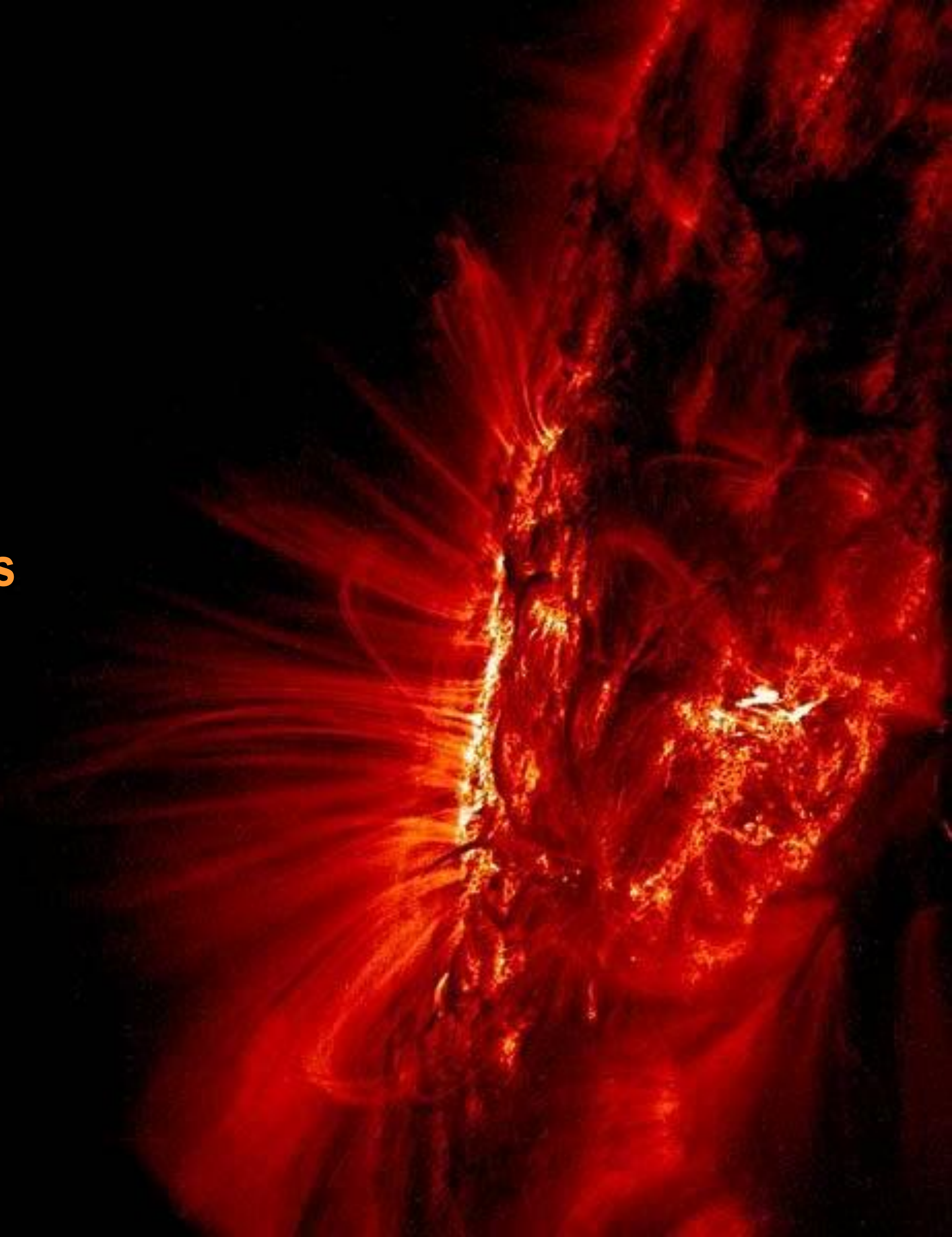
Alberto Alvarez-Herrero
Laboratorio de Instrumentación Espacial, LINES
Área de Cargas Útiles e Instrumentación
Instituto Nacional de Técnica Aeroespacial

Polarimeters with Liquid Cristal Variable Retarders for PHI & METIS



METIS 2nd Science and Technical Meeting
12-13 December 2012

Introduction

Liquid Crystal Variable Retarders is a well-know technology for ground applications and currently in use by many instruments.

During last 10 years have undergone an important development driven mainly by the fast expansion of the LCDs.

•**Polarimetric applications:**

-Study of the human eye **(J.-M. Bueno et al. 1999)**

-Hyperspectral imaging polarimeter for the observation of ice clouds **(C. Beeler et al 2000)**

-Optimization of the modulation scheme **(del Toro et al. 2000, J. S Tyo 2002)** of polarimeters using LCVRs **(A. De Martino et al 2003)**

-Target detection **(F. Goudail et al 2004)**

-Glucose sensor **(Y.-L. Lo 2006)**

-Polarimeter in the IR range **(E. Garcia-Caurel 2004, J. Ladstein et al 2008, L.M. S. Aas et al 2010)**

-High speed cameras: DoP **(L. Gendre et al 2008, M. Vedel et al 2010)**

-Cancer diagnosis **(T. Novikova el al 2012)**

Introduction

•**Astrophysics and Solar Physics:**

- Full Stokes polarimeter **(L.J. Novemeber et al 1995)**
- La Palma Stokes Polarimeter (LPSP) and Tenerife Infrared Polarimeter (TIP) **(V. Martinez Pillet et al 1998)**
- Liquid imaging Stokes polarimeters for the Gregory Coudé telescope **(T. Horn et al 1999)**
- SOLIS vector-magnetograph **(C. U. Keller et al 2001)**
- HAO/NSO diffraction limited Spectro-Polarimeter
- PIc du Midi Turret Dome magnetograph **(J.-M. Malherbe et al 2004-2007)**
- Solar Flare telescope polarimeter **(Y. Hanaoka 2005)**
- Yunnan solar tower polarimeter **(F. Snik et al 2006)**

Introduction

- **Space applications**

Alternative to the traditional rotary polarizing optics

- Mass reduction
- Volume reduction
- To avoid the utilization of mechanism

⇐

- Resources are very limited
- The risk of a mechanical failure should be minimized

First attempt Flare Genesis mission (P.N. Bernasconi et al 2000)

LCVRs + Etalon $LiNbO_3$

⇓

IMaX of the SUNRISE mission **(V. Martinez-Pillet et al 2011)**

KPol for the SCORE coronagraph **(S. Fineschi et al 2011)**

Introduction

The SUNRISE mission

The **SUNRISE** mission consisted of a **stratospheric balloon**, with a **solar telescope of 1 m aperture** onboard. It was **successfully launched on June 8th 2009 in the Artic**, within the NASA Long Duration Balloon Program.

The flight duration was 5 days and 17 hours

The **main scientific objective** of SUNRISE is the study of **the solar magnetic fields with high spatial resolution** (100km in the solar surface)

Post-focal instruments

- **SUFI**: **SU**NRISE **F**ilter **I**mager
- **IMaX: I**maging **Ma**gnetograph e**X**periment
- **CWS: C**orrelation Tracker and **W**avefront **S**ensor

2nd flight: 2012-13

Quality data and observation time never achieved before

Introduction

IMaX is a solar magnetograph

The spectral line is sensitive to the solar magnetic fields due to the Zeeman effect

- High sensitive polarimeter ($<10^{-3}$) → LCVRs
- High resolution spectrometer (<70mÅ) → LiNbO3 etalon
- Diffraction limited Imager(<0.14 arcsec)

