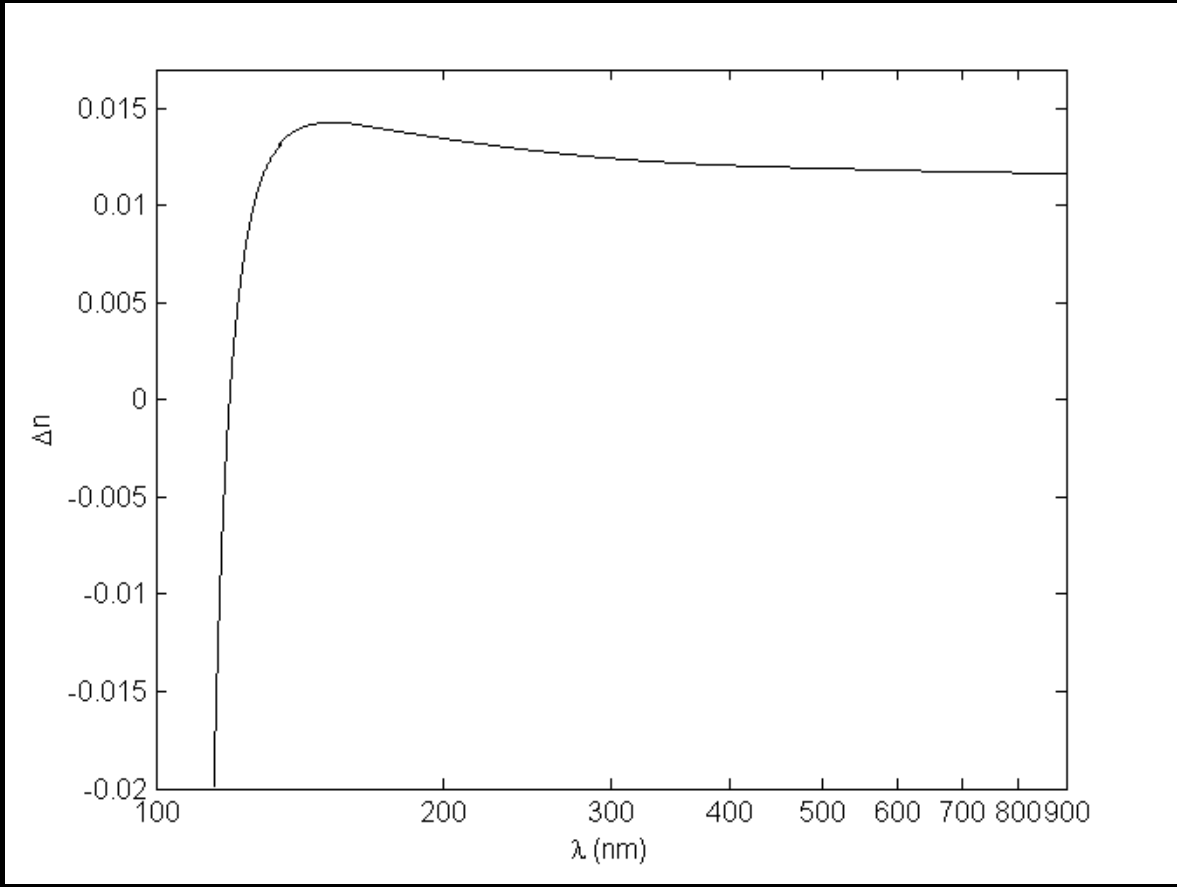
I=1, Q=0, U=0, V=1

Issues

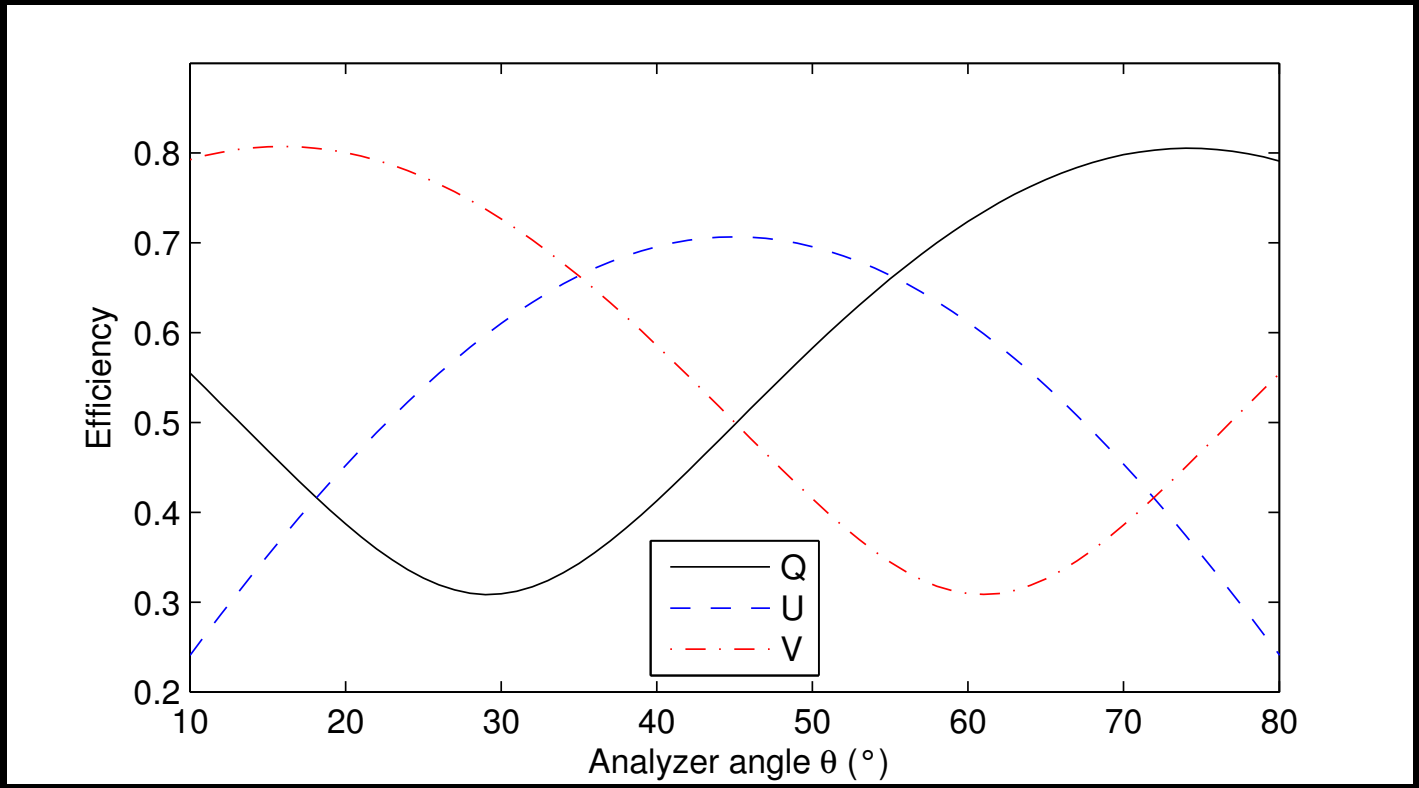
- Large orders -> large detectors
- Calibration
- Transmission
  - To limit the number of interfaces：



Birefringence MgF2



Efficiency



To be compared with 40-60% efficiency for polychromatic rotating modulator

Application to Arago

Fourier analysis-> periods of 2π, π et $2\pi/3$

We have to sample at $\pi/3$ (Nyquist) over a 2π signal (to have at least 1 period of the low frequency part)

At the minimal space gap (145nm) with a wedge angle ξ=1.5°, a phase difference of $\pi/3$ corresponds to 32µm. On the other side, a phase difference of 2π at 888nm corresponds to 1440µm
If the magnification of the spectro is set to 0.7, we can sample the signal correctly on the detector with 20 µm pixels. This implied an order thickness of 0.7*1.44=1mm

-> CCD of ~45 mm for the visible
-> 2 MCP detectors of ~85mm for the UV
(x2 if we want dual-beam …)

Targets

Legacy survey:

- 5490 stars with V>3 and V or B <6
- observed twice during the mission
