A Dual Beam UV-Polarimeter for the Solar Corona

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Abstract

DualPol-UV is a project for a prototype of an innovative ultraviolet imaging dual-beam polarimeter for the HI Ly-alpha 121.6 nm line. A beam-splitter MgF_2 window is the heart of the instrument, allowing the separation of the two linear polarization states, of the radiation from solar and stellar coronae/chromospheres, and feeding them into two separate channels. The beam-swap technique will ensure the correction of the instrumental effects of the two channels, allowing the required high-accuracy imaging polarimetry (<1\%) in the UV spectral range. This will open a new window in astronomical UV imaging polarimetry for the diagnostics of magnetic fields. A future engineered version of DualPol-UV could be used in a coronagraph designed for a sub-orbital rocket flight.

Scientific motivation

Ground-based polarimetric observations have achieved considerable success in the diagnostics of the magnetic field in solar and stellar photospheres. In the solar chromosphere and corona, the magnetic field controls (through the Lorentz force) the structure and dynamics of the atmosphere. In these high-temperature (10^4–10^7 K) outer layers, strong resonance lines are formed in the far ultraviolet (UV) wavelength region. In the inner solar corona and in the outer solar and stellar envelopes, the Zeeman effect will not be observable because the magnetic fields are relatively weak. However, in the solar corona and stellar envelopes, line scattering polarization can be modified by a magnetic field through the Hanle effect. For UV wavelengths and temperatures typical of the solar corona and hot stars, the Hanle effect is expected to be a viable diagnostic of magnetic fields in the range of 1-10^2 G. The dominance of the magnetic field over the plasma in solar and stellar outer layers occurs when the β parameter (gas over magnetic pressure) is <1.