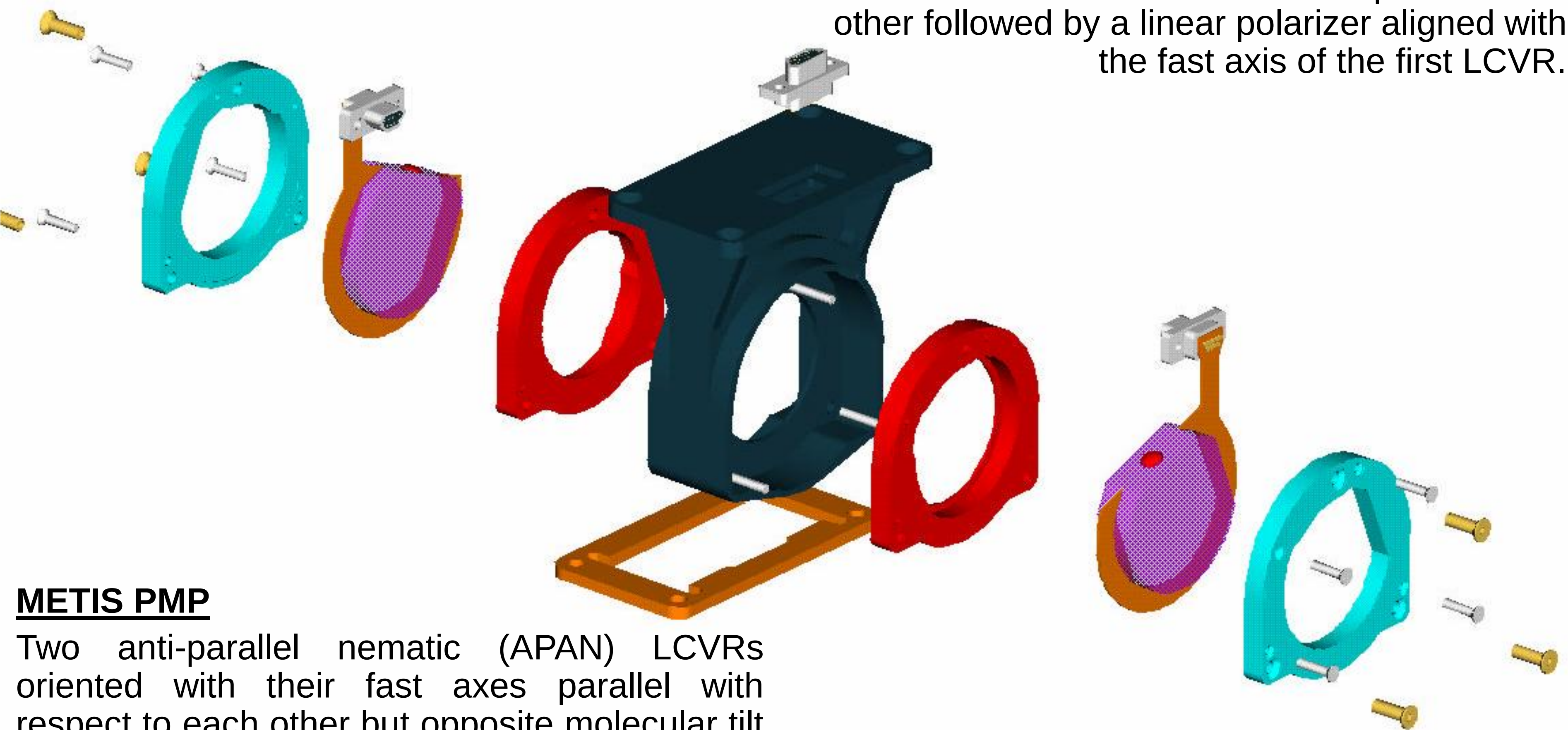
→ SO/PHI precursor

R.L. Heredero et al 2007

SO/PHI and METIS Polarisation Modulation Packages

SO/PHI PMP

Two anti-parallel nematic (APAN) LCVRs oriented with their fast axes at 45° with respect to each other followed by a linear polarizer aligned with the fast axis of the first LCVR.

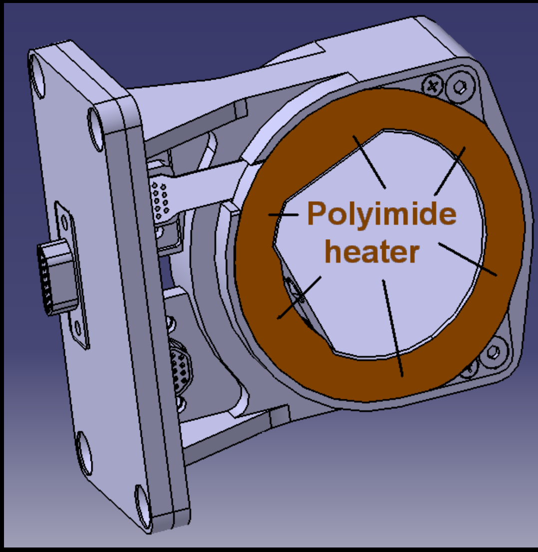


METIS PMP

Two anti-parallel nematic (APAN) LCVRs oriented with their fast axes parallel with respect to each other but opposite molecular tilt angle followed by a linear polarizer at 45º with the fast axes of the LCVRs.

SO/PHI and METIS Polarisation Modulation Packages

METIS LCVRs will identical to the PHI ones to reduce costs during design, procurement and qualification activities.



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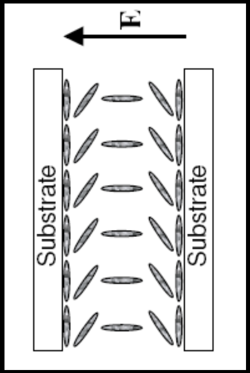
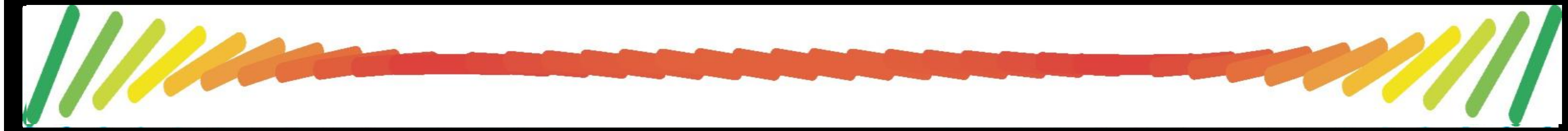
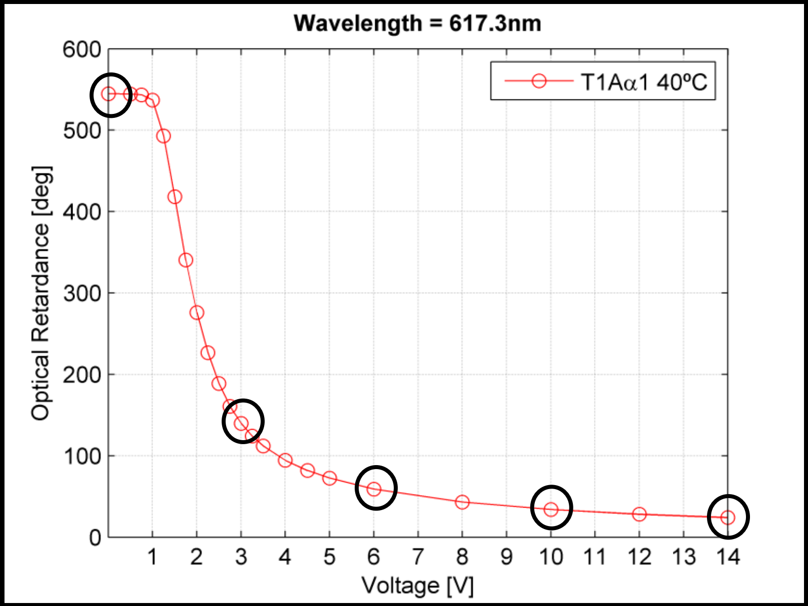
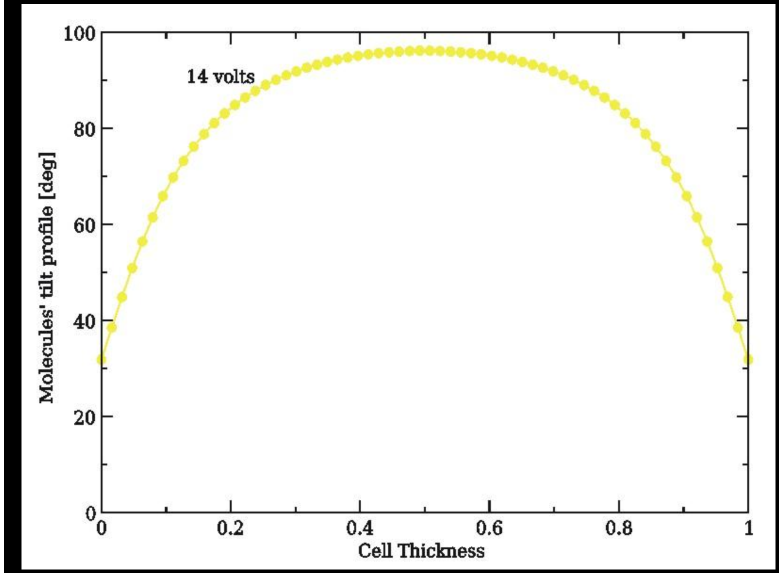
SO/PHI and METIS Polarisation Modulation Packages



Molecular tilt







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Polarization Modulation

SO/PHI PMP

[deg]	PM_1	PM_2	PM_3	PM_4
$LCVR_1$	225.00	225.00	315.00	315.00
$LCVR_2$	234.74	125.26	54.74	305.26

METIS PMP

[deg]	PM_1	PM_2	PM_3	PM_4
$LCVR_1$	δ_0	δ_0 +90	δ_0 +180	δ_0 +270
$LCVR_2$	δ_0	δ_0 +90	δ_0 +180	δ_0 +270