- SNR ≥ 100

Mapping of stars and their environment (3<V<10):

- Cartography of ~100 stars monitored during a stellar rotation period
- Solar-type stars mapped every year → cycle
- SNR = 100 for V=7

Focused surveys (3<V<15):

- Statistical samples of stars (e.g. O stars, planet-hosting stars,...)
- observed once each

Target of Opportunity (ToO): supernovae, outbursts,...

- Observations triggered by external alerts

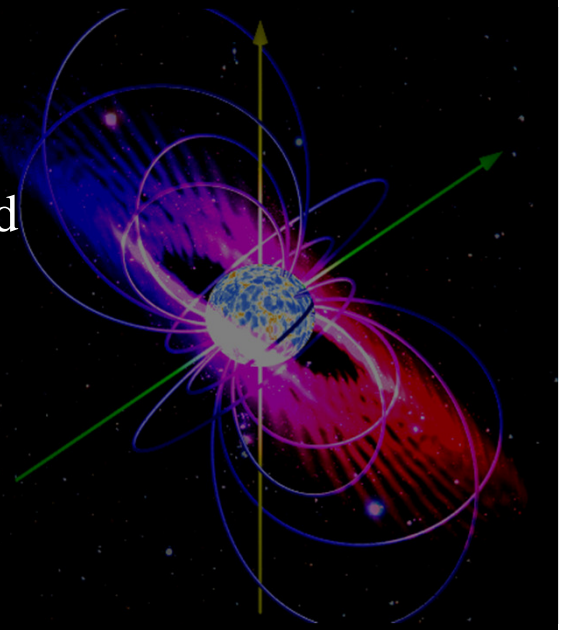
Observing program

Survey program:

- statistical sample of several thousands stars
- each star is observed twice during the mission → variability
- including a magnitue-limited (B=6) Legacy survey
- other samples (50%) chosen through calls for proposals

Mapping program:

- about 100 well-chosen stars (all types,
- all evolutionary stages, hosts of exoplanets,...)
- each star is observed during a full rotation period
- → full 3D cartography of its surface and
- environment
- from calls for proposal



Target of Opportunity program:

- supernovae
- outbursts of Be stars
- ...