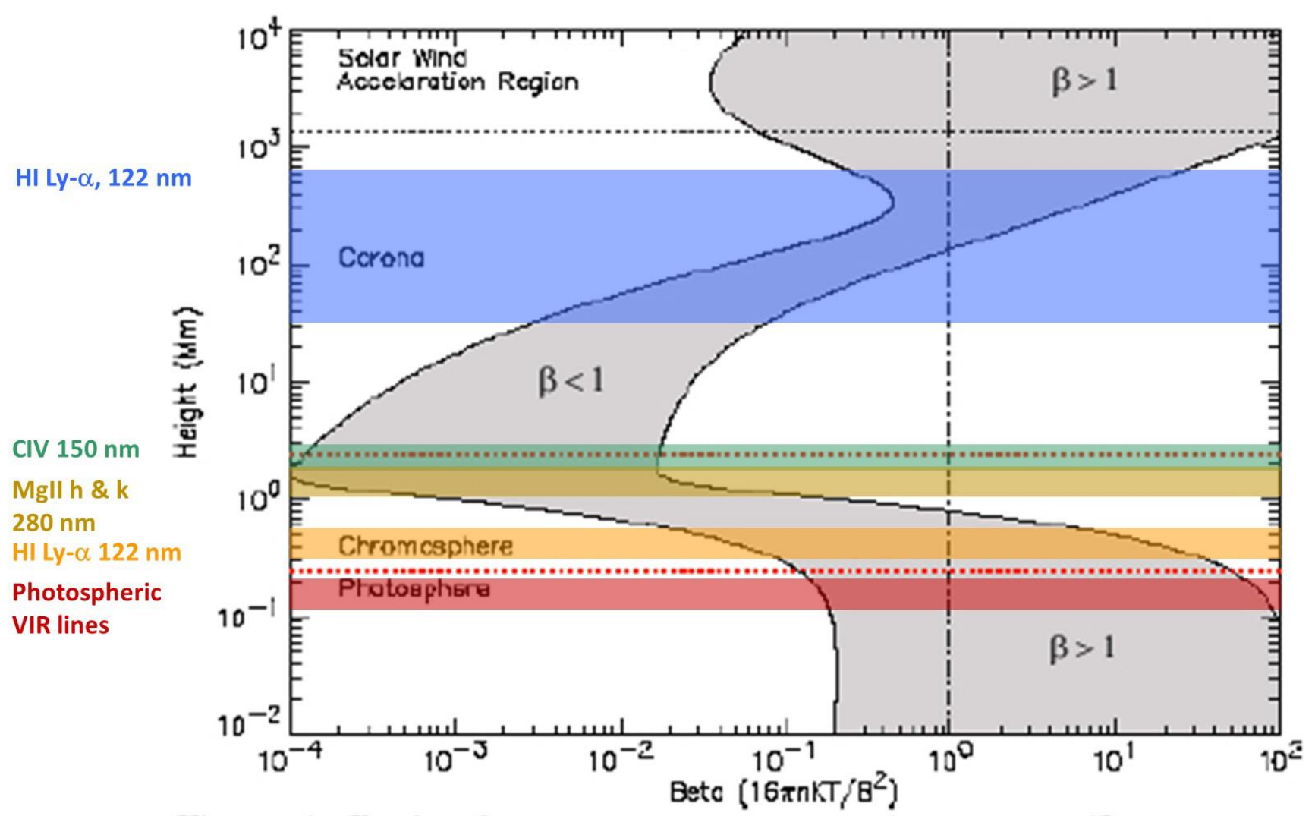


Figure 1. Ratio of gas pressure to magnetic pressure (β) as a function of height[1].

The DualPol-UV project

DualPol-UV is a project for a prototype of an innovative ultraviolet imaging dual-beam polarimeter for the HI Ly-alpha, 121.6 nm, line. The key, element of DualPol-UV is the polarizing beam splitter. This consists of a polarization reflecting and transmitting MgF_2 window coated with an original multilayer that we developed and tested over the years in collaboration with CSIC Spain. DualPol-UV will extend high-accuracy imaging polarimetry (<1 %) to the UV spectral range. This would open a new window in astronomical UV (122-280 nm) imaging polarimetry for the diagnostics of magnetized plasma in stellar and solar coronae/chromospheres, as well as in the extended solar corona, providing, in particular, direct diagnostics of the magnetic fields in the solar corona and chromosphere.

