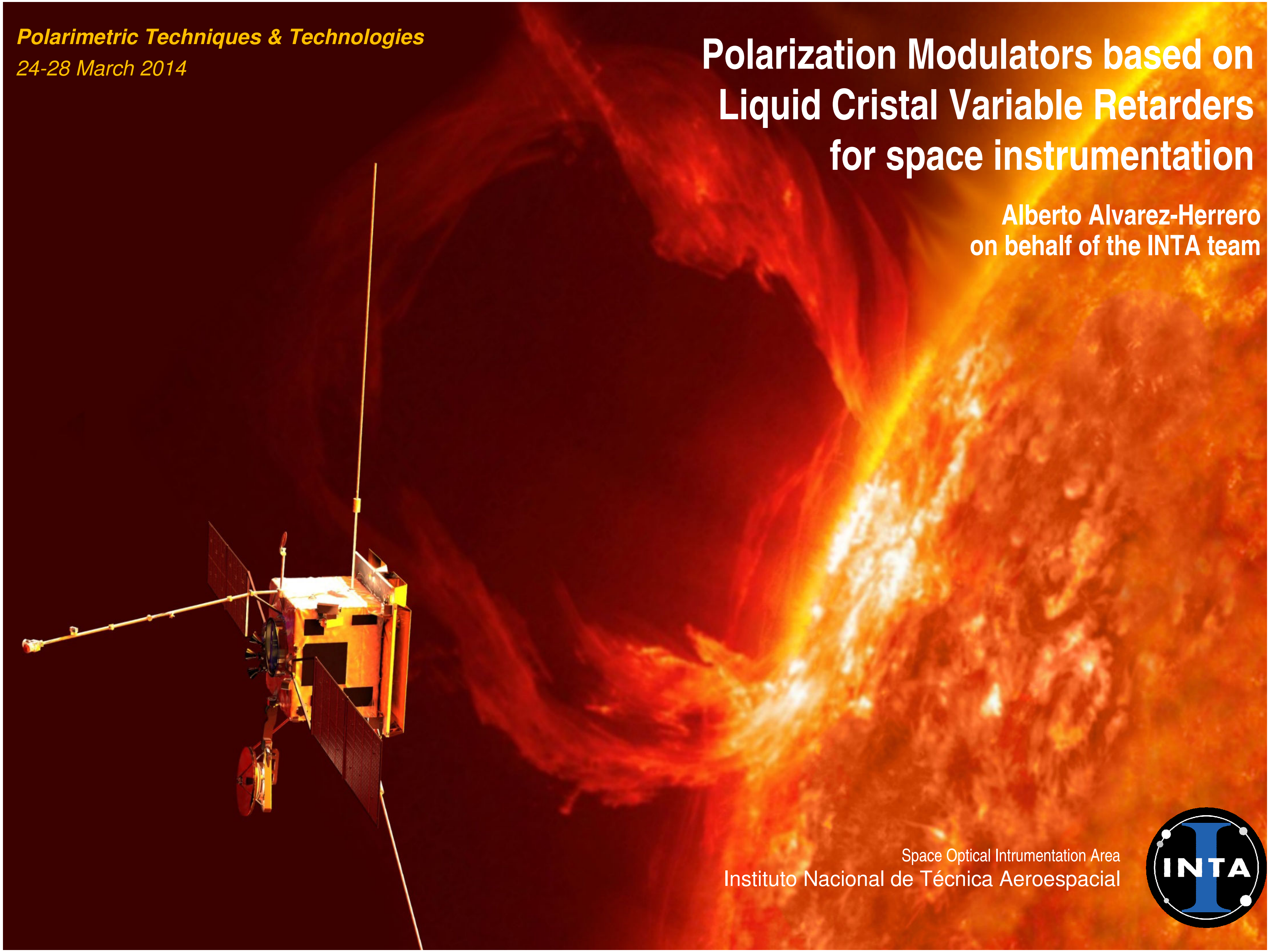
*Polarimetric Techniques & Technologies*
*24-28 March 2014*

