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Inverted-COR:
Inverted-Occultation Coronagraph
for Solar Orbiter

OATo Technical Report

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0.0 Abstract

This document describes a new, original optical scheme for the METIS-COR of Solar Orbiter (SO). The scheme is based on an inverted external-occulter (IEO). The IEO consists of a single, small (∅ 40 mm) circular aperture on the SO's thermal shield. This replaces the annular aperture in the current METIS-COR design. A small (∅ 72 mm) spherical mirror (M0) rejects back the disk-light through the IEO. The imaging system is an on-axis Gregorian telescope. Some of the advantages, over the current design, resulting from this scheme are summarized in the following points:

1. Thermal load on M0 reduced by 94%.
2. Smaller diameter boom (≈ 3 times) through the S/C thermal shield
3. On-axis telescope configuration yields better optical performances.
4. More compact, cylindrical structure
5. M0+Lyot-trap move to compensate the orbital "zooming" effect and S/C off-pointing

1.0 Optical concept of the inverted-occultation coronagraph

Figure 1 shows a schematic layout of the inverted-occultation coronagraph. The inverted external occulter (IEO) consists of a hole in the spacecraft (S/C) thermal shield. The disk-light is rejected back through the IOE by a spherical high-rejection mirror (M0). This configuration allows the adoption of an on-axis Gregorian design for the telescope. The suppression of the diffracted light off the edges of the IOE and M0 is achieved, respectively, with an internal occulter (IO) and a Lyot trap, in a way similar to the current design.

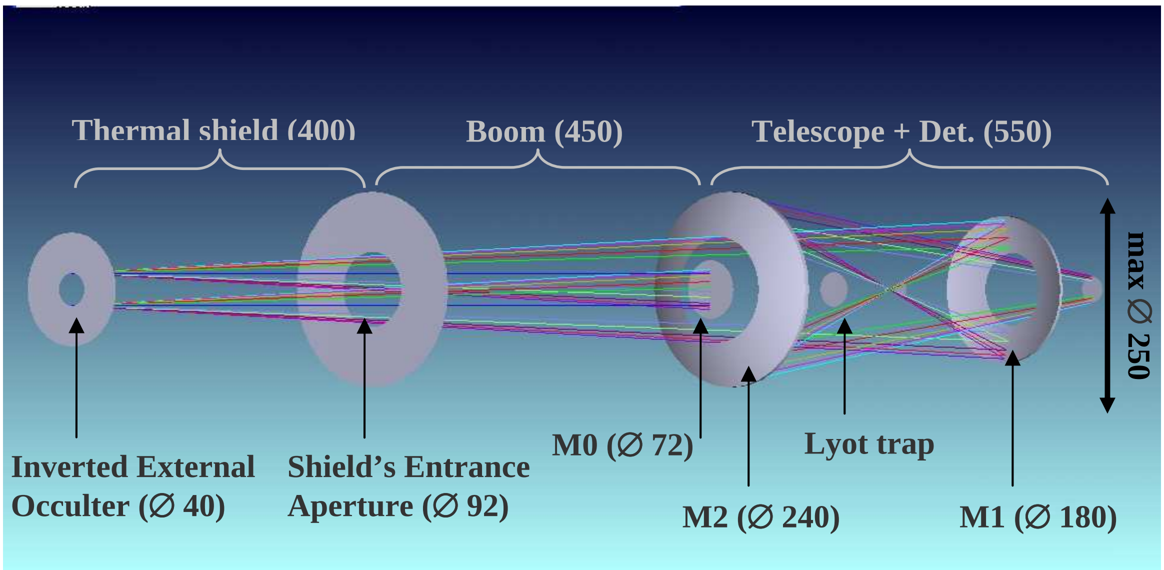

Figure 1 Conceptual layout of the inverted-occultation coronagraph optimized for perihelions up to 0.275 AU. (Dimensions are in mm.)

1.1 Optical design of the inverted-occultation coronagraph

Figure 2 and Figure 3 show the ray-traces of the inverted-occultation coronagraph for the EUV/UV and visible-light (VL) paths, respectively. Table 1 summarizes the optical specifications.