TBC

Selected to optimize the modulation efficiencies ➡ $\xi_i = \left(n \sum_{j=1}^{n} D_{ij}^2 \right)^{-1/2}$ ⟶ $\xi_{\max,1} = 1$, $\sum_{i=2}^{4} \xi_{\max,i}^2 = 1$

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SO/PHI and METIS Polarisation Modulation Packages

Important Issues to be taken into account:

as PMP

1. Angle of incidence dependence of retardance
2. Temperature dependence of retardance
3. Homogeneity of retardance across clear aperture
4. Response times
5. Chromatism

-Double cells
-Instr. optical design

-Thermal control (±0.5º)

-Manufacturing quality,
-instr. optical design
-pixel per pixel calibration

-Operational temperature
-High birefringence LC

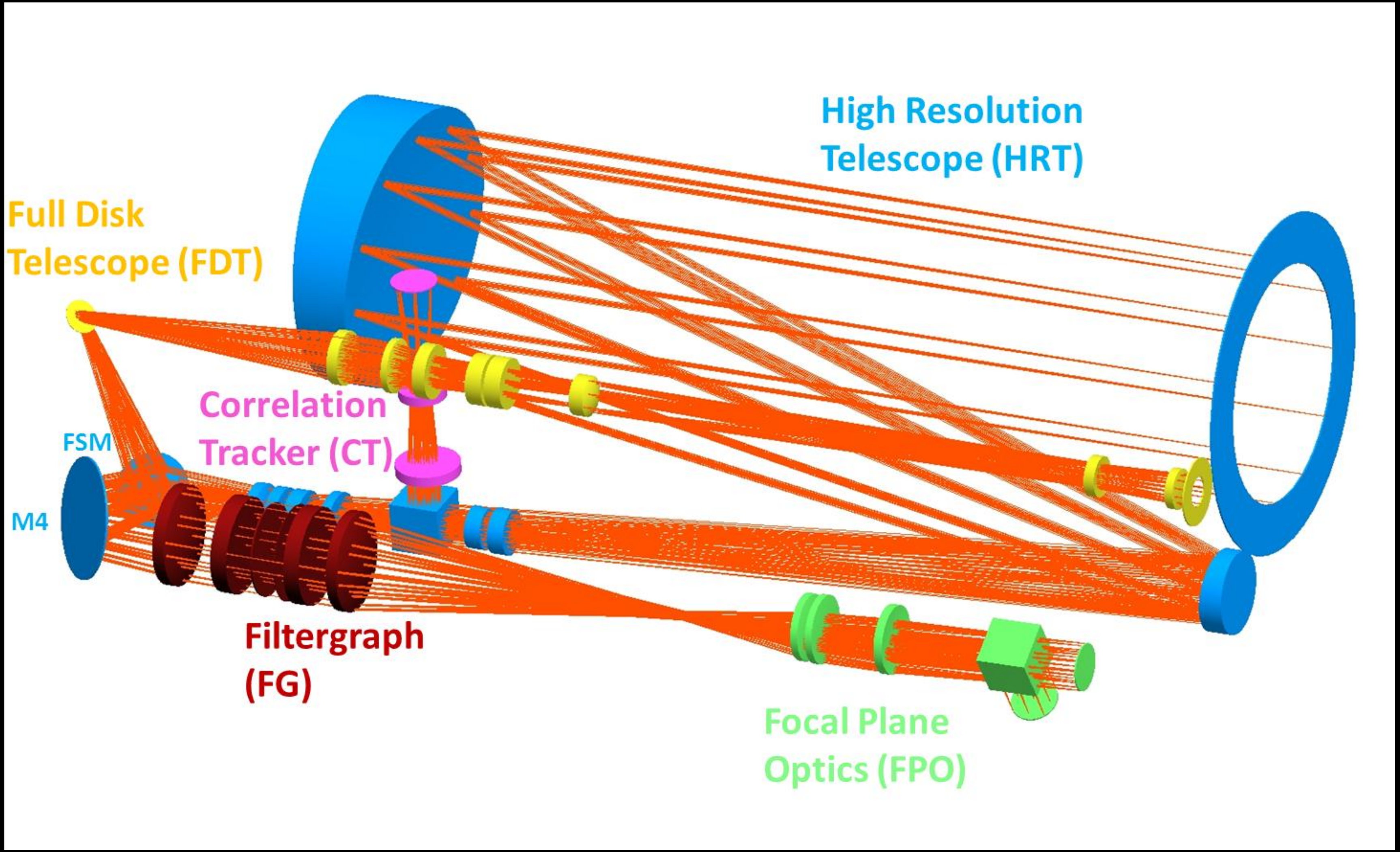
-Achromatic LCVRs
-λ range and voltage selection