# Polarization Modulators based on Liquid Cristal Variable Retarders for space instrumentation

**Alberto Alvarez-Herrero**
**on behalf of the INTA team**



Space Optical Intrumentation Area
Instituto Nacional de Técnica Aeroespacial

Public institution
Headquarters: Torrejón de Ardoz (Madrid)
Employees: ~1200

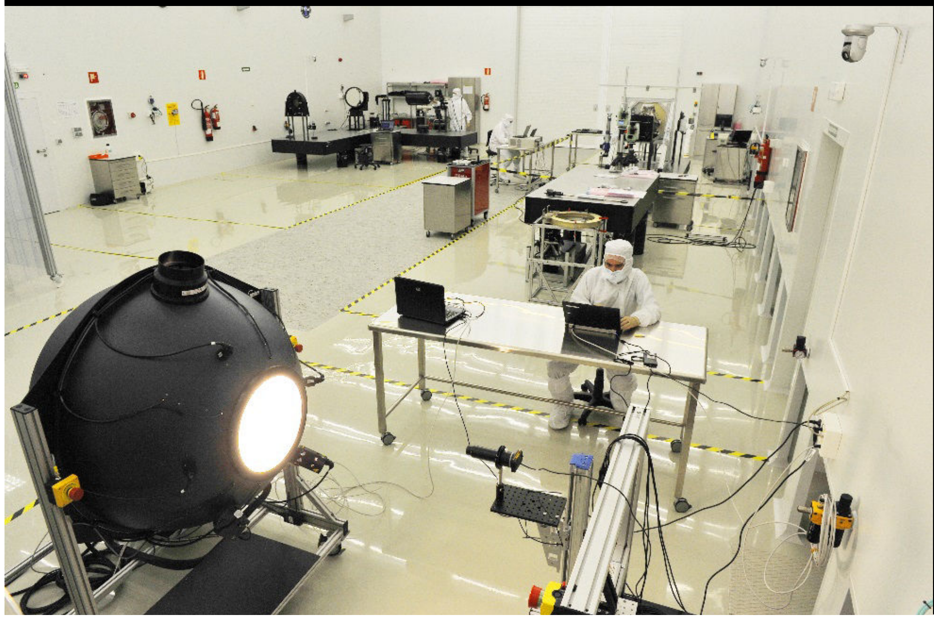

## Space Optical Instrumentation Area

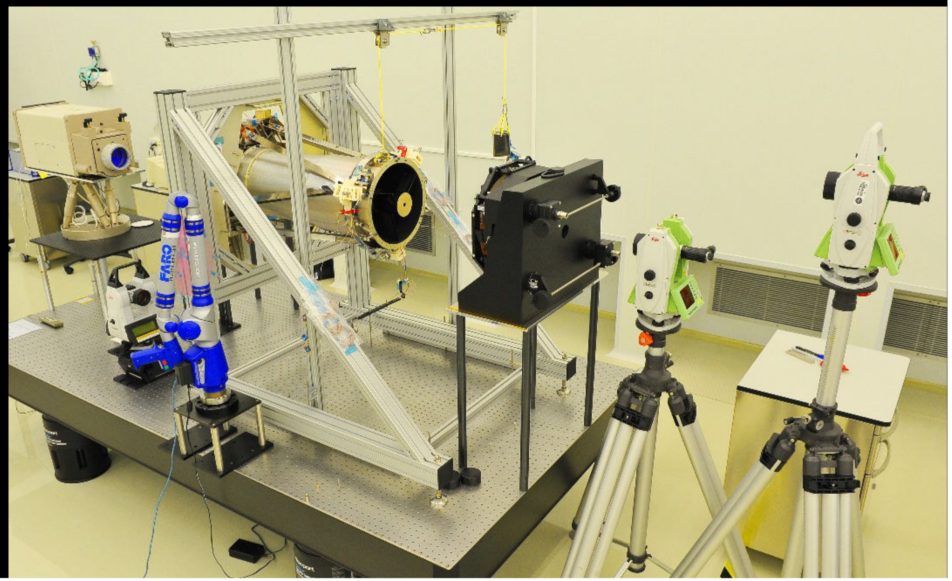
# OPTICS for SPACE

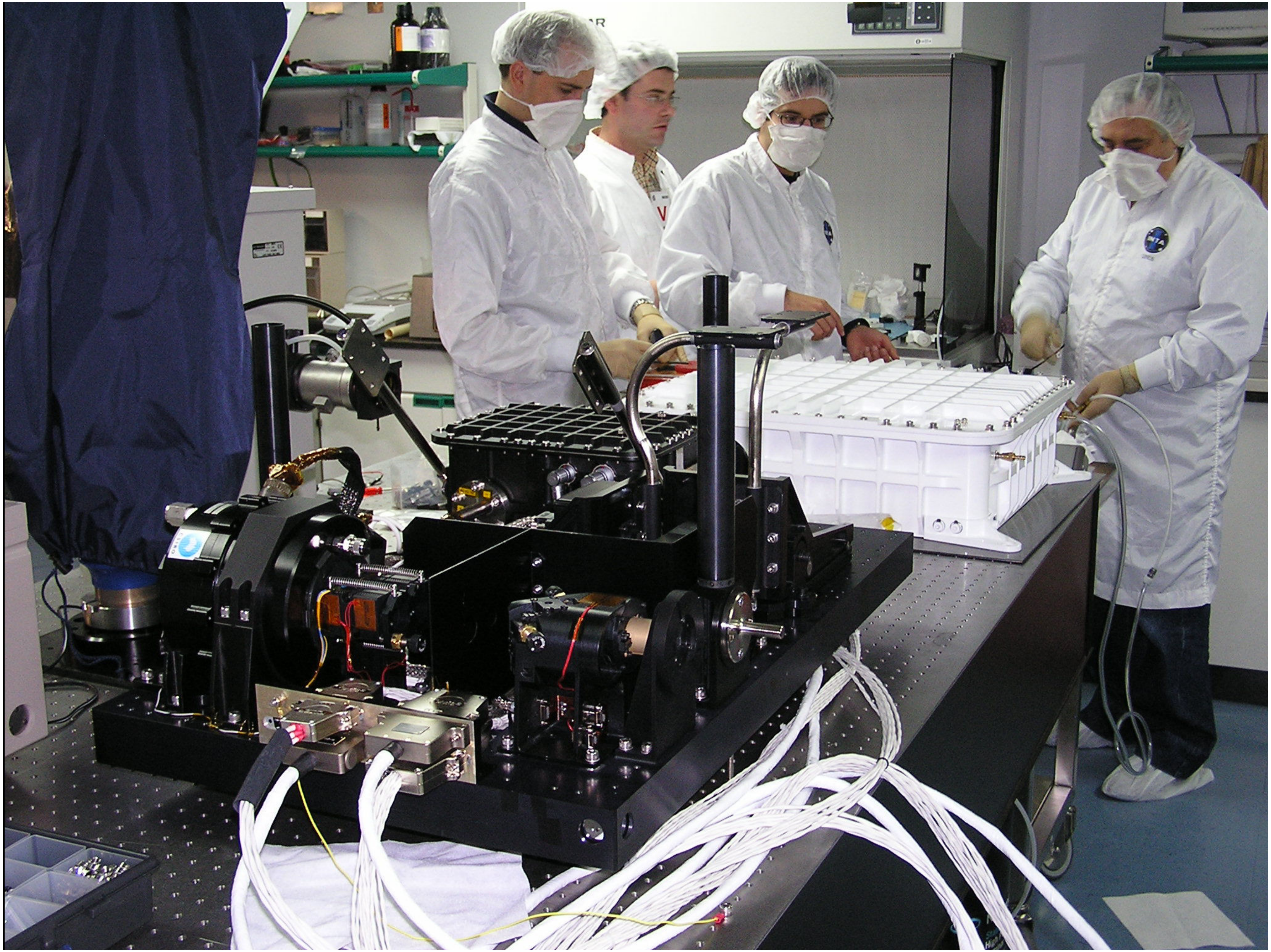
**Engineering**
Develop instrumentation
Optical metrology

↔

**Science**
Knowledge
Innovation







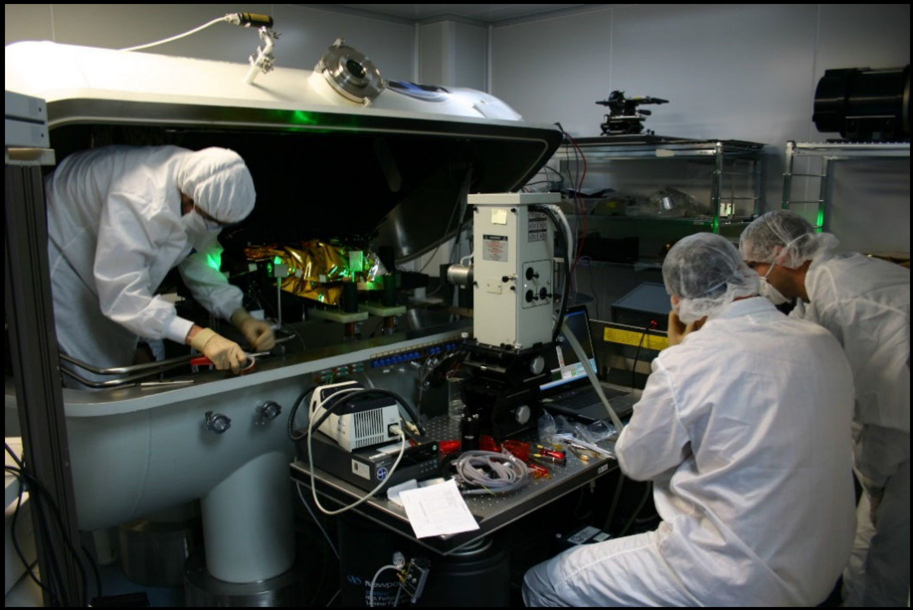
# Outline

- **Introduction**
  - Motivation
  - Goal
  - Background
  - Solar Orbiter mission: SO/PHI and METIS instruments
- **LCVRs validation for Solar Orbiter**
- **Progress in the characterization and design**
  - Temperature behavior
  - Dispersion laws
  - High birefringence LC: repeatability
  - Capacitance
  - Design
- **Conclusions**

# Motivation

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.



## 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

⇕

**Space industry**

Conservative ↔ innovation

# Goal

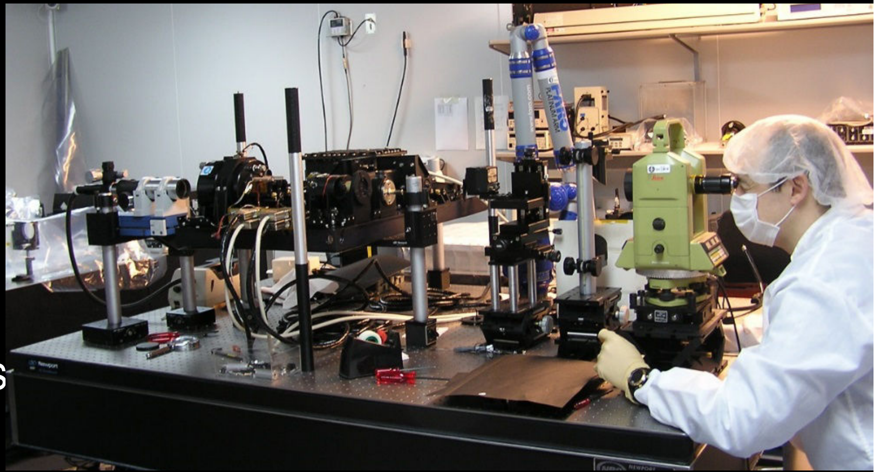
Solar Orbiter will be the **first space mission using LCs** for polarimetric measurements:

- **METIS :** Multi Element Telescope for Imaging and Spectroscopy → coronagraph
- **SO/PHI:** Polarimetric and Helioseismic Imager → solar magnetograph

- High sensitive polarimeter ($<10^{-3}$)
- High resolution spectrometer (<100mÅ)
- Diffraction limited Imager(<1 arcsec)

# Constrictions

- Mass < 33kg
- Power < 31 W
- Harsh Environmental Conditions : space 0.28 AU
- Reliability: ground, cruise and operation >11 years



# Missions background

## Stratospheric flights

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)

# INTA background and future

**SUNRISE mission**

**IMaX instrument:**
Scientific goals
Technological precursor for Solar Orbiter

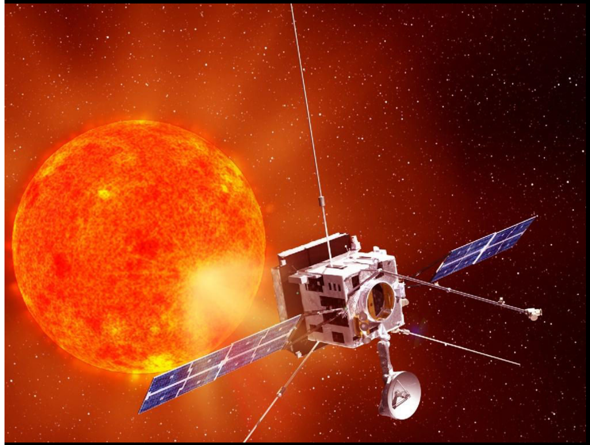
Start
**2002**

**SUNRISE 1st flight**
**2009**
Starts LCVRs space validation (2009-2011)

**SUNRISE 2nd flight**
**2013**
**STM/EBB/QM/FM and LCVRs qualification (2014)**

**2017**
**Solar Orbiter launch**

**Solar Orbiter mission**



**SO/PHI and METIS instruments**
Scientific goals
Technological goal: 1st space polarimeter based on LCVRs

# Polarization Modulation Packages (PMPs) based on LCs

Important Issues to be taken into account:

-Operational temperature

-High birefringence LC

## 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

-Achromatic LCVRs

-λ range and voltage selection

## as IMAGER

1. Wavefront error
2. Alignment quality

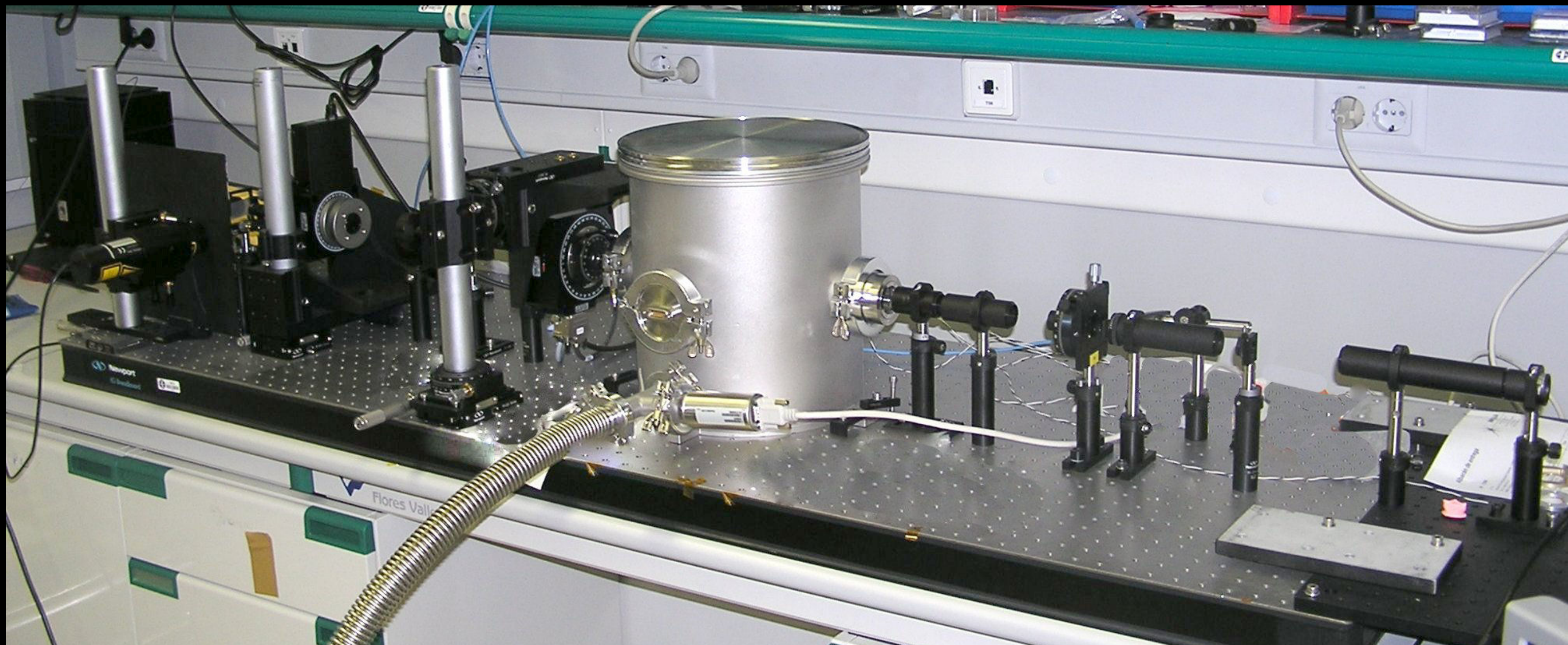
-Manufacturing quality

-Instrument optical design

# Polarimeter for testing IMaX PMP

Preflight calibration of the Imaging Magnetograph eXperiment polarization modulation package based on LCVRs, N. Uribe-Patarroyo, A. Alvarez-Herrero, V. Martínez Pillet (2012)

Simulating optical and environmental conditions



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**Instituto Nacional de Técnica Aeroespacial**

# 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**<br>Anti-Parallel Aligned Nematic | 4 types | 40 cells |
| **HAN**<br>Hybrid Aligned Nematic | 1 type | 10 cells |
| **Wide Acceptance Angle**<br>Anti-Parallel Aligned Nematic | 1 type | 20 cells |
| **Achromatic LCVRs**<br>Anti-Parallel Aligned Nematic | 1 type | 20 cells |

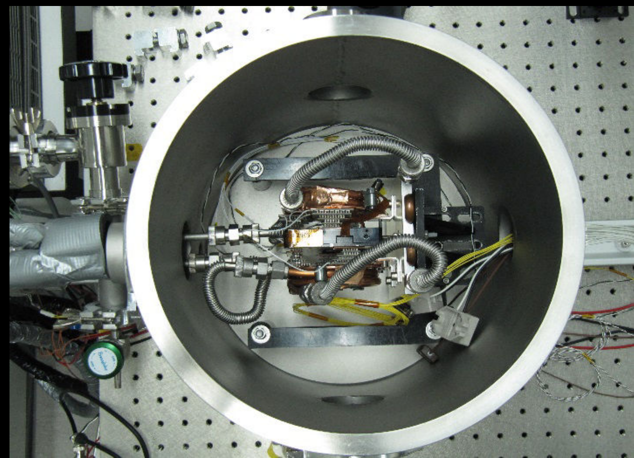
**TOTAL: 7 types, 90 cells**

**2 years of work**

**SUCCESSFULLY FINISHED**

**on May 2011**

*Results presented in SPIE2011, San Diego*



# LCVRs under study

| LC Type | Symbol | Comment | Alignment | Glass | Manufacturer | LC mixture | $\Delta n$ | $\Delta n$ 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] |

# Validation of LCVRs for Solar Orbiter

## Requirements

**Functional & Performance**

From the instruments to fulfill scientific requirements

**Environmental**

- Thermal
- Vibration/Shock
- UV radiation
- Ionizing radiation
- Non-ionizing radiation

**Others**

Outgassing, physical, operational…

## Indicators

1. Retardance versus voltage
2. Retardance over full aperture
3. Retardance at different acceptance angles
4. Retardance versus temperature
5. Retardance versus wavelength
6. Transmission
7. Contrast
8. Response time
9. Transmitted wavefront error
10. Beam deviation
11. TML & CVCM

    Total Mass Loss of material outgassed
    Collected Volatile Condensable Materials

## Measurements

- VASE
- Null ellipsometry
- Mach-Zehnder (p&s)
- Transmission (p&s)
- Autocollimator
- Contrast Setup

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# Test campaign

## Ionizing radiation tolerance (Gamma)

>75krads (100krads)

## Protons radiation tolerance

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

# Conclusions from the validation technology activity

1. Considering the different characteristics of all the cell types tested and the results obtained, the general conclusion is that the **LCVRs is a valid technology for a Polarisation Modulator Package in the Solar Orbiter environmental conditions**.

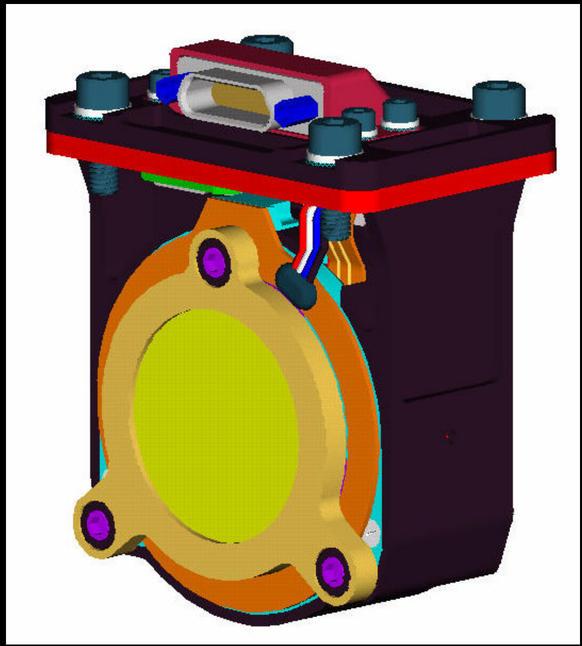
2. The cell type with better performance is the **T1Aα** due to its repeatability, robustness and good behaviour in simulated space conditions.
   – Response time should be reduced optimizing the thickness or the modulation scheme.

3. Also the cells based on the LC mixture **BL006** are good candidates (TBα and T6Ax.1) because these high birefringence LCs provide low response times and high stability against UV radiation.
   – Repeatability issues should be clarified.

4. Because the knowledge of the retardance versus voltage values is critical for the well-working of the polarisation modulation package, **an in-flight calibration of the PMP is strongly recommended** in order to prevent possible small changes of the optical retardance of the LCVRs during the mission.