The VL and UV paths are split by an UV interference filter at 45°. The UV-capped multilayer (ML) coatings in the primary (M1) and secondary (M2) telescope mirrors are optimized for narrow bandpass reflectivity at 30.4 nm. The ML cap-layer has good reflectivity also in the UV (122 nm) and visible-light (500-650 nm). In the EUV path, the longer wavelengths are blocked by Al filter. The VL-UV beam splitter selects the 122 nm UV band and reflects the VL band. Inside the polarimeter a broad band filter selects the VL bandpass (500-650 nm).

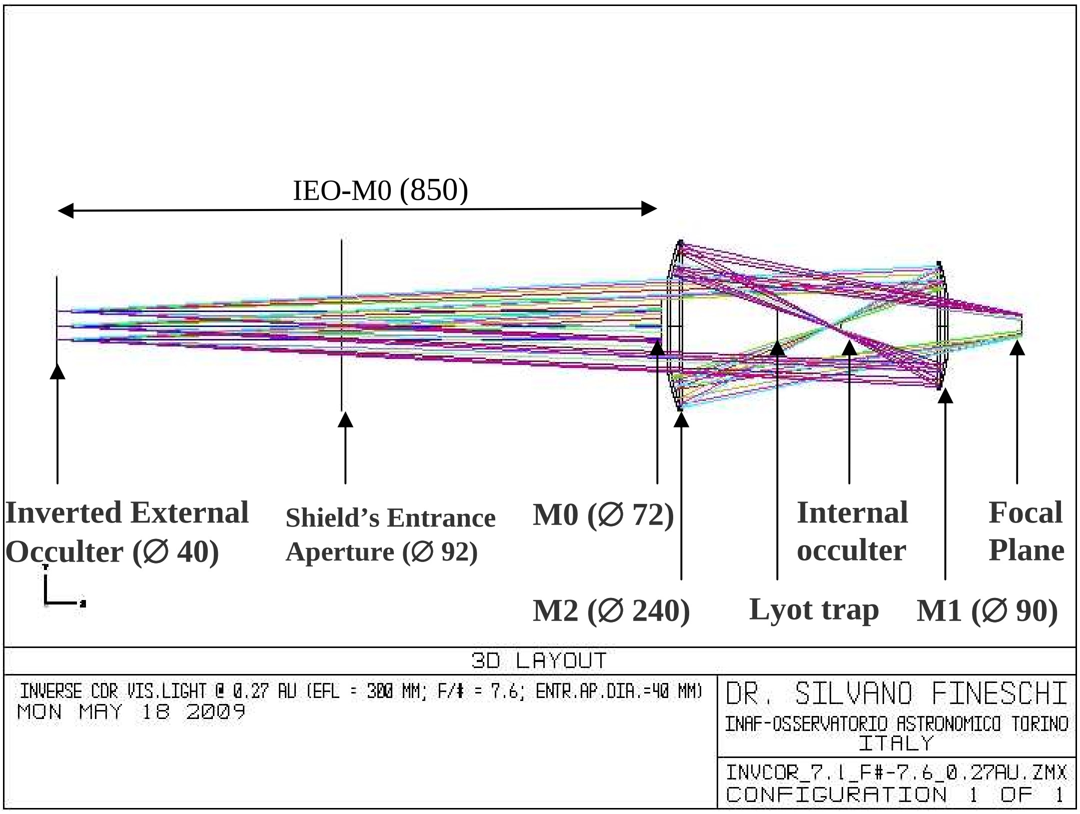

Figure 2 Ray-trace of the inverted-occultation coronagraph: UV and EUV path. (Dimensions are in mm).

The VL polarimeter consists of a liquid crystal variable retarder (LCVR) together with a fixed half-wave retarder and linear polarizer in "Senarmont" configuration. The polarimeter is in telecentric mount with collimating and camera lenses (cfr. Figure 3).

