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RELATÓRIO ANUAL 2015 - TELESCÓPIO SOLAR EXPERIMENTAL BRASILEIRO

Luis Eduardo Antunes Vieira
Fernando Luis Guarnieri
Alisson Dal Lago
Braulio Fonseca Carneiro de Albuquerque
Odim Mendes Junior

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São José dos Campos
2015

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INPE
São José dos Campos
2015

Brazilian Experimental Solar Telescope

Annual Report - 2015

(DRAFT)

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Table of Contents

List of Figures

PROJECT CHARTER

Goals

Build a visible-light imager and magnetograph for solar observations.

Project Team Members

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Background

The solar electromagnetic and corpuscular emissions are strongly modulated by the evolution of the magnetic structure of the solar atmosphere, which is imprinted in the solar surface. The evolution of the magnetic structure leads to gradual changes of the solar activity (space climate) as well as violent events (space weather) that affect the whole Heliosphere. In particular, the solar output affects the ionized and neutral components of the Earth's atmosphere that have direct impact on human activities from agriculture to high-technological systems. The solar magnetism is driven by the energy transport from the inner layers of the solar structure to the solar atmosphere. Although systematic observations have revealed several features related to the evolution of the solar activity, there is not a complete explanation of the physical processes that lead to the solar activity cyclic variability and its long-term changes. Here we present a report of the development of a magnetograph and visible-light imager instrument to study the solar dynamo processes through observations of the solar surface magnetic field distribution. The instrument will provide measurements of the vector magnetic field and of the line-of-sight velocity in the solar photosphere. As the magnetic field anchored at the solar surface produces most of the structures and energetic events in the upper solar atmosphere and significantly influences the Heliosphere, the development of this instrument plays an important role in reaching the scientific goals of The Atmospheric and Space Science Coordination (CEA) at the Brazilian National Institute for Space Research (INPE). In particular, the INPE's Space Weather program will benefit most from the development of this technology. Additionally, we expect that this project will be the starting point to establish a strong research program on Solar System Research that could benefit the three divisions of the CEA/INPE. The proposed instrument is been designed to operate on ground, but with a conceptual design flexible enough to be adapted to operate on balloon and space-based platforms. In this way, our main aim is acquiring progressively know-how to build state-of-art solar vector magnetograph and visible-light imagers for space-based platforms to contribute to the efforts of the solar-terrestrial physics community to address the main unanswered questions on how our nearby Star works.

Scope

The instrument will provide remote-sensing estimates of the distribution of the magnetic field vector and line-of-sight velocity in the solar photosphere. In order to achieve the proposed goal, it is in the scope of this project the implementation of a laboratory for solar spectropolarimetry, the demonstration of the proposed concept, the development of an intermediate prototype, and, the development of an advanced prototype. Furthermore, the development of models and image processing algorithms needed to estimate the solar surface magnetic field are also subject of this project. Specifically, we will develop algorithms for the inversion of Stokes profiles, extrapolation models of the magnetic field, and, magnetic field flux transport models.

It is out of the scope of this project the design of an instrument to fly on balloon or in space-based platforms. Additionally, the development and design of complementary instruments, such as broadband radiometers, ultraviolet images, and solar coronagraphs are not addressed in this project.

We point out that the installation of the solar telescope at the observatory will be addressed as a complementary project.

Key Stakeholders

National Funding Agencies	FAPESP, CNPq, FINEP
International Funding Agencies	EU, NSF, NASA, ESA
Universities	UFMG, EEL-USP, Mackenzie, Stanford, Alcalá
Research Institutes	NSO, MPS, LNA, INPE
Scientific Communities	Astrophysics, Solar Physics, Solar-terrestrial Physics, Climatology

Constraints, Assumptions, Risks and Dependencies

Constraints	• We have to follow “time-consuming” governmental procedures to acquire components to develop the project employing the governmental budget. • We are employing a pre-defined commercial optical structure for the telescope and tracking system. • The operation of the instrument should be under supervision.
Assumptions	• We assume that the 2015 budget needed will hold. • We assume that the 2016 budget needed will be available. • We assume that the concept employed will allow us to achieve the requirements for the instrument. • We assume that we have the technical capability to integrate the instrument. • We assume that we have human resources available to develop the project. • We assume that there is industrial competence to manufacture the mirrors and optical components. • We assume that the currency exchange rate between Brazilian Reals to US Dolar will not exceed 4.00. • We assume that the industry can manufacture key opto-mechanical components.
Risks and Dependencies	• If the 2015 budget delays or fails, the project will delay approximately one year. • If the human resources are not available, the project will delay while the necessities are not fulfilled. • If the acquired components do not follow the specifications, the overall requirements for the instrument will not be fulfilled.

Lead Funding

National Institute for Space Research (INPE/Brazil)

Av. Dos Astronautas, 1758 – 12.227-010 São José dos Campos – SP - Brazil

Project Budget

Description	Funding	Total (USD)	Status
Non-expendable Material			
Intermediate Prototype			
sCMOS Cameras	CEA/INPE	41,231.70	Delivered
Commercial Ritchey-Chrétien Telescope 500 mm aperture	CEA/INPE	114,000.00	Contracted
Fabry-Perot Etalon		200,000.00	
Pre-filters		15,000.00	
Narrow-band filters		20,000.00	
Polarization Package		15,000.00	
Customized optics		15,000.00	
Control System		3,000.00	
Coolers		1,000.00	
Data acquisition system		5,000.00	
Software		15,000.00	
Laboratorial Components			
Optical tables (2 items)	DGE/CEA/INPE	40,558.18	Contracted
Opto-mechanical components	CEA/INPE	31,029.90	Selected
Optical Power/Energy Meter System		9,800.00	
Container		60,000.00	
Spectrum analyzer		20,000.00	
Total (Permanent material)		**605,619.78**	
Expendable materials/Service			
Expendable materials for subsystems constructions		5,000.00	
Expendable materials for administrative support		2,500.00	
Total (Expendable materials/Services)		**7,500.00**	
Total		**613,119.78**	

Budget Execution*

Year	Funding	Total Available** (USD)	Total Executed (USD)
2014 Budget	CEA/INPE	41,231.70	41,231.70 (100%)
2015 Budget	CEA/INPE, DGE/CEA/INPE	145,029.90	185,588.08 (128%)***
Total:			226,819.78

*The Budget does not include salaries and fellowships.

**Total Available in January 1st of each year.

***The budget of the Space Geophysics Division (DGE) was employed to acquire the optical tables.

External Advisers and Collaborators

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SYSTEMS ENGINEERING

Introduction

The project started in 2014 and it was still in its initial phase in the beginning of 2015, where there was a concept of the instrument and the project team was being established. Based on several team meetings hold weekly, we found that it was timely the implementation of a project development methodology. We decided, in collaboration with the General Coordination for Space Engineering and Technology (ETE) of INPE, to implement a formal and structured systems engineering procedure for the Brazilian Experimental Solar Telescope to ensure that the goals of the project will be achieved efficiently. This approach allows us to define objectively the requirements for the instrument to be developed. Specifically, the systems engineering program is being used to develop and manage the following:

- Definition of the goals, the scope, and the products of the project
- Identification of constraints, assumptions, risks and dependencies
- Identification of the key stakeholders