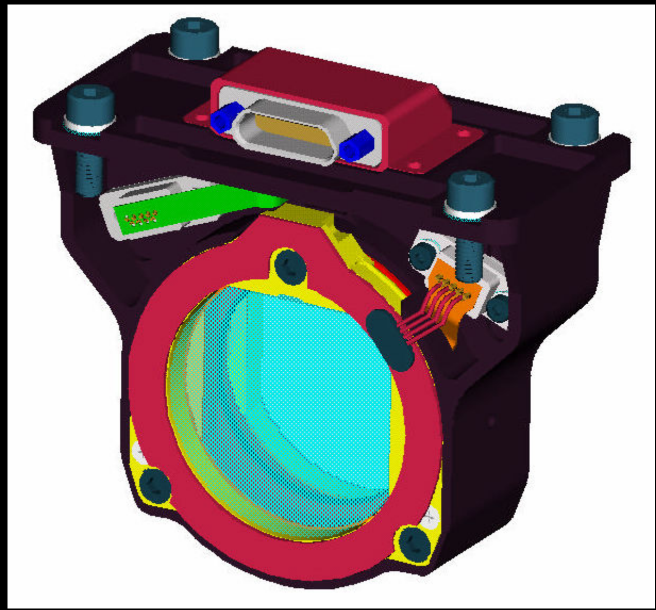
# SO/PHI and METIS

*Optimizing the modulation efficiencies following*
*J. C. del Toro Iniesta, M. Collados (2000)*



**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.



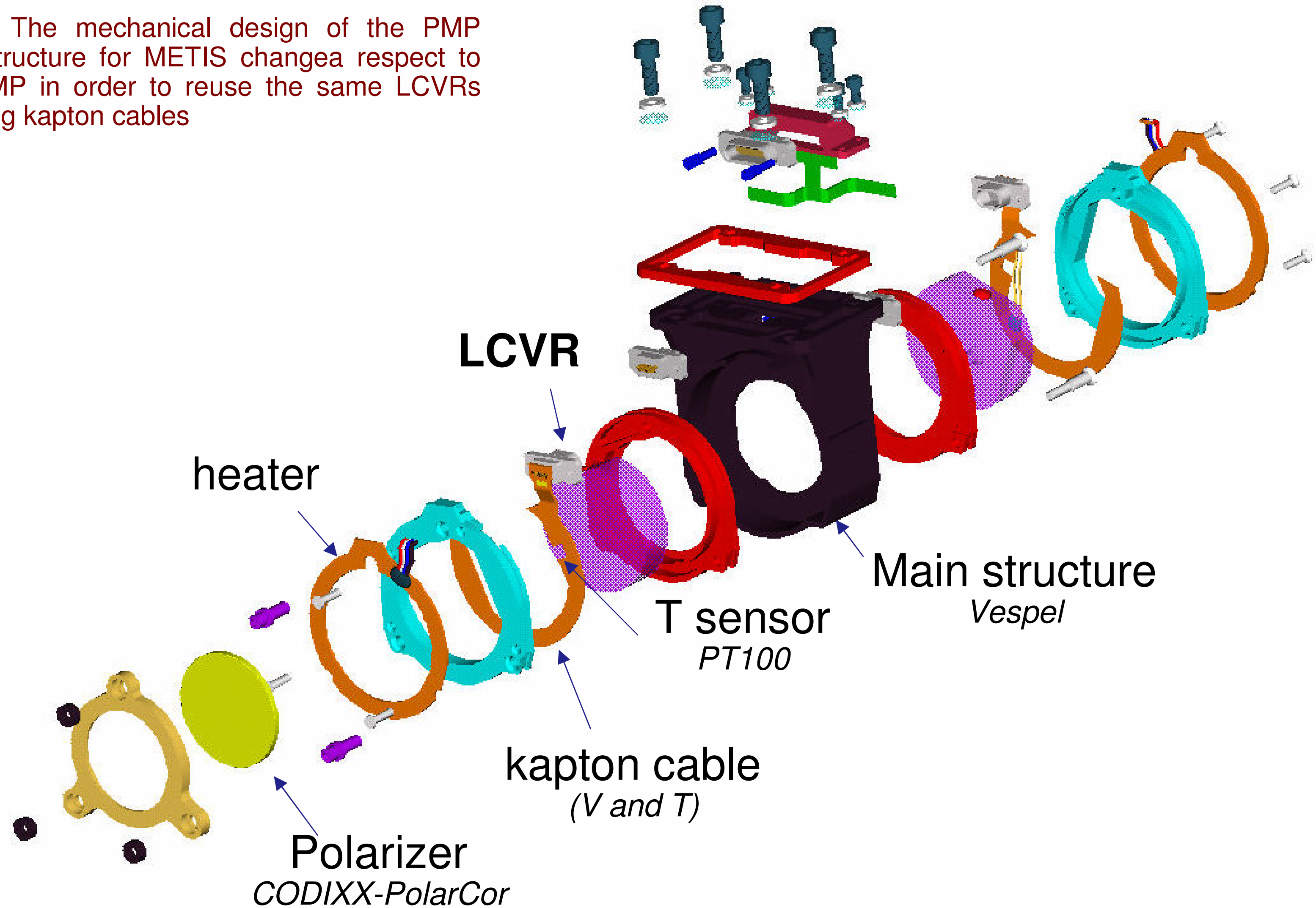
**METIS PMP**

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.

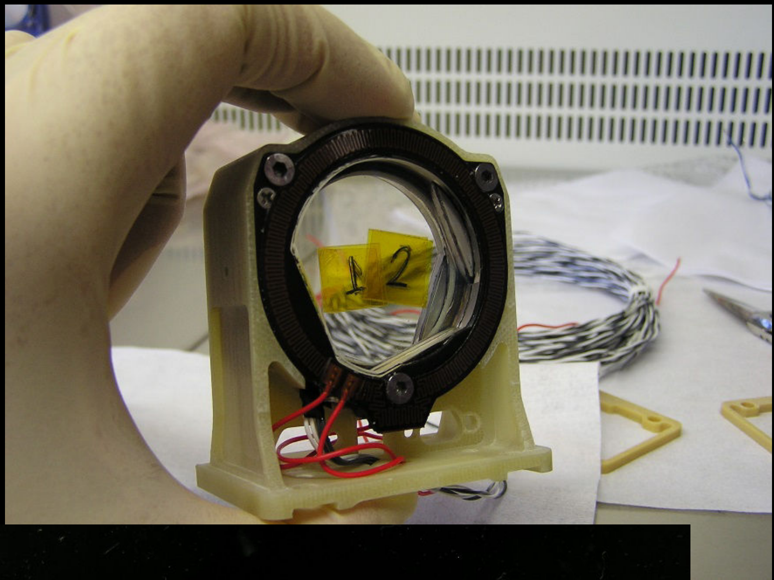
Wide acceptance angles

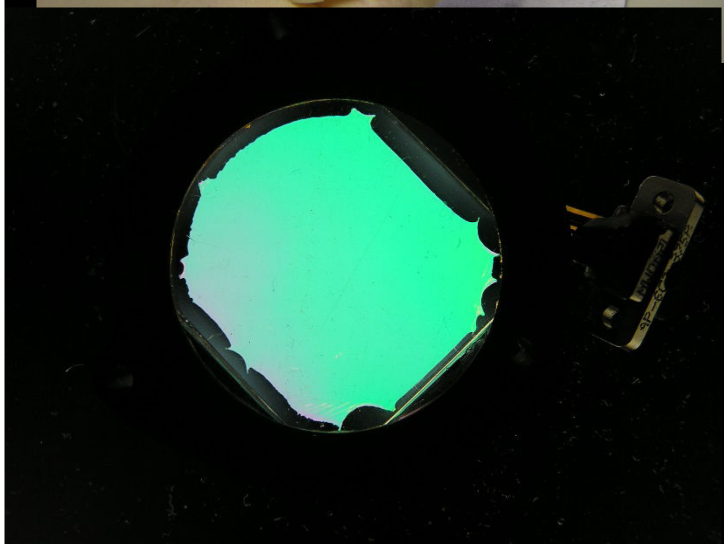
# PMP design

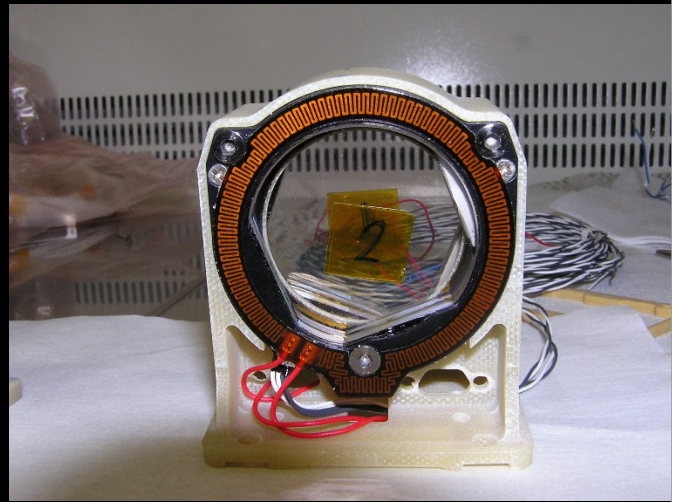
NOTE: The mechanical design of the PMP main structure for METIS changea respect to PHI PMP in order to reuse the same LCVRs including kapton cables