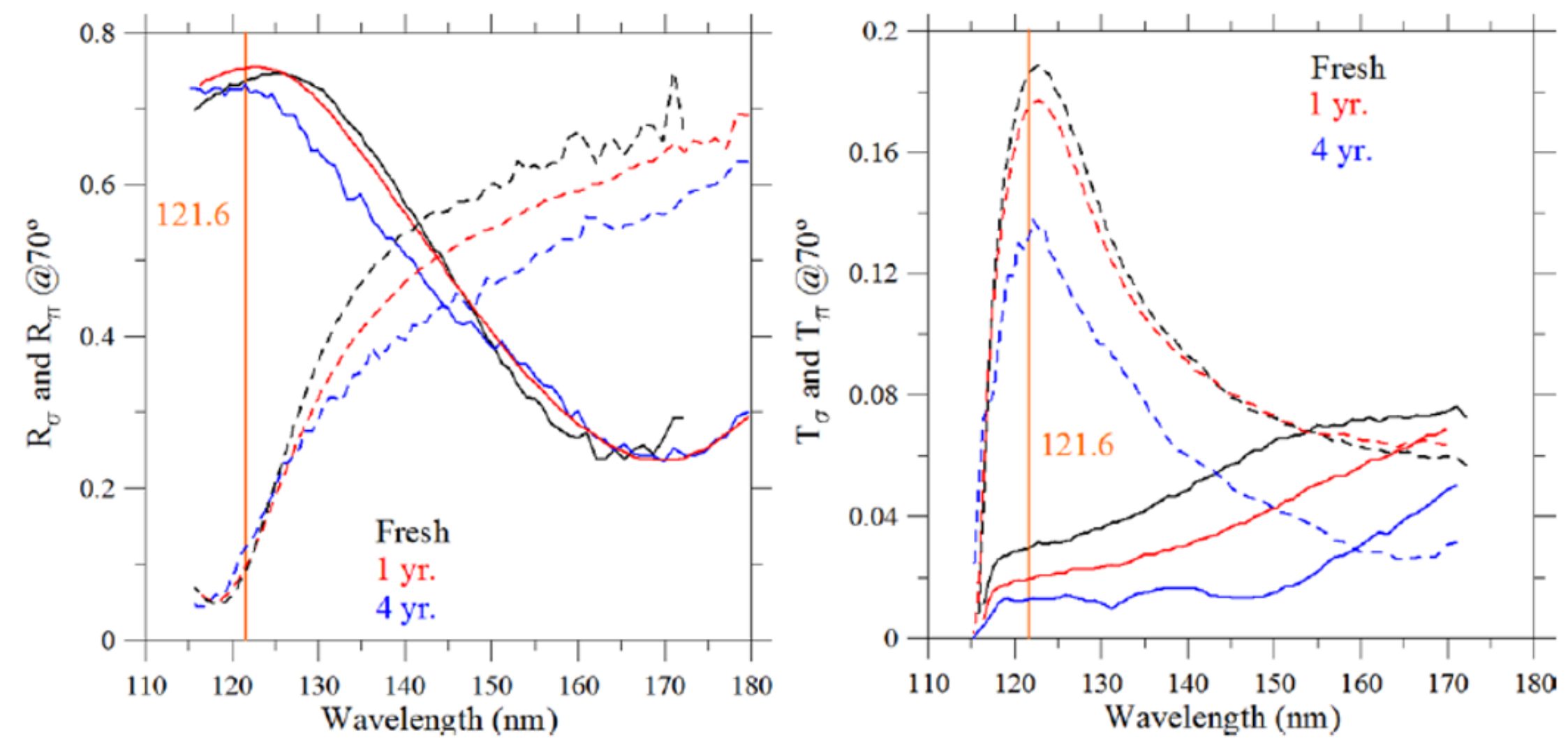


*Figure 1 - Reflectance (left) and transmittance (right) at 70° of a multilayer beam-splitter polarizer optimized at 121.6 nm for fresh sample and for the sample aged of one and four years. R**σ**, R**π**, T**σ**, and T**π** stand for experimental reflectance/transmittance measurements before deducting the contribution of the cross polarization. Solid line: **σ**; dashed line: **π**.*

Innovative aspects of the Project

This proposal builds on the successful development of UV ML beam-splitter polarizers with large enough beam aperture and beam separation to allow - for the first time – high sensitivity (< 1%), dual-beam imaging polarimetry in the 122 – 280 nm wavelength range.

With reference to the surface of the beam-splitter plate, the polarization component ***π*** is parallel to the plane of incidence, and the component σ is perpendicular to the plane of incidence. The purpose of the multilayer beam-splitter polarizer is to reflect as much as possible of the σ component, minimizing the transmission, and to transmit as much as possible of the ***π*** component minimzing the reflection.

Innovative aspects of the project:

- use of a multilayer beamsplitter polarizer;
- beam-swap polarimetry in UV (da 100 a 300 nm);

Advantages of using a multilayer beamsplitter:

- with a single device separates σ from ***π*** polarization; minimizes attenuation and enables a compact and light polarimeter, which is important for space instruments;
- the beam-swap scheme reduces the instrumental differences of using two detecting channels.

Case study:

measurement of the coronal H Lyman alpha emission, linearly polarized by resonant scattering, and modified by Hanle effect and anisotropic Doppler Dimming.

	@155 nm				@280 nm				@121.6 nm			
Angle	μ_R	κ_R	μ_T	κ_T	μ_R	κ_R	μ_T	κ_T	μ_R	κ_R	μ_T	κ_T
65°	0.516	0.369	0.913	0.227	0.816	0.398	0.912	0.216				
70°	0.596	0.425	0.946	0.230	0.868	0.427	0.899	0.193	0.937	0.602	0.929	0.281
75°	0.683	0.486	0.975	0.230	0.685	0.354	0.952	0.209	0.823	0.529	0.767	0.252

*Table 1 - **μ** and **κ** at the indicated wavelengths and angles of incidence for the multilayer beamsplitter polarizers.*

$$\mu_R = \frac{R_s - R_p}{R_s + R_p} \quad \mu_T = \frac{T_p - T_s}{T_p + T_s}$$

$$\kappa_R = \mu_R\sqrt{R} \quad \kappa_T = \mu_T\sqrt{T}$$

		155 nm				280 nm				121.6 nm			
		μ_R	κ_R	μ_T	κ_T	μ_R	κ_R	μ_T	κ_T	μ_R	κ_R	μ_T	κ_T
ML Beamsplitter	70°	0.596	0.425	0.946	0.230	0.869	0.428	0.899	0.193	0.814	0.531	0.839	0.262
	75°	0.683	0.486	0.975	0.230	0.685	0.354	0.952	0.209	0.943	0.610	0.881	0.265
MgF_2 plate (BA)[a]		~1	0.263	0.074	0.072	~1	0.238	0.061	0.058	~1	0.251	0.067	0.065
LiF pile of plates (BA)[b]	4 plates									0.992	0.505	0.67	0.235
	6 plates									0.986	0.488	0.80	0.179
$(MgF_2/Al)_2$[c]										0.92	0.55	-	-
Quartz plate (BA)[a]		0.996	0.366	0.156	0.145	0.996	0.316	0.112	0.106				