as IMAGER

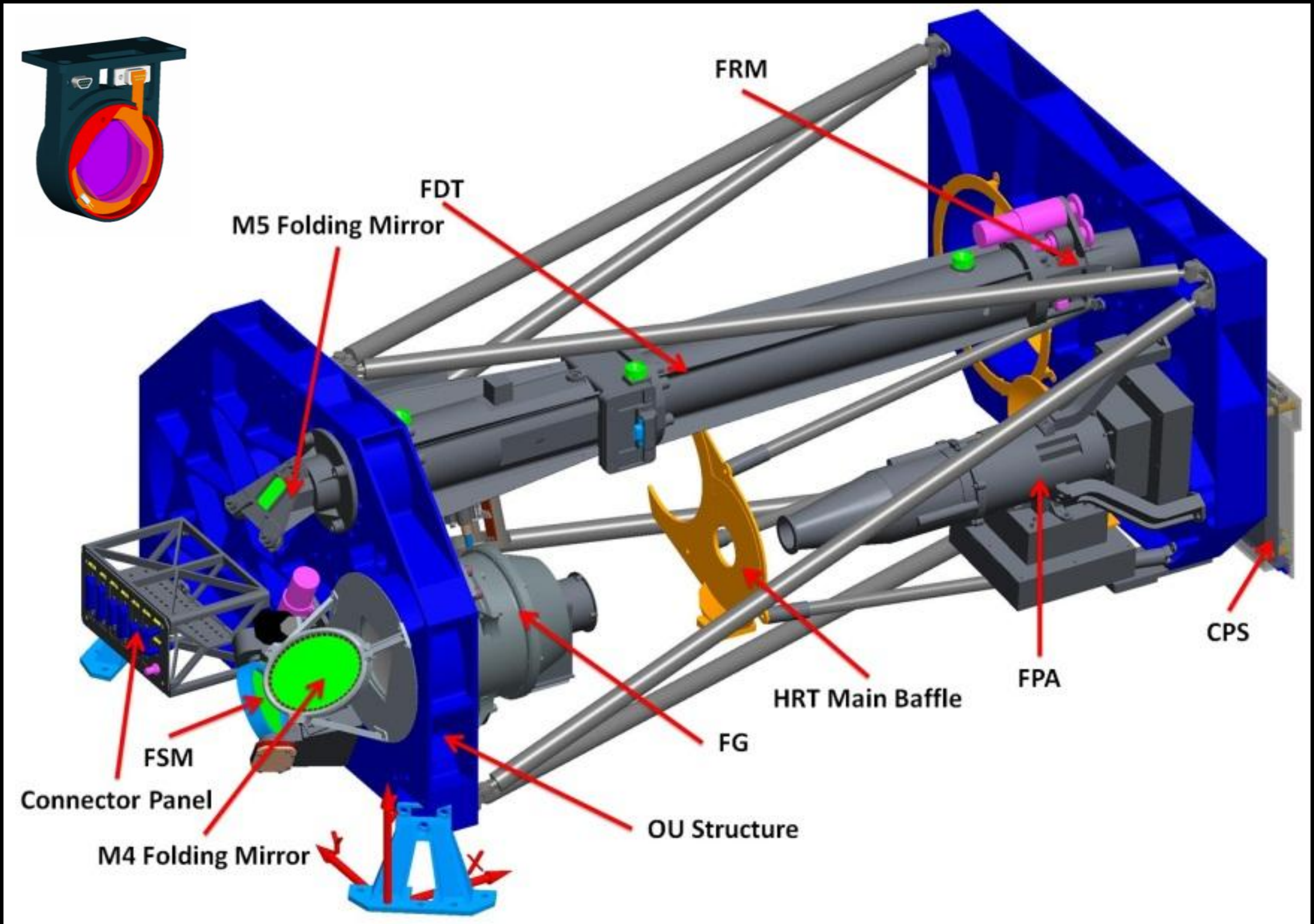
1. Wavefront error
2. Alignment quality

-Manufacturing quality
-Instrument optical design

SO/PHI PMPs

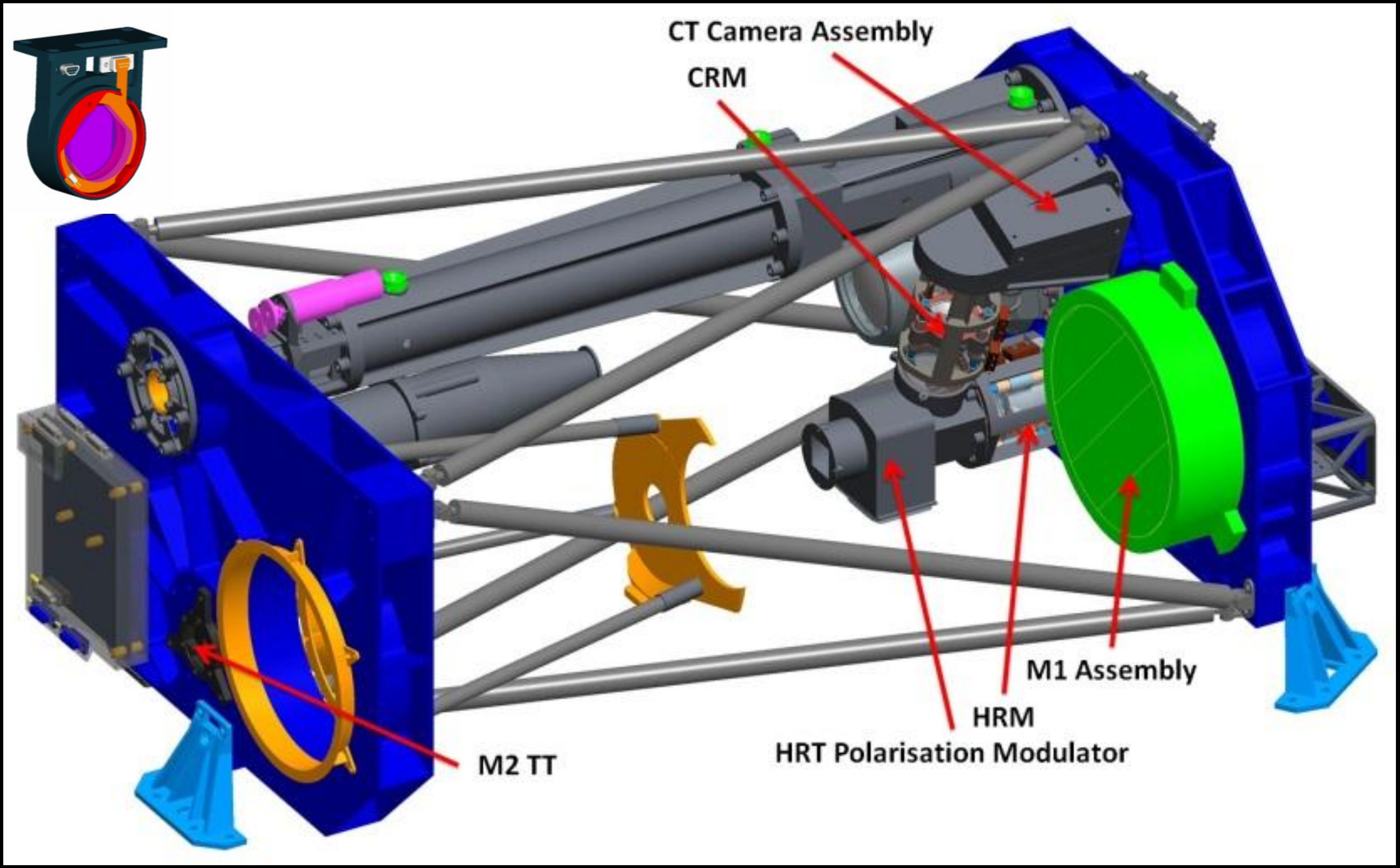

High Resolution
Telescope (HRT)
Full Disk
Telescope (FDT)
Correlation
Tracker (CT)
FSM
M4
Filtergraph
(FG)
Focal Plane
Optics (FPO)

SO/PHI PMPs



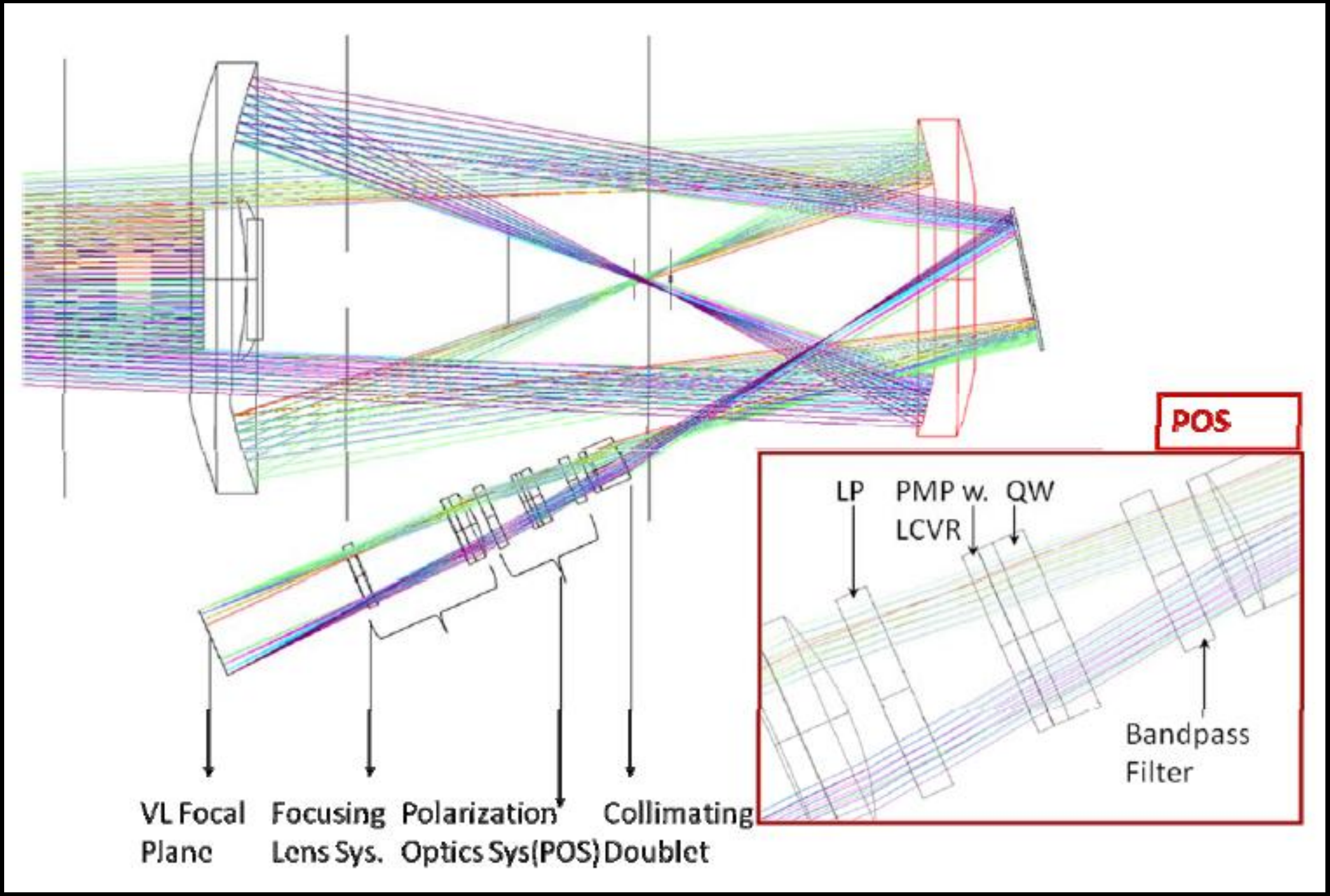
FRM
FDT
M5 Folding Mirror
CPS
FPA
HRT Main Baffle
FG
FSM
Connector Panel
OU Structure
M4 Folding Mirror

SO/PHI PMPs



CT Camera Assembly
CRM
M1 Assembly
HRM
HRT Polarisation Modulator
M2 TT

METIS PMP


POS
LP
PMP w. LCVR
QW
Bandpass Filter
VL Focal Plane
Focusing Lens Sys.
Polarization Optics Sys(POS)
Collimating Doublet

Validation of LCVRs for Solar Orbiter

ESA contract No.22334/09/NL/SFe

GOAL: "this activity aims at increasing the relevant technology readiness level in Europe from TRL4 "Component Validation in Laboratory Environment" to TRL5 "Component Validation in Relevant Environment" by providing a significant step towards full space qualification of high-performance LCVRs for the Solar Orbiter mission."