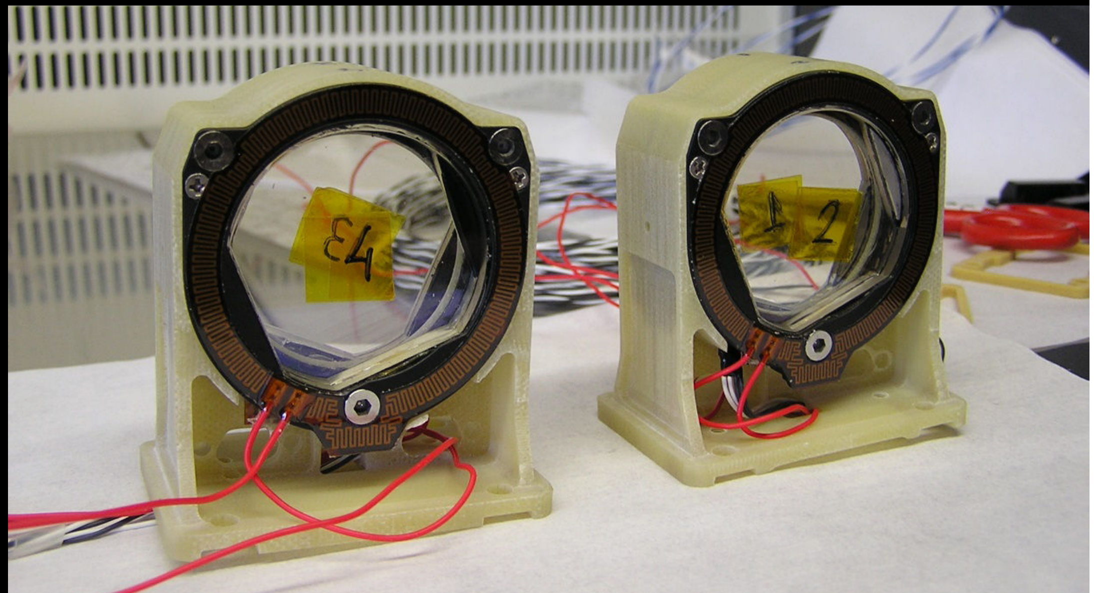


# STM prototype









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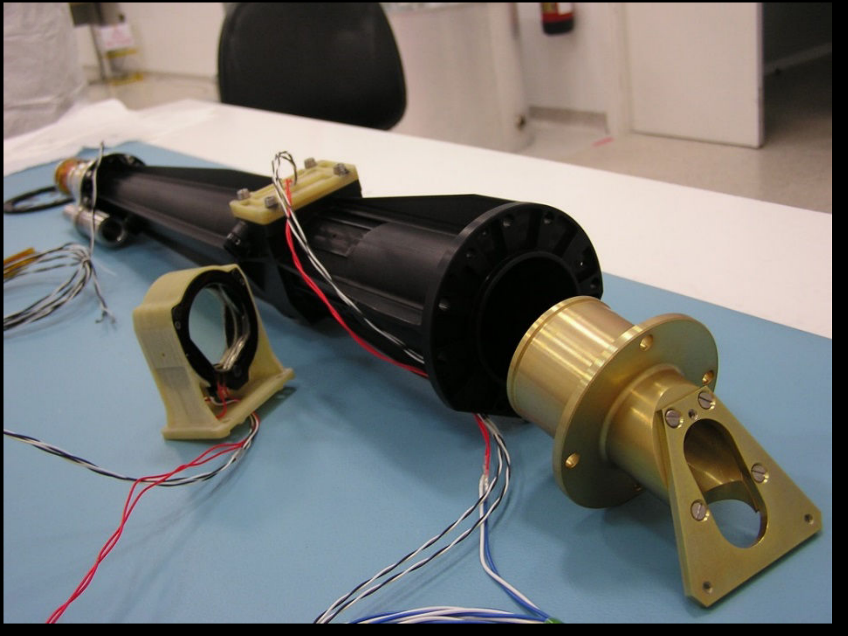
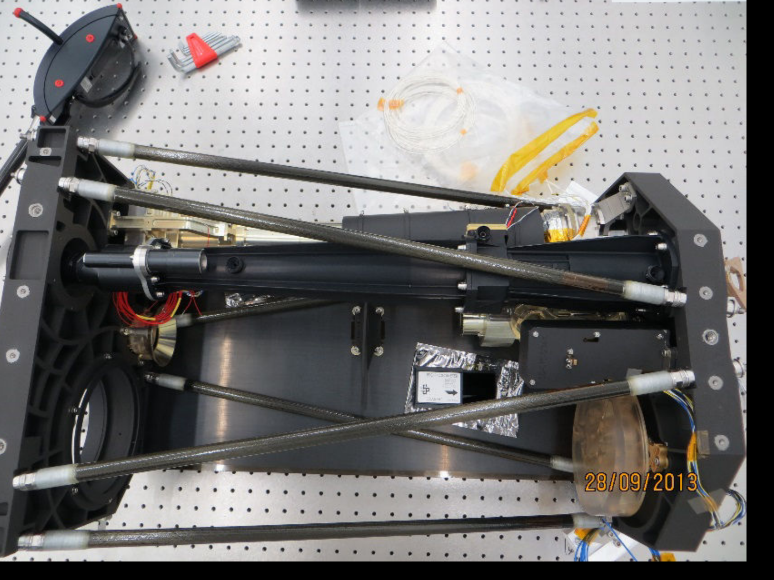
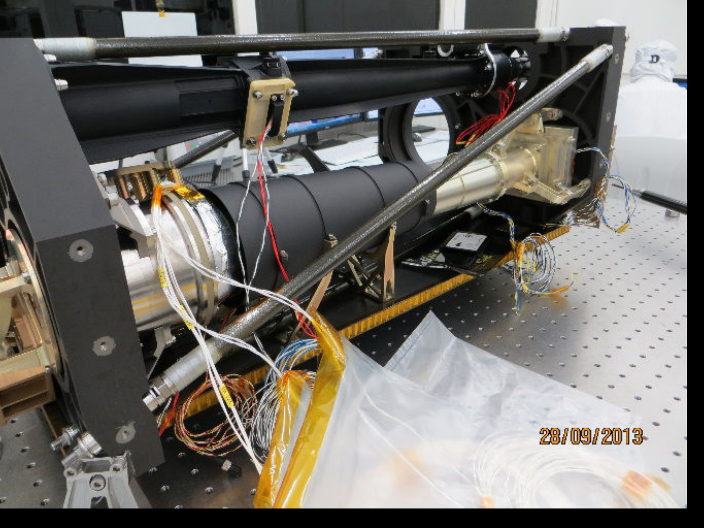
# STM prototype





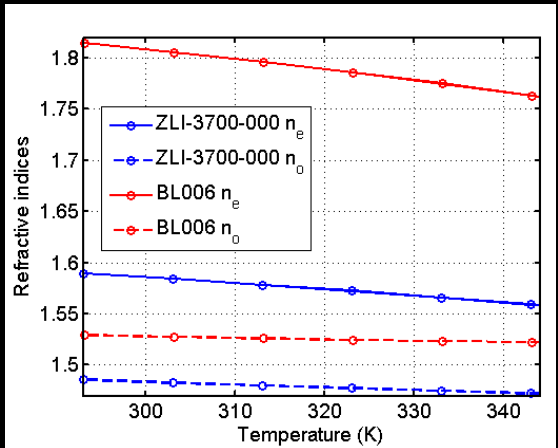



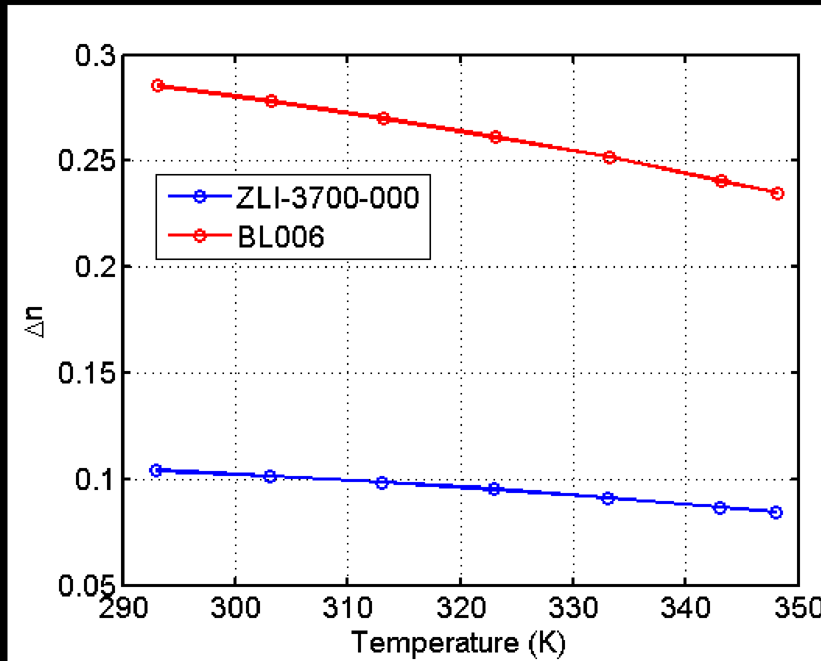
# Thermal behaviour

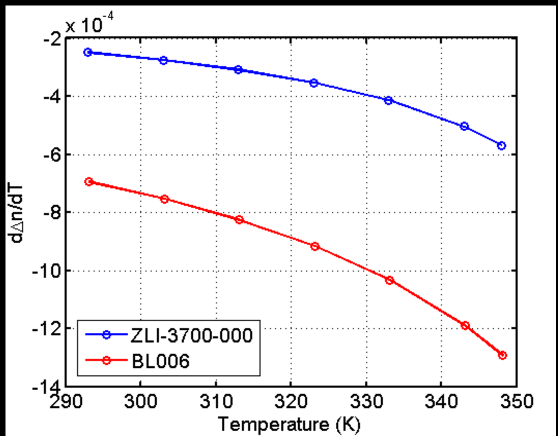
LC measurements (out of the cell)
Abbe refractometer, model 60/HR