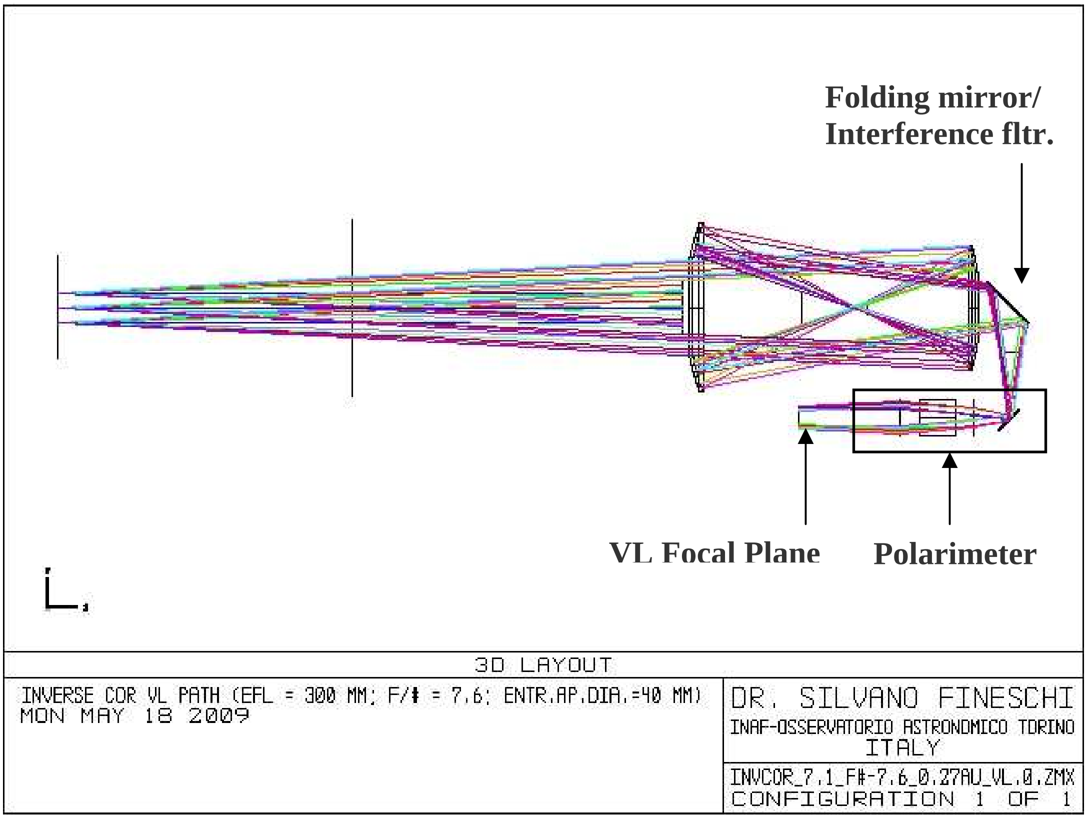

Figure 3 Ray-trace of the inverted-occultation coronagraph: Visible-light path.

Field of View	Annular Sun-centered 1.3 – 3. $R_\odot$ @ 0.23 AU and @ 0.27 AU (adjusting M0) 1.8 – 5.3 $R_\odot$ @ 0.3 AU
Dimensional envelope	Length 1350 mm (boom 850 mm+tel.500 mm) × max ∅ 250 mm
Telescope type	Externally occulted on-axis Gregorian
Effective focal length	300 mm
Inverted External Occulter (IEO)	Circular hole, Ø: 40 mm
Distance EO - M0	850 mm @ 0.23 AU; 700 mm @ 0.27 AU (by adjusting M0)
Sun-light Rejection mirror (M0)	Spherical: Ø: 72 mm, Curvature radius: 1600 mm Substrate: SiC Coating: SiC, Thickness: 12 mm
Stop aperture	Ø: 135 mm
Distance M0 - M1	408 mm @ 0.27 AU; 558 mm @ 0.23 AU (adjusting M0)
Primary mirror (M1)	On axis ellipsoidal: outer Ø: 180 mm, inner Ø: 90 mm Curvature radius: 300 mm, conic: -0.713 Substrate: SiC Coating: Multilayer, Thickness: TBD
Distance M1 - M2	395 mm
Secondary mirror (M2)	On axis ellipsoidal: outer Ø: 240 mm, inner Ø: 135 mm Curvature radius: 329 mm, conic: -0.169 Substrate: SiC Coating: Multilayer, Thickness: TBD
Internal occulter (IO)	Distance M1 -IO: 170 mm; Circular: Ø: 5.2 mm TBC
Lyot trap	Distance M1 – Lyot-trap: 249 mm; Circular: Ø: 44 mm @ 0.27 AU Distance M1 – Lyot-trap: 209 mm; Circular: Ø: 28 mm @ 0.22 AU
Spatial resolution	VL: 25 arcsec UV and EUV: 17 arcsec ≤ 2.5 R; 20 arcsec at > 2.5 R
Stray light levels	VL: < 10^{-9} ; UV, EUV: < 10^{-7}
Wavelength band-pass	VL: 500-650 nm; UV HI (121.6 ± 10) nm; EUV HeII (30.4 ± 2) nm
Detectors	EUV/UV: IAPS ; VL: APS Scale factor (TBC): 0.68 arcsec/μm; 17 arcsec/pixel Image size: 30 mm (1250x1250) with 25 μm pixel size

Table 1 Optical specifications of the inverted-occultation coronagraph

1.2 Optical Performances

Figure 4 and Figure 5 show the optical performances (spot diagram and rms spot versus field-of-view) of the inverted-occultation METIS-COR.

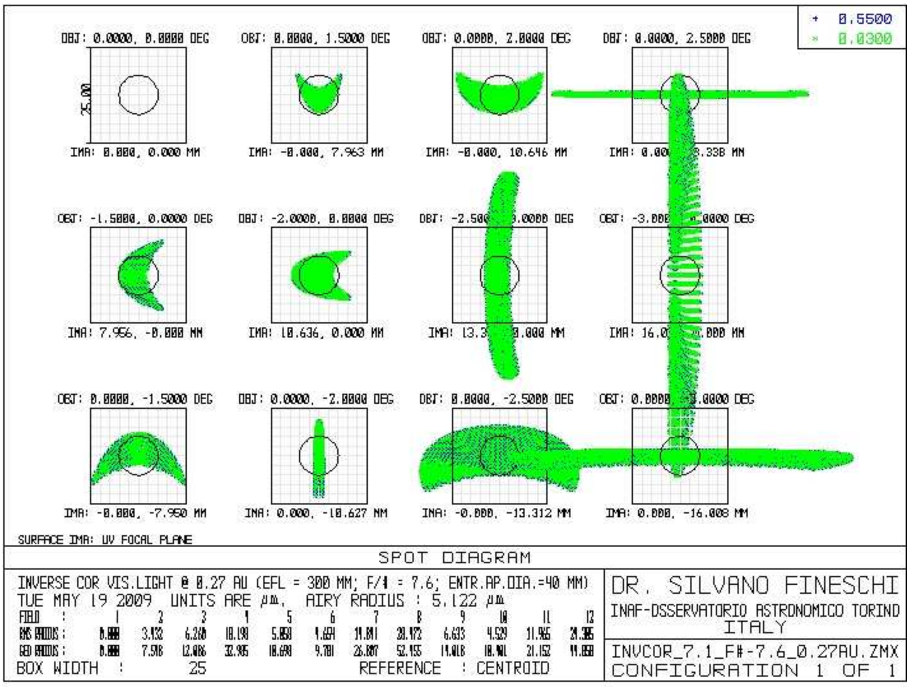

Figure 4 VL spot diagram (rms)

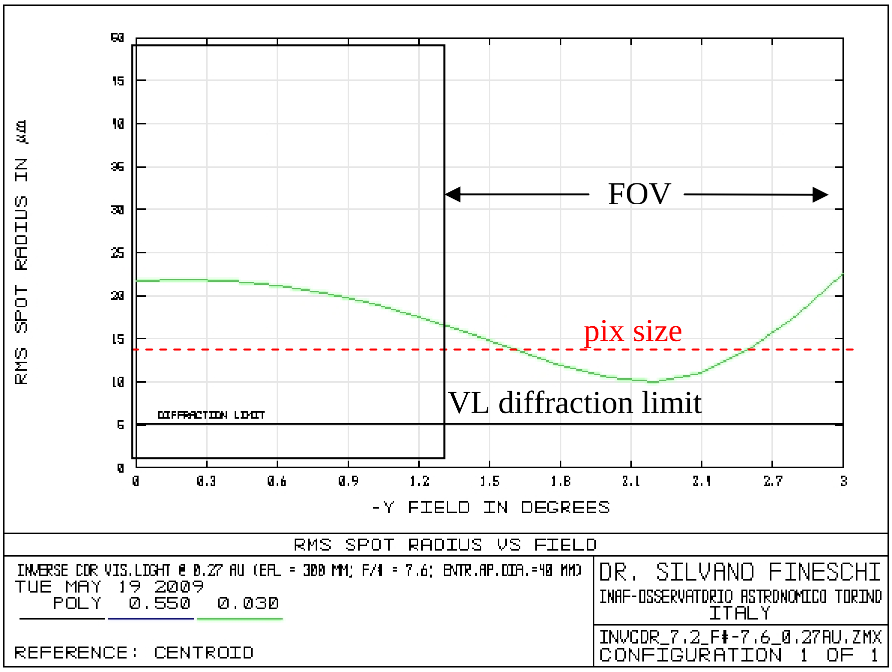

Figure 5 Geometrical visible-light spot size (rms) versus field-of-view (FOV). Pix size= 25

2.0 Compensating FOV changes

The spherical high rejection mirror (M0) refocuses the disk-light back through the entrance aperture of the external occulter (Figure 6). In the inverted-occultation configuration, the position of M0 can be easily adjusted to compensate for the FOV changes in COR due to the S/C off-set pointing and the “zooming” effect from the orbit’s eccentricity.

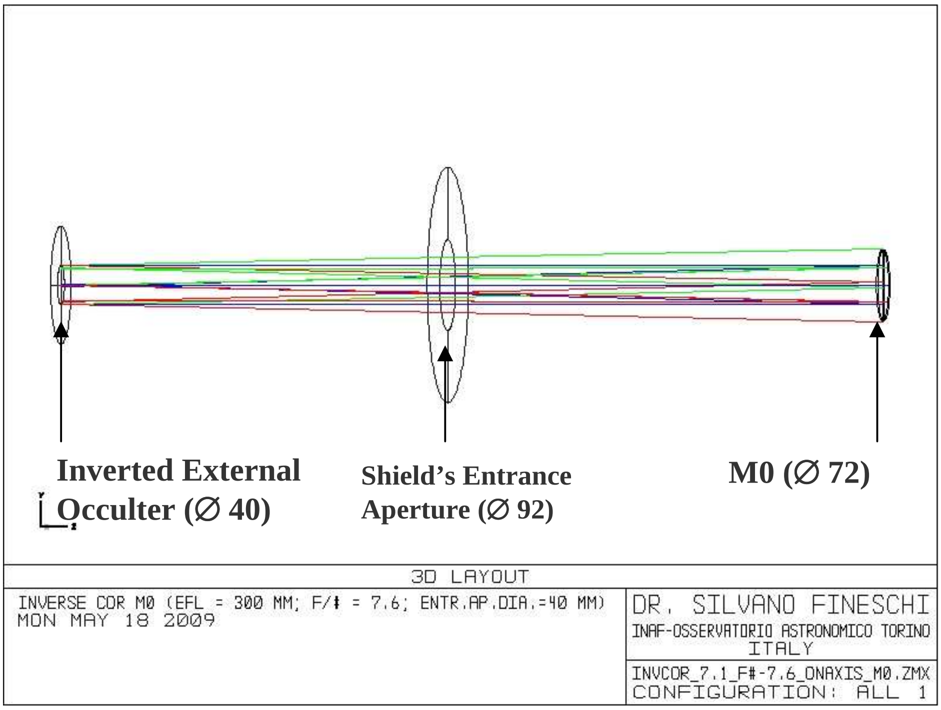

Figure 6 High-rejection mirror (M0) refocusing the disk-light back through the external occulter’s aperture

2.1 S/C offset-pointing

The S/C offset pointing can be compensated by translating M0 along the arc traced by an arm of radius IEO-M0, and pivoted around the IEO’s center. With offset pointing range of ± 1°, the arc’s range is ± 15 mm for a IEO-M0 arm of 850 mm (cfr. Figure 7). The Lyot trap is moved in the opposite direction by ± 9 mm.

2.2 “Zooming” effect

The change in the FOV physical range (i.e., solar radii) can be compensated by moving M0 along the optical axis, closer or away from the IEO. For instance, with a M0 sized for a perihelion of 0.275 AU, and located 850 mm behind the IEO (cfr. Figure 1), the same physical FOV (i.e., 1.4-3 Ro) can be maintained when the perihelion is at 0.225 AU by moving M0 towards the IEO by 150 mm. In this way, the IEO-M0 distance is changed from 850 mm, for perihelion 0.274 AU, to 700 mm, for perihelion distance 0.225 AU (cfr. Figure

8). The diameter of the Lyot stop also changes size from 44 mm to 28 mm to block the image of the edge of M0 made by M1 (cfr. Table 1).

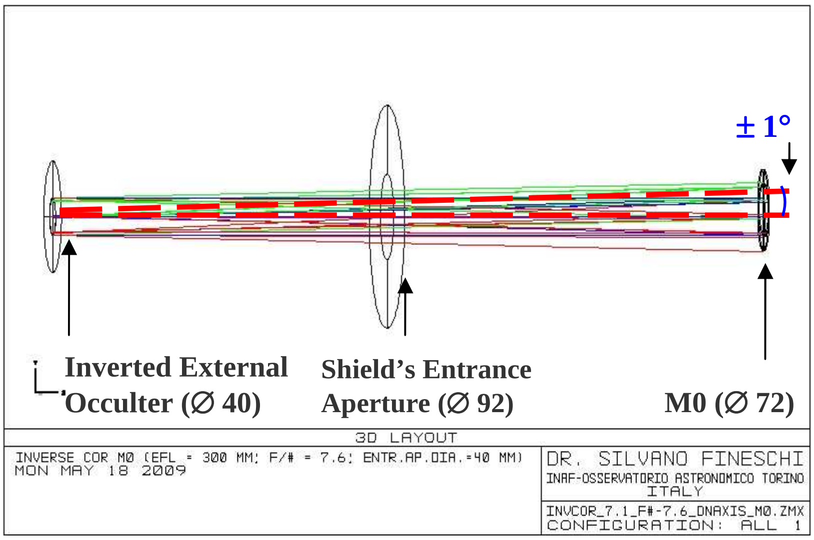

Figure 7 S/C offset pointing can be compensated by translating M0 along the arc traced by an arm of radius IEO-M0, pivoted around the IEO's center. (Dimensions are in mm).

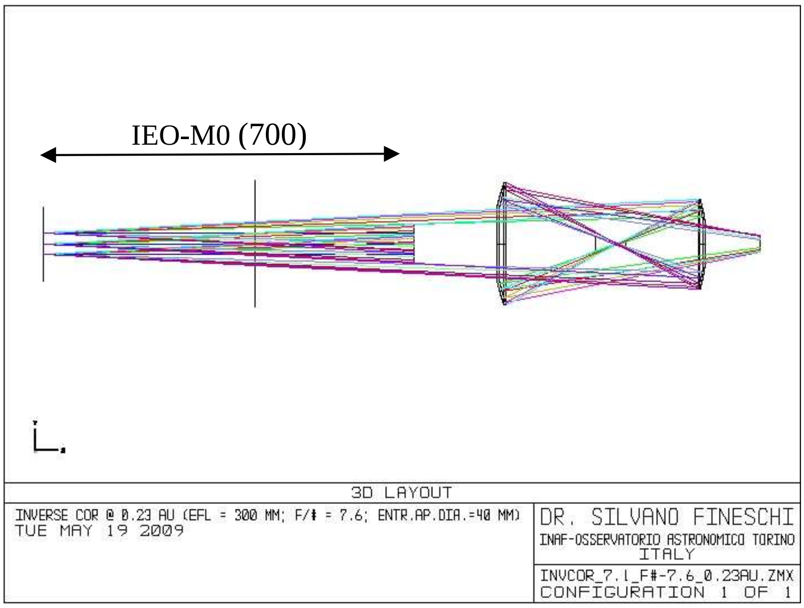

Figure 8 The "zooming" effect due to the S/C orbit can be compensated by moving M0 closer to the IOE at the perihelion distance 0.225 AU. (Dimensions are in mm)

APPENDIX A

Abbreviation/ Acronym	DEFINITION
APS	Active pixel sensor
AU	Astronomical unit
EP	Entrance Pupil
EUV	Extreme ultraviolet
IAPS	Intensified Active pixel sensor
IEO	Inverted External Occulter
FOV	Field-of-view
LCVR	Liquid crystal variable polarimeter
ML	Multilayer
S/C	Spacecraft
TBC	To be confirmed
TBD	To be determined
UV	Ultraviolet
VL	Visible-light