APAN Anti-Parallel Aligned Nematic	**4 types**	**40 cells**
HAN Hybrid Aligned Nematic	**1 type**	**10 cells**
Wide Acceptance Angle Anti-Parallel Aligned Nematic	**1 type**	**20 cells**
Achromatic LCVRs Anti-Parallel Aligned Nematic	**1 type**	**20 cells**

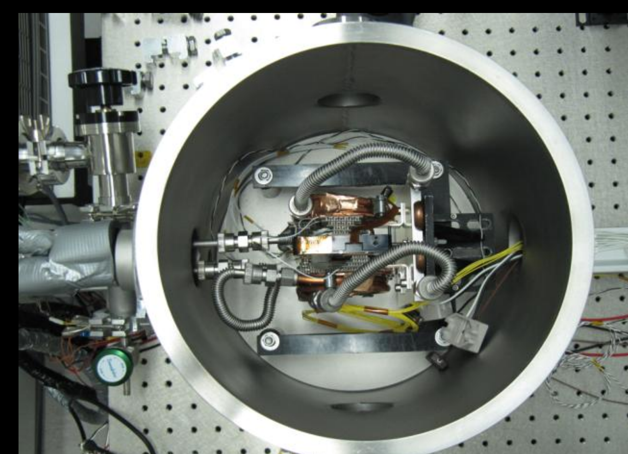
TOTAL: 7 types, 90 cells

2 years of work

SUCCESSFULLY FINISHED

on May 2011

Results presented in SPIE2011, San Diego



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LCVRs under study

LC Type	Symbol	Comment	Alignment	Glass	Manufacturer	LC mixture	Δn	Δn 20ºC/ 589nm	T-Range ºC
APAN	**1.Aα**	anti-parallel nematic	Poly PI2545	fused silica	Arcoptix	**ZLI-3700-000**	medium	0.101	[<-30, +105]
APAN	**1.Bα**	anti-parallel nematic	Poly PIA2000	fused silica	Visual Display	**BL006**	high	0.285	[-20, +118.5]
APAN	**1.Aβ**	anti-parallel nematic	Poly PI2545	fused silica	Arcoptix	**MLC-6025-000**	low	0.084	[-40, +103]
APAN	**1.C**	anti-parallel nematic	Poly PIA2000	SF57	Visual Display	**BL006**	high	0.285	[-20, +118.5]
HAN	**4.A**	hybrid aligned nematic	Poly PI2545	fused silica	Arcoptix	**MLC-6610**	negative	0.0996	[<-30, +79.5]
Dual APAN	**5.A**	dual anti-parallel	Poly PI2545	fused silica	Arcoptix	**MDA-98-1602**	high	0.267	[-20, +109]
ALCVR	**6.A**	achromatic	Poly PI2545	fused silica	Arcoptix	**BL006 + MLC-6025-000**	high+low	0.285/ 0.084	[-20, +118.5] + [-40, +103]

ALCVRs: Patent pending INTA-INAF

M-MOD1 Analysis, LCVRs-INTA-RP-115, Issue 1, Revision 0 (2011)

Test campaign

Ionizing radiation tolerance (Gamma)

>75krads (100krads)

Protons radiation tolerance

fluence (60 MeV)> 1.39 10^{11} p+/cm^2 (2.78x10^{11} p+/cm^2)

fluence (80 MeV) >1.08 10^{11} p+/cm^2 (2.16 10^{11} p+/cm^2)

UV radiation tolerance

1.50 ESH 200-400 nm

1.00 ESH 160-200nm

Vibration/Dynamic test

Random vibration

Sine vibration

Shock (>3000g)

Outgassing test

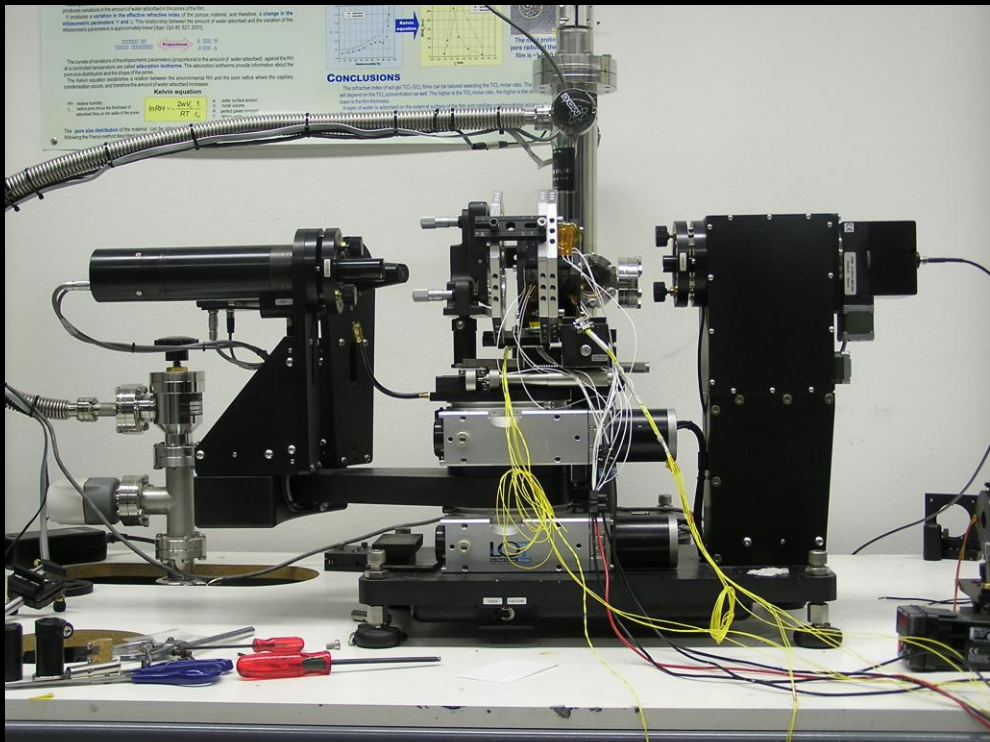
TML < 1%, CVCM <0. 1%

Thermal-Vacuum test

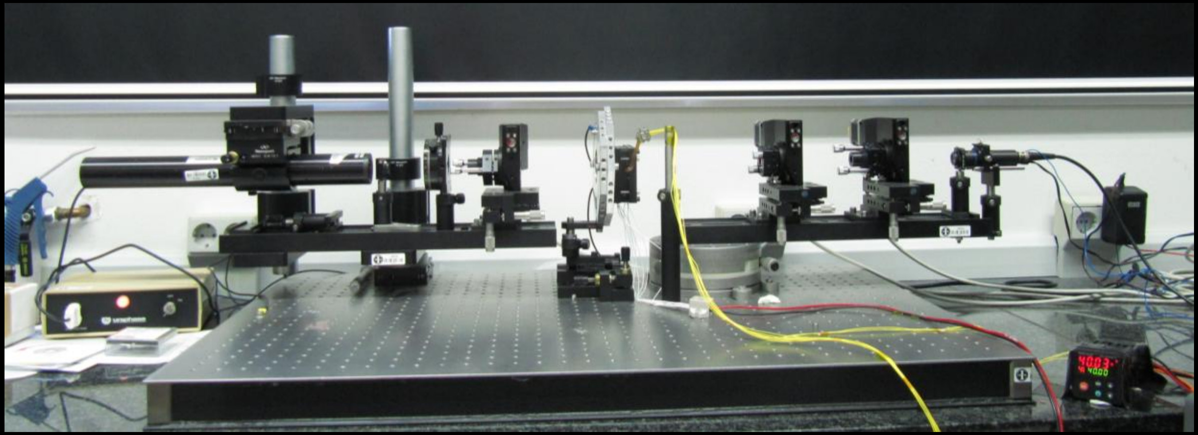
Operational Temperatures [-20º,+60º]

Non-operational Temperatures [-40º,70º]