$$\Delta n = \Delta n_o \left(1 - \frac{T}{T_c}\right)^{\beta}$$

J. Li, S. Gauzia, S.-T.Wu (2002)



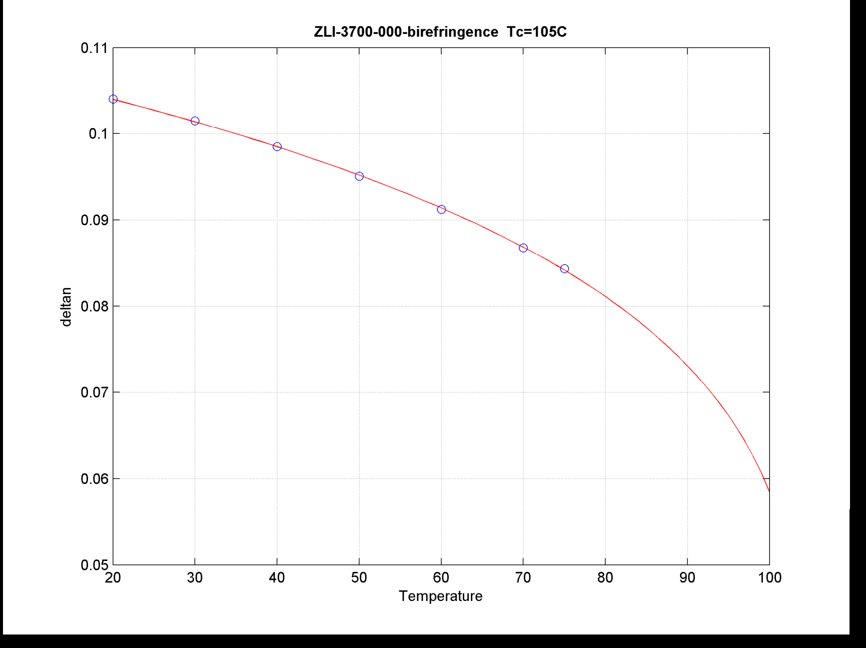



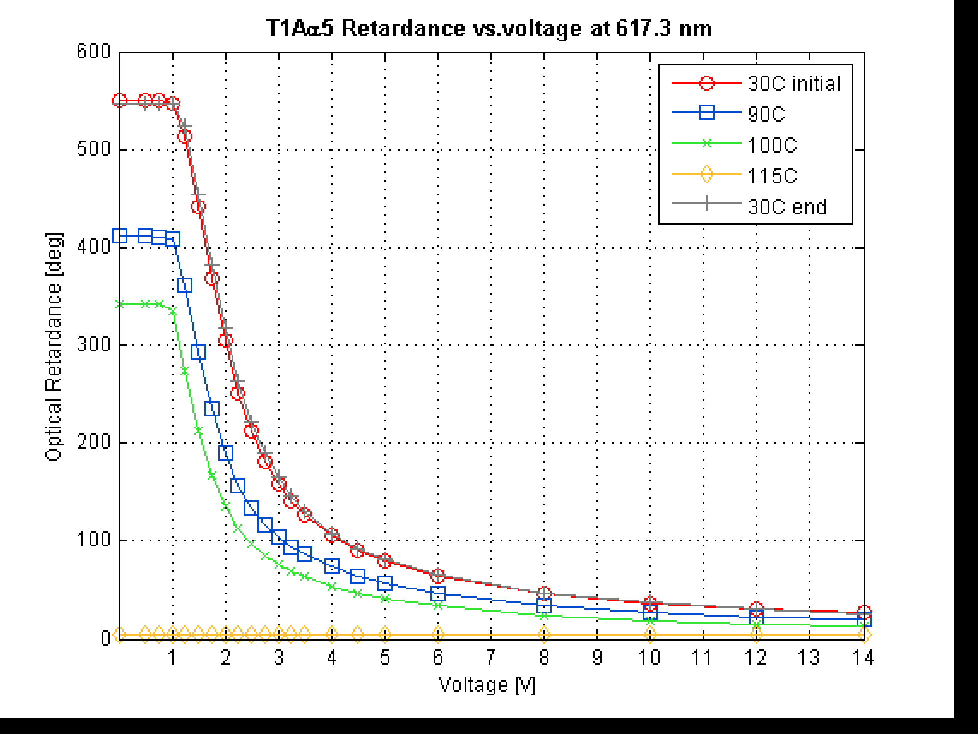

$$\frac{d\Delta n}{dT} = -\frac{\beta * \Delta n_o}{T_c}\left(1 - \frac{T}{T_c}\right)^{\beta - 1}$$

Predominant effect. It allows to model the cells thermal behaviour at different voltages from the ellipsometric measurements

# High temperature tests

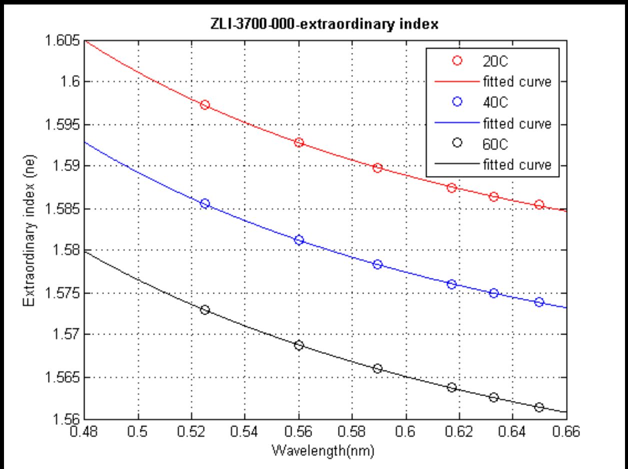
## Reversibility from the clearing point