Table 2 - **Comparison between the present multilayer beam-splitter polarizers shown in Figs. 5 (for a 3-year aged multilayer beam-splitter tuned at 155 and 280nm and aged at 70° and 75°) and Fig. 10(for the multilayer beams-plitter tuned at 121.6nm and aged one year at 70° and 75°), a parallel plate of MgF_2 at Brewster angle (BA), a LiF pile of plates at BA, a $(MgF_2/Al)_2$ coating polarizer at 66° only operating by reflectance, and a parallel plate of quartz at BA**

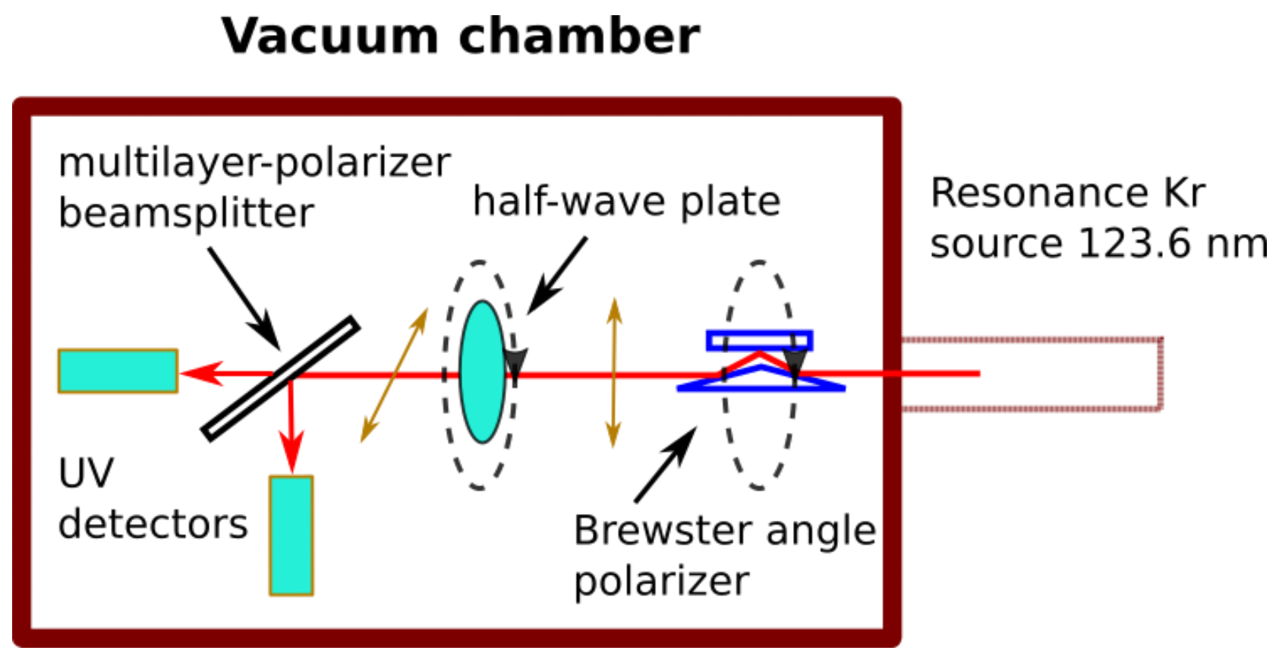
Multilayer properties:

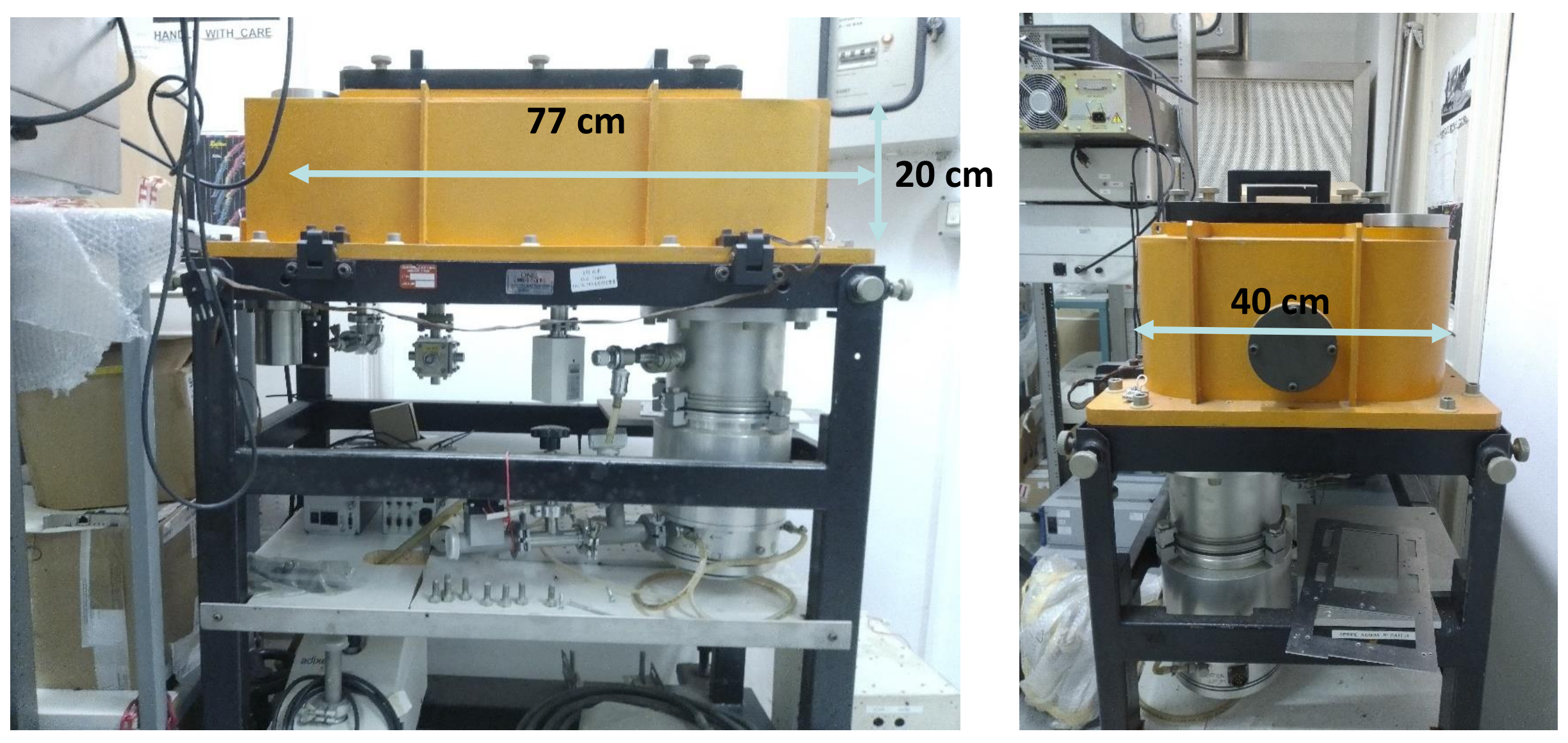
- Good reflectance and transmittance.
- Maintenance of performances with ageing.
- Maximum quality factor among other different possible choices.

UV Pol Demonstration Setup

The demonstration model will be assembled and tested in the Vacuum Technology Laboratory at the Osservatorio Astrofisico di Torino.

- The light from a Resonance Kr 123.6 nm UV source is linearly polarized by means of a rotating Brewster angle polarizer.
- An half-wave plate rotates the polarization of the incoming radiation, in order to apply the beam-swap measurement technique, by virtually exchanging the role of the reflected and transmitted channels.
- The beam-splitter polarizer plate separates the two σ and ***π*** polarization states in the reflected and transmitted channels.
- The two signals are measured by two UV vacuum compatible detectors.





Demonstration setup and vacuum chamber in the vacuum technology laboratory at the Osservatorio Astrofisico di Torino

Beam-swap Technique

The beam swap technique allows, by rotating the polarization of the incoming beam, to avoid the problem of the different sensitivities of the two channels, yielding Stokes Q/I and U/I quantities that are largely free of instrumental effects:

- 1st exposure: no rotation angle
- 2nd exposure: the polarization is rotated by 90 deg with respect to the polarization axes of the beam-splitter

$$S_1^s = g_s\alpha_1(I-Q), \quad S_1^p = g_p\alpha_1(I+Q)$$

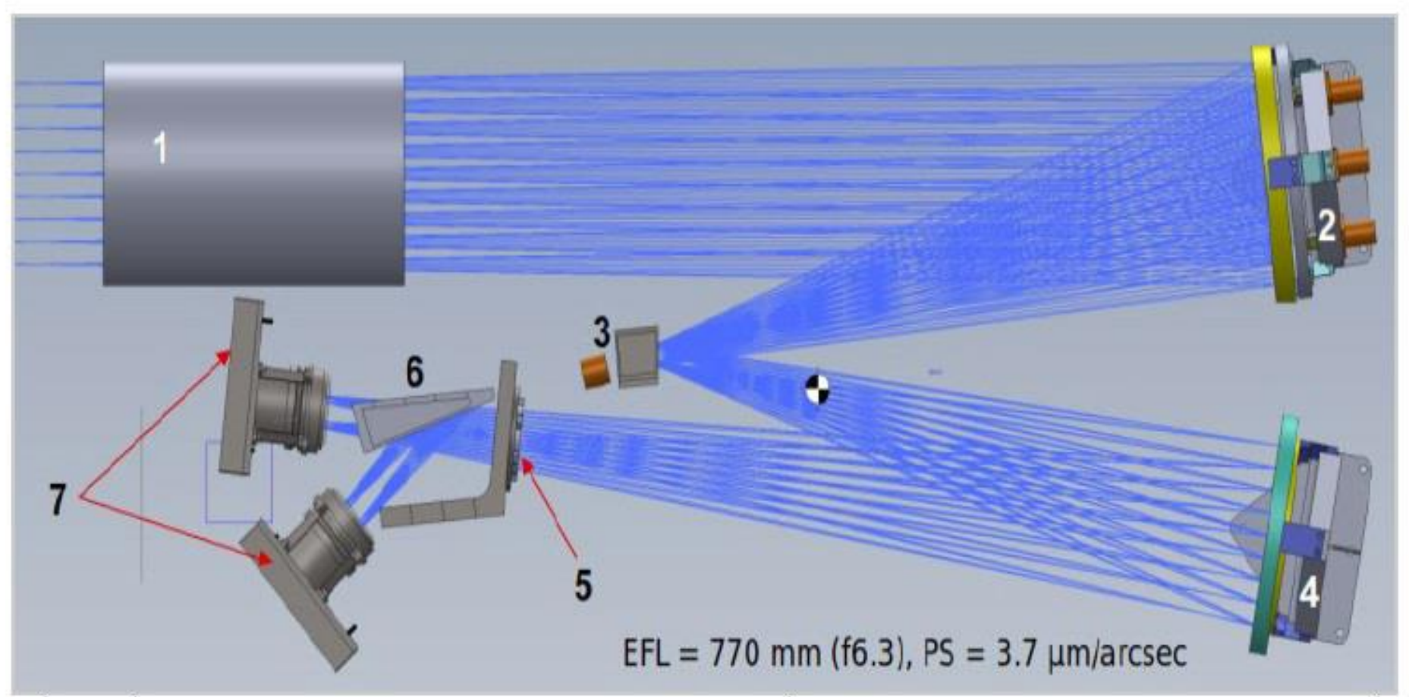
$$S_2^s = g_s\alpha_2(I+Q), \quad S_2^p = g_p\alpha_2(I-Q)$$

$$\frac{1}{4}\cdot\left(\frac{S_1^p S_2^s}{S_1^s S_2^p}-1\right) = \frac{1}{2}\cdot\frac{2IQ}{(I^2-2IQ+Q^2)} = \frac{Q}{I}$$

In a similar fashion, the polarization is then turned by 45, and 135, to obtain U/I.

DualPol-UV as a Prototype for a Sub-orbital Rocket Flight

The lesson learned by DualPol-UV will provide invaluable information to develop in the future an engineered version of a dual-beam, beam-swapping UV polarimeter that could be used in a coronagraphic payload for NASA suborbital missions. The following figure shows a possible accommodation of an engineered version of the DualPol-UV prototype for a coronagraph designed for a rocket flight (SCORE heritage).



#	Subsystem	Functionality
1	Entrance aperture (EA) + Baffles	Stray light control
2	Primary Mirror (M1)	Imaging
3	Inverse Occulter (M2/IO)	Disk rejection & light trap
4	Relay Mirror (M3) + Lyot trap	Imaging, stray light control
5	λ/2 rotating waveplate (stepped)	Polarization modulation
6	Polarizing Beam Splitter (PBS)	Dual-beam polarimetry
7	Detectors (2)	Dual-beam polarimetry

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