Optical measurements



Variable Angle Spectroscopic Ellipsometry



Null ellipsometer

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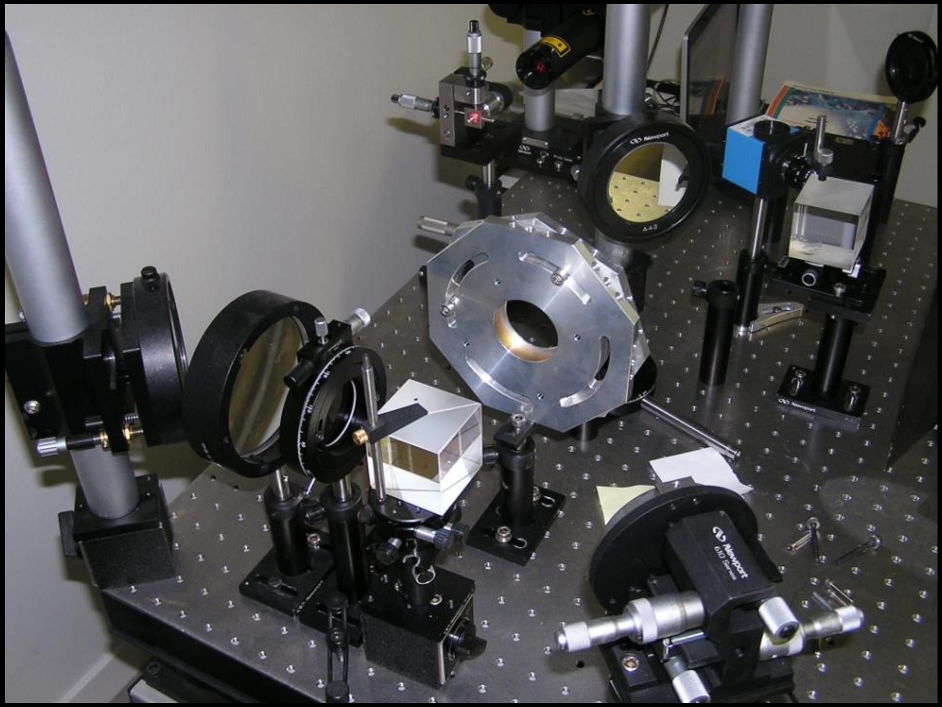
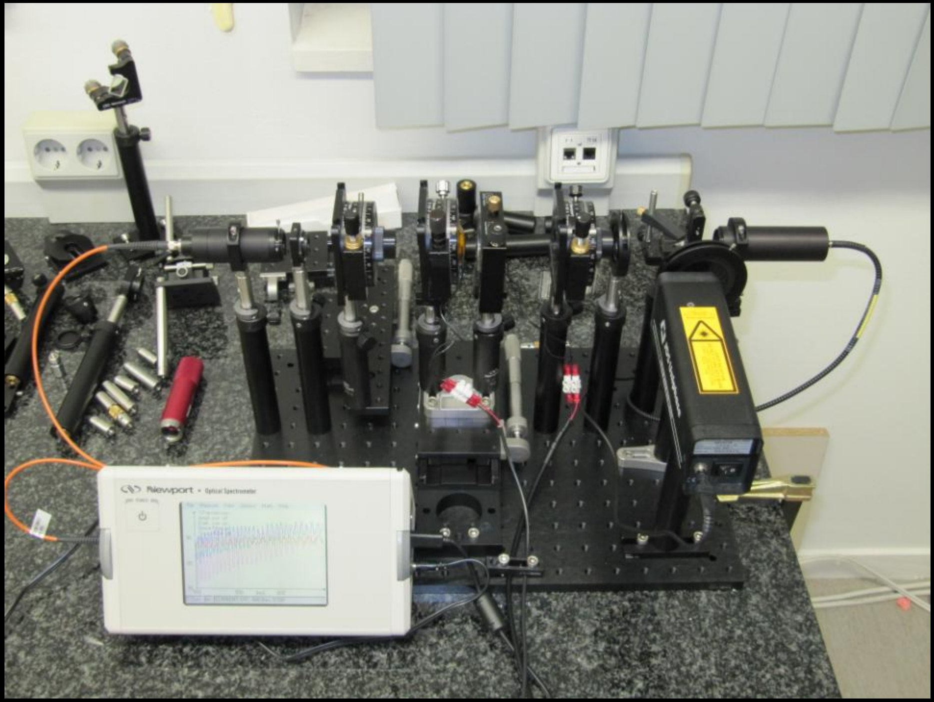
Optical measurements