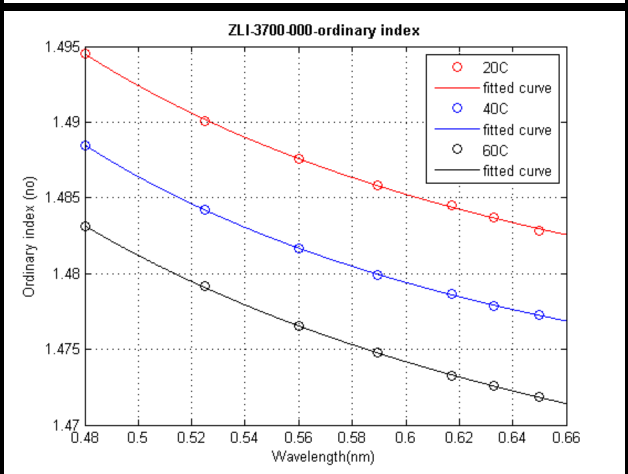


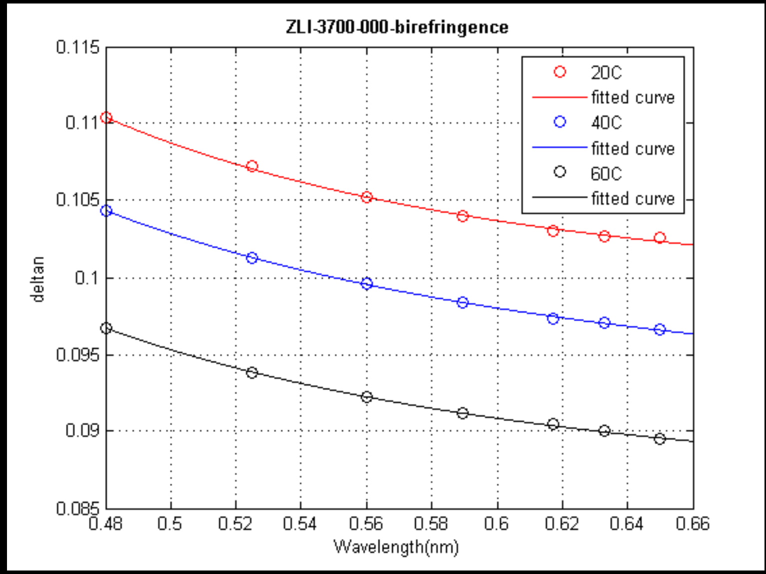



# Dispersion law

## LC measurements (out of the cell)
## Abbe refractometer, model 60/HR

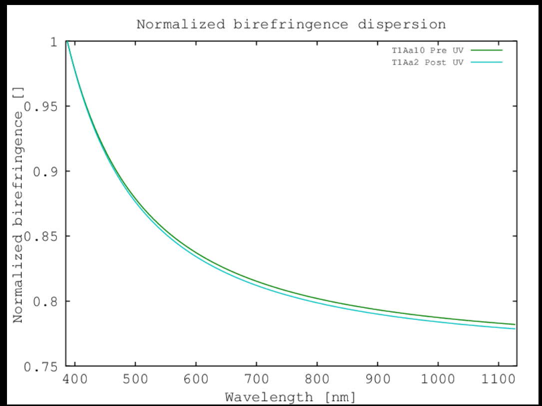


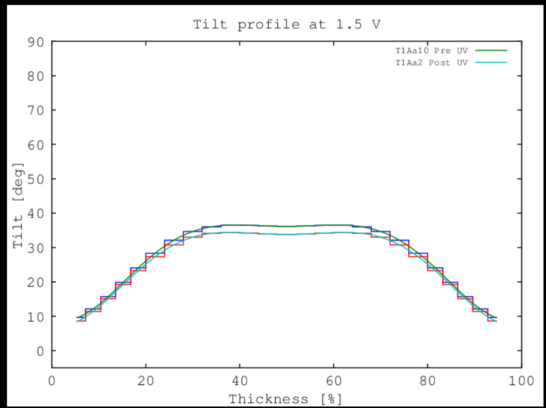



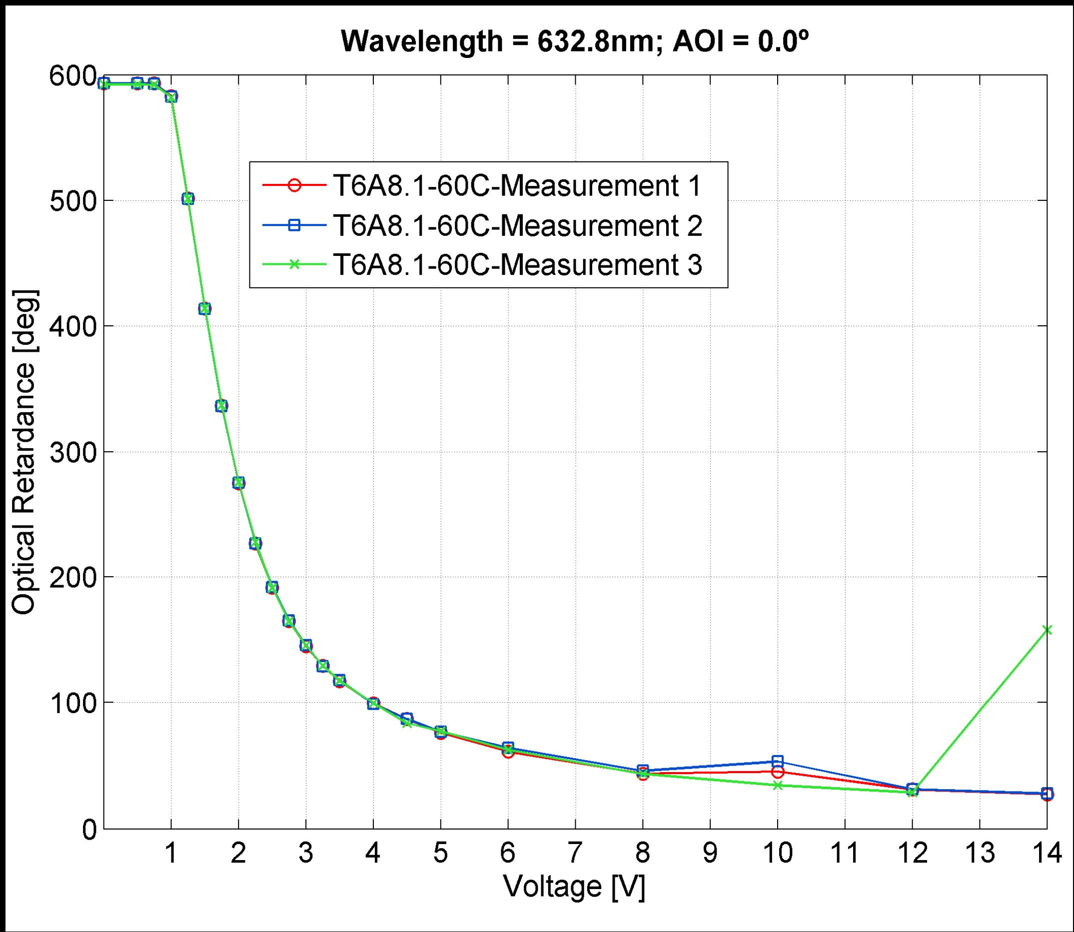

## Variable Angle Spectroscopic Ellipsometry

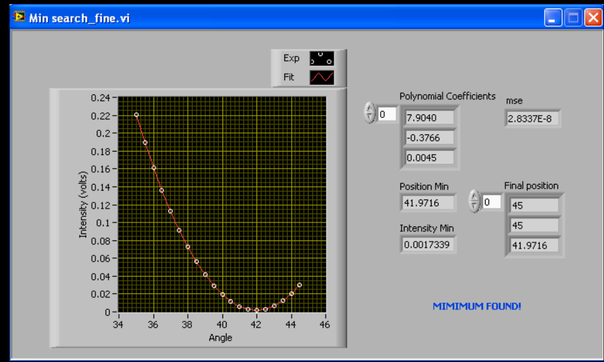
N. Uribe-Patarroyo, A. Alvarez-Herrero (2009)

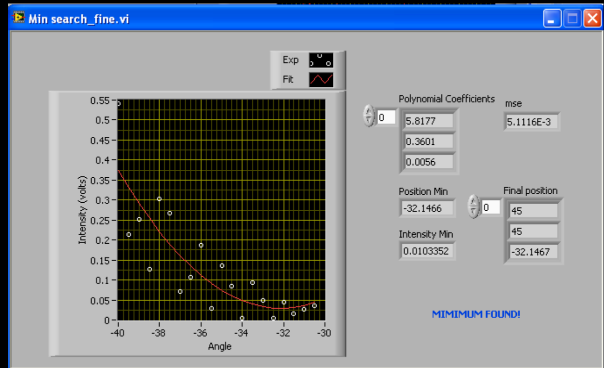


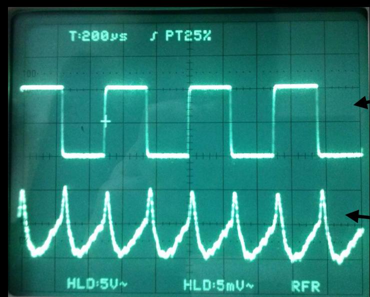



# Repeatability of high birefringence LCs mixtures



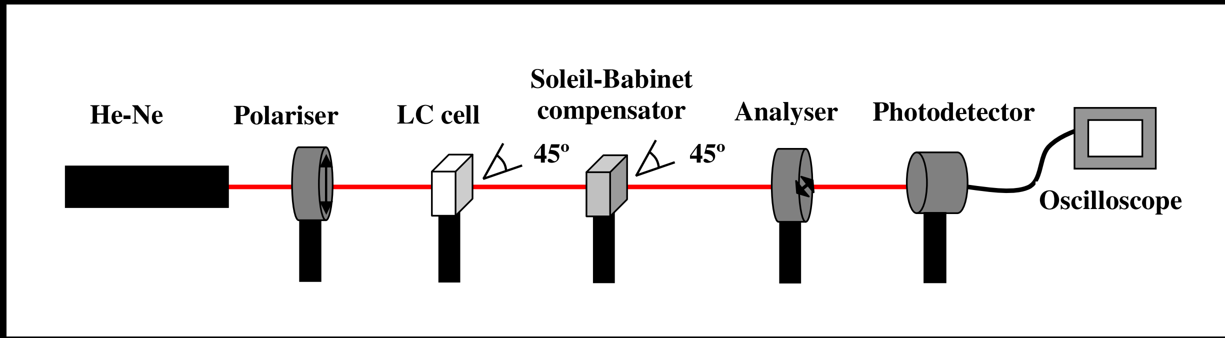



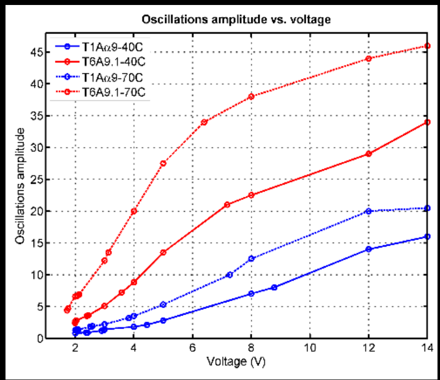



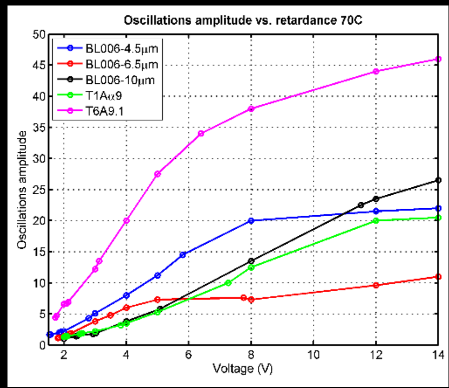
*Voltage signal applied to the LC cell*

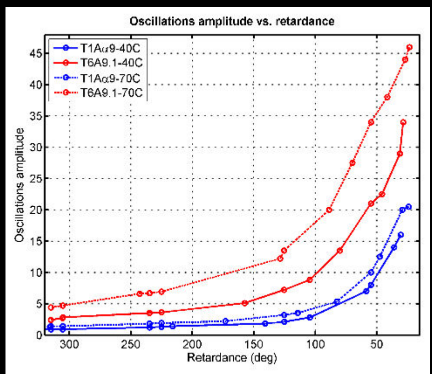
*Photodetector signal. LC molecules following the AC voltage applied*

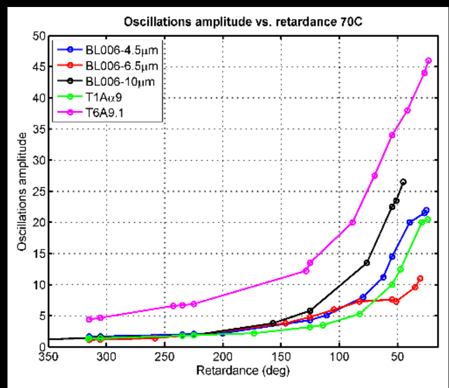
# Repeatability of high birefringence LCVRs




The oscillations amplitude

- increases with V
- Increases with T
- Decreases with thickness
- Increases with the area
- Increases with the birefringence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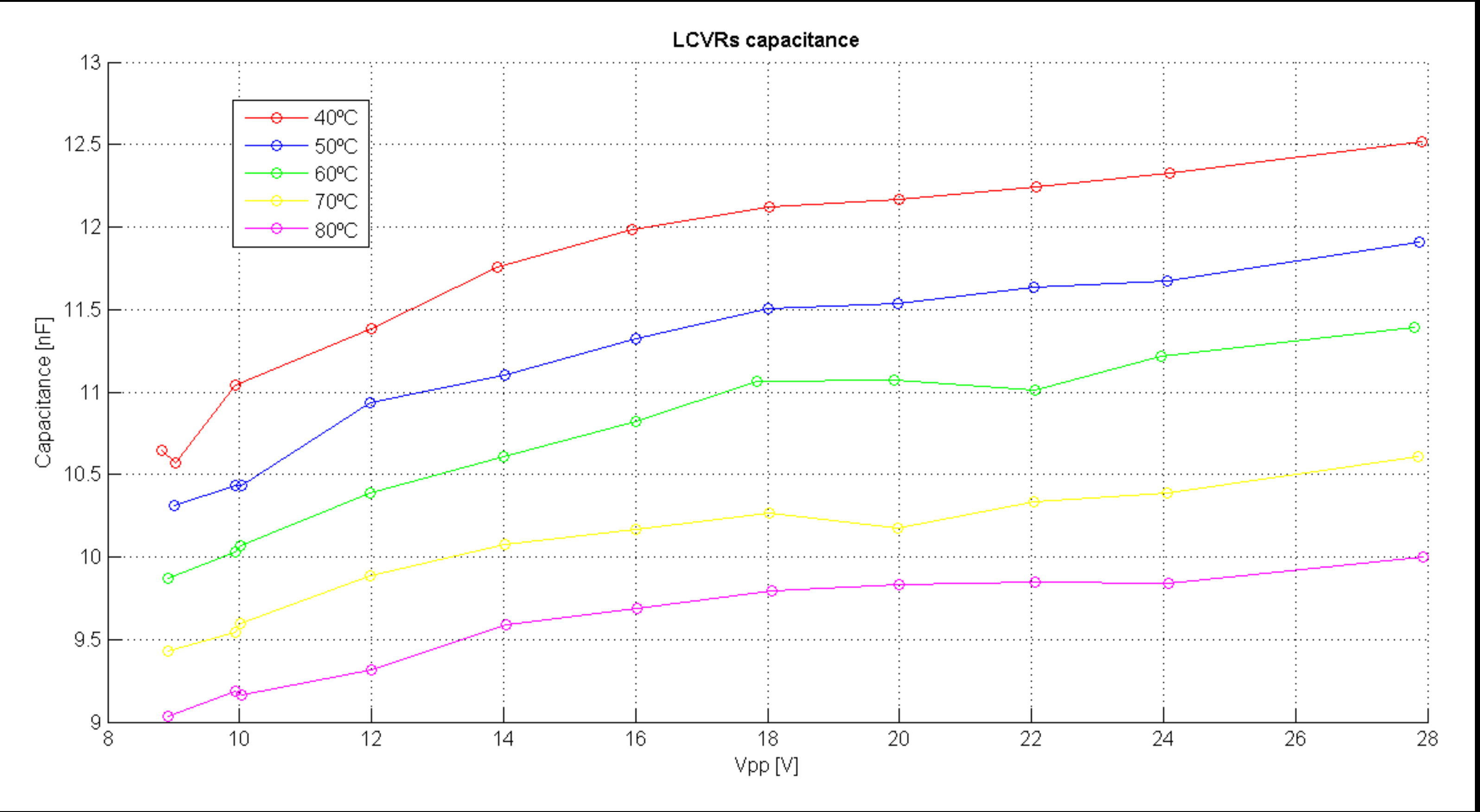
# Capacitance measurements

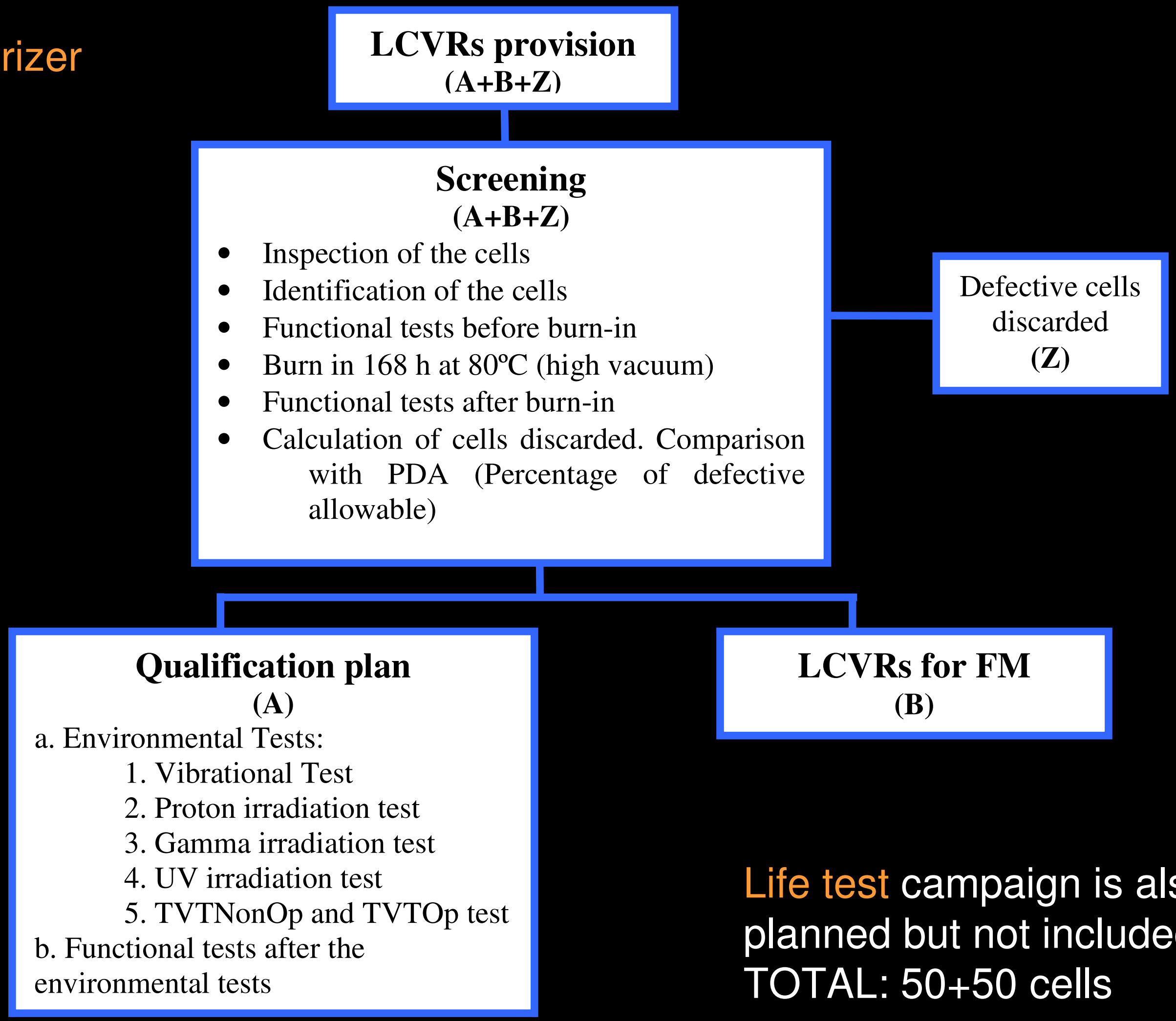
Critical issue for the electronics




The results are in agreement with Lo, Kuang-Yao; Shiah, Chi-Ching; Huang, Chia-Yi (2006)

# Qualification plan

Similar for the polarizer
**2014**




Life test campaign is also planned but not included here.
TOTAL: 50+50 cells

# Conclusions

The technical development activity of the LCVRs for Solar Orbiter is well-advanced. The technology has been validated in relevant environment (TRL5). Additional characterizations and tests have been carried out obtaining positive results. The design has been frozen and the flight models are being manufactured.

## Milestones

- Quallification and life tests campaign: 2nd half 2014
- PMP Elegant BreadBoards: September 2014
- PMP Qualification Model: December 2014
- PMP Flight Model: April 2015
- PMP Spare Model: June 2015

# Thanks to

**The INTA team, specially to:**

- Pilar García Parejo
- Néstor Uribe-Patarroyo
- Raquel López Heredero
- René Restrepo

**The SUNRISE and SO/PHI consortium: IAC, IAA, GACE, UPM, UB, MPS, KIS, HAO, IAS…**

**INAF,** Silvano Fineschi, G. Capobianco

**ESA,** Ilias Manolis

**Ministerio de Economía y Competitividad de España**