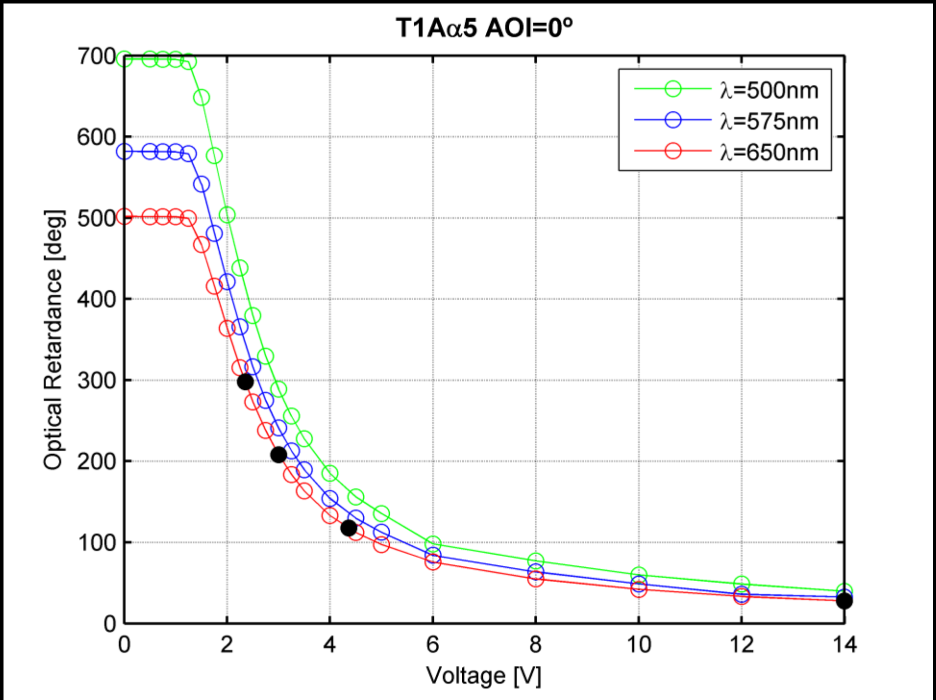


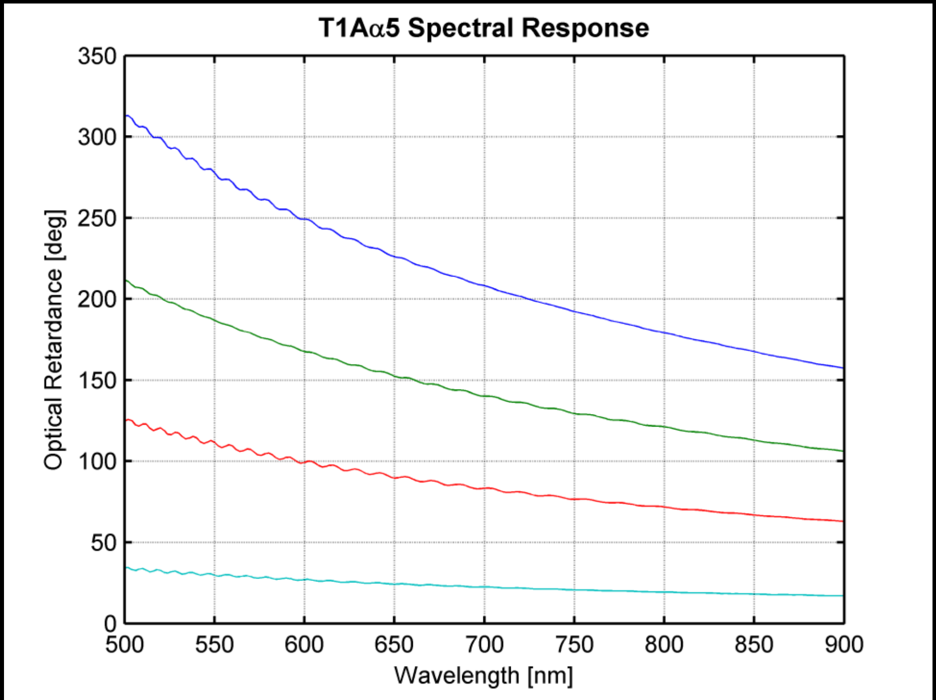
Mach-Zehnder interferometer



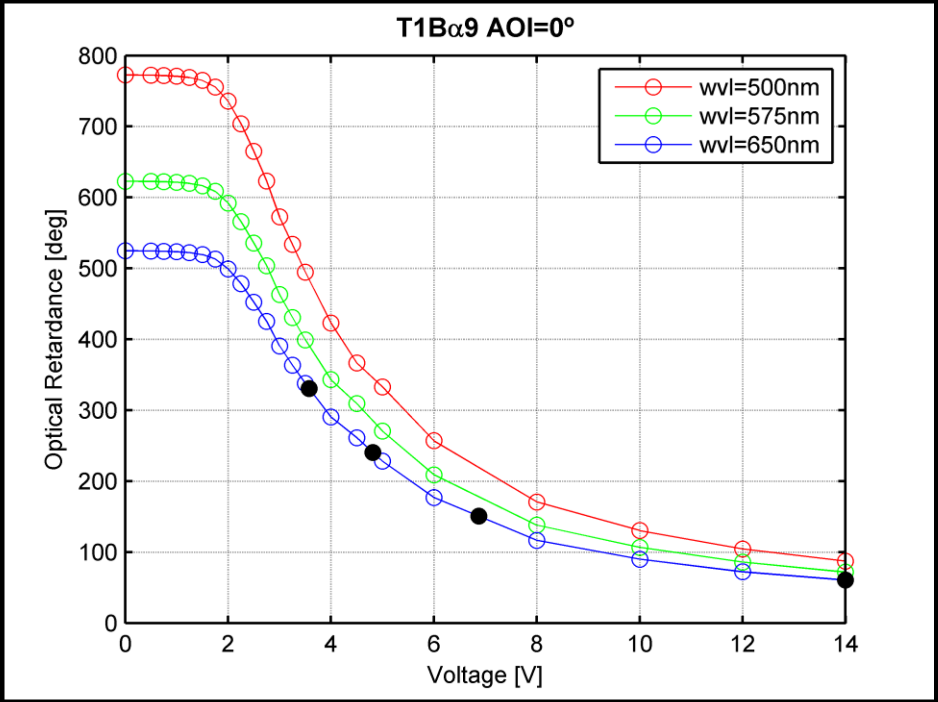
Transmittance

Chromatism

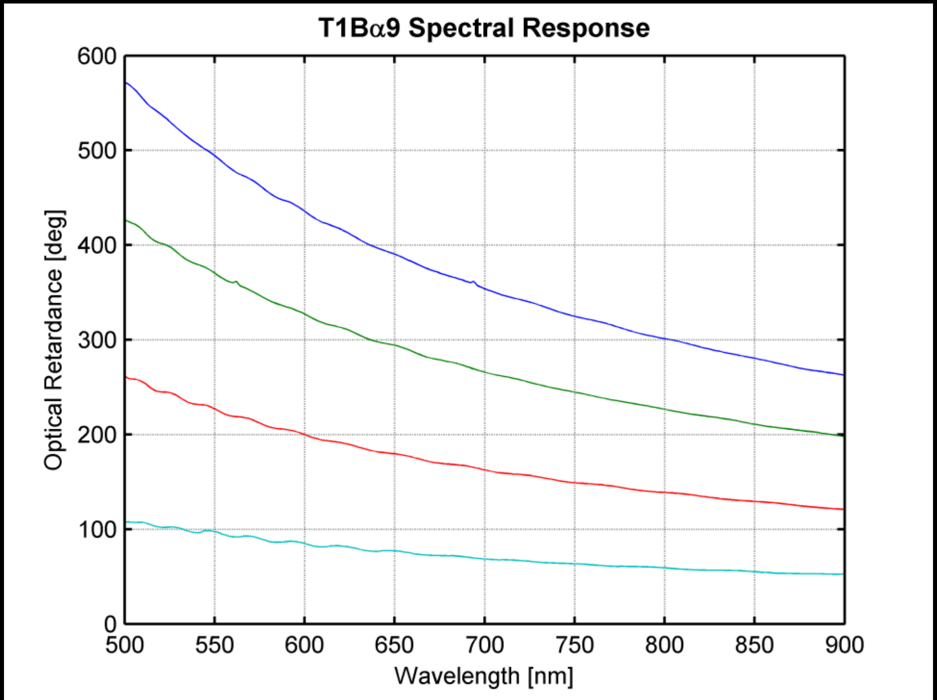

T1Aα5 AOI=0º
λ=500nm
λ=575nm
λ=650nm
Optical Retardance [deg]
Voltage [V]
0
100
200
300
400
500
600
700
0
2
4
6
8
10
12
14


T1Aα5 Spectral Response
Optical Retardance [deg]
Wavelength [nm]
0
50
100
150
200
250
300
350
500
550
600
650
700
750
800
850
900

Chromatism

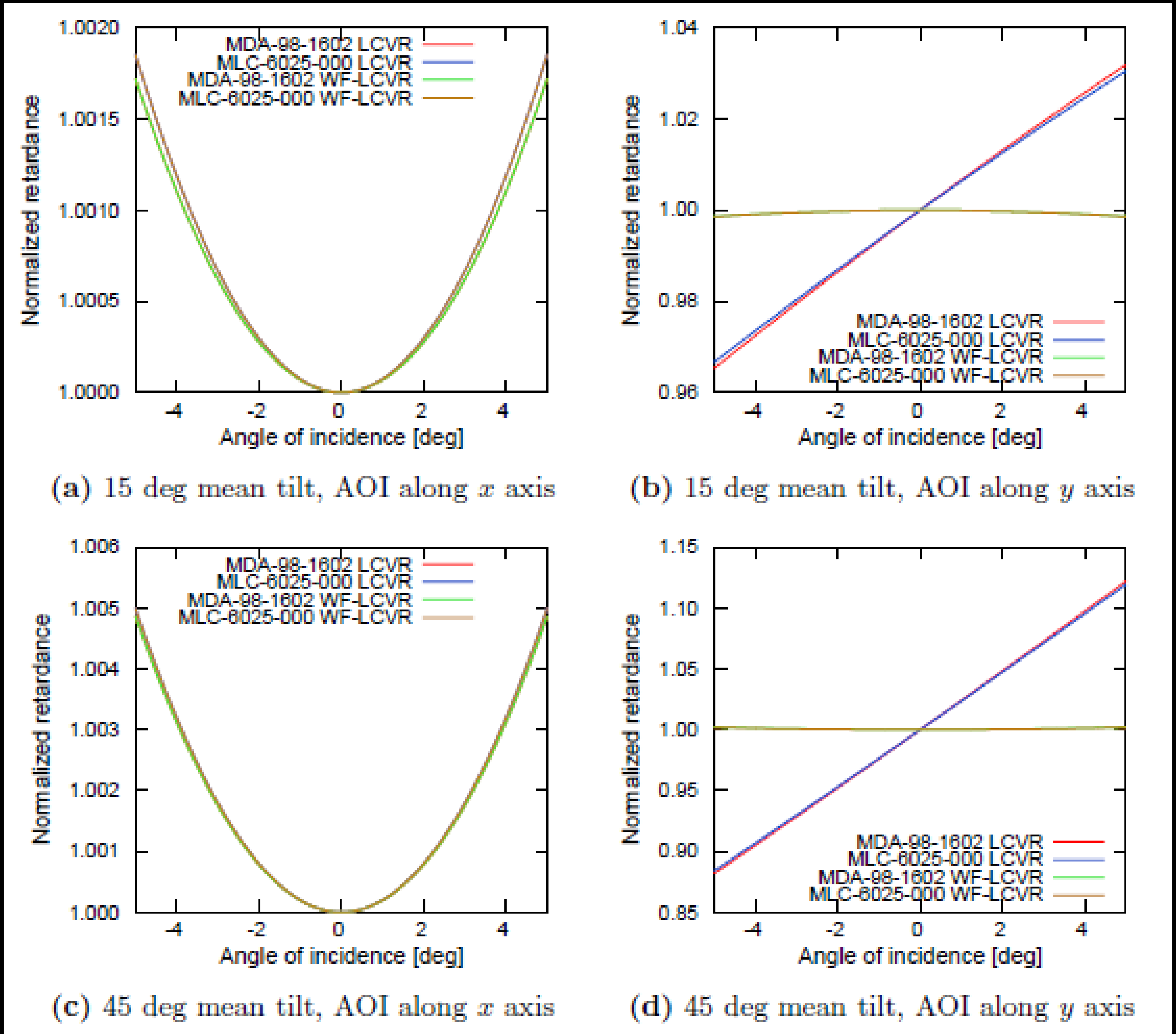


T1Bα9 AOI=0º
Optical Retardance [deg]
Voltage [V]
wvl=500nm
wvl=575nm
wvl=650nm
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14



T1Bα9 Spectral Response
Optical Retardance [deg]
Wavelength [nm]
0
100
200
300
400
500
600
500
550
600
650
700
750
800
850
900

Wide acceptance angles



(a) 15 deg mean tilt, AOI along x axis

(b) 15 deg mean tilt, AOI along y axis

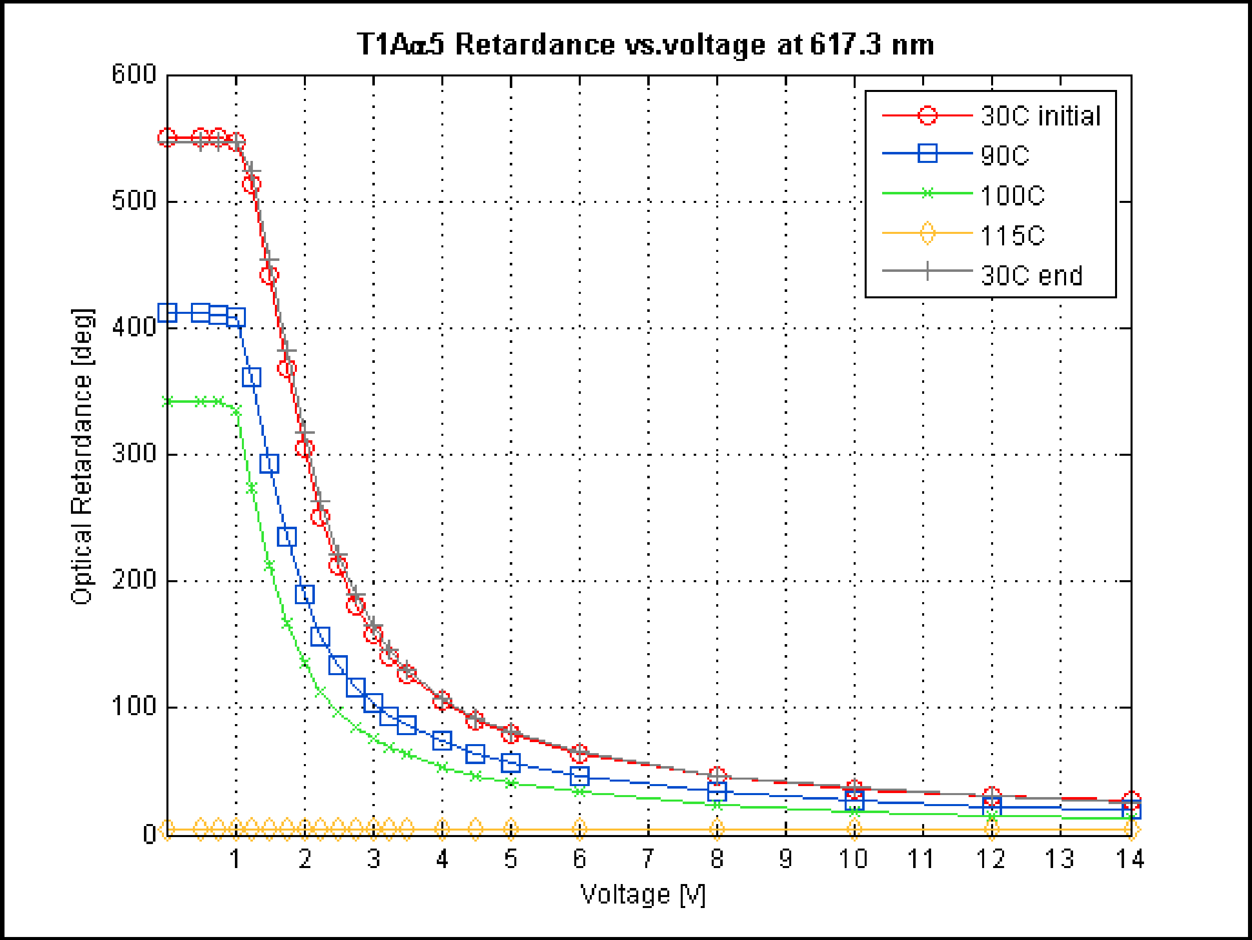
(c) 45 deg mean tilt, AOI along x axis

(d) 45 deg mean tilt, AOI along y axis

Nominal retardante for MDA-98-1602 LCVR and WF-LCVR is 1.3782 waves and for MLC-6025-000 1.3921 waves

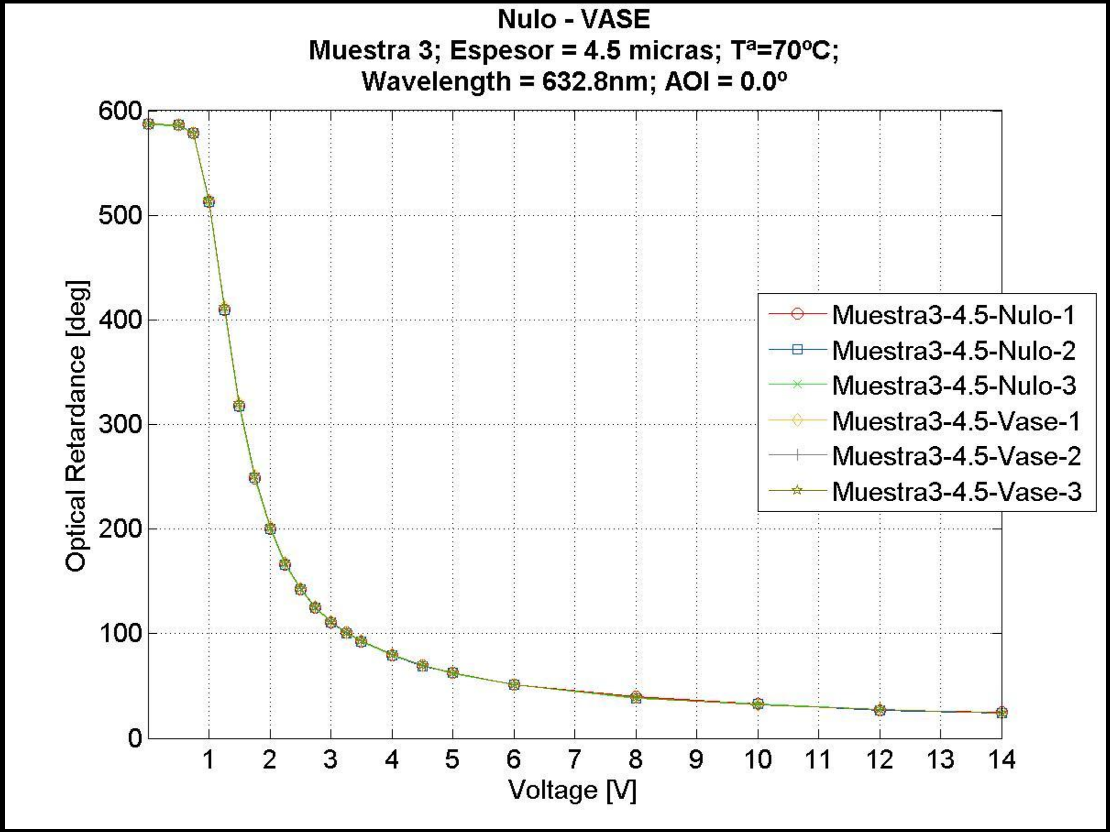
Other tests performed

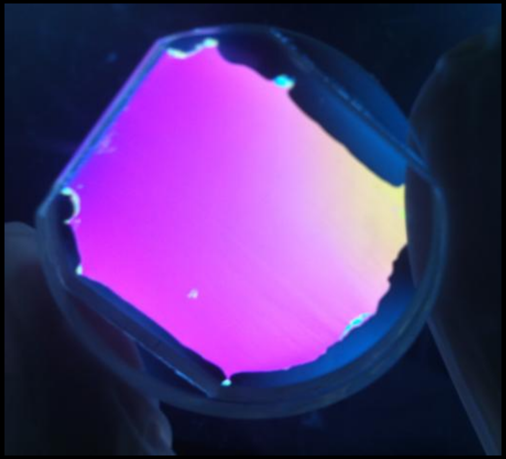
- **High Temperature tests**
- **Reversibility clearing point**



Other tests performed

- Repeatability of cells with high birefringence LC mixtures





Next actions

- Breadboards: (4 cells) mechanical manufacturing in progress. Cells received
- Selection of final LC mixture (decision to be taken in the next days)
- UV irradiation tests (10 cells). Additional test requested by ESA during TDA, manufacturing in progress
- Life test: 2013 (50 cells)
- Qualification: 2013 (50-60 cells)

General conclusions

1. LCVRs is a promising technology for imaging polarimeters on-board space platforms. In order to validate the technology for the Solar Orbiter mission, an exhaustive investigation was carried out.

2. PHI and METIS successfully passed PDR with PMPs based on LCVRs as baseline (no RIDs).

3. The detail design is well advanced as well as the remaining tests before the life tests and qualifications tests foreseen for 2013. This last LCVRs batch will include the flight cells for both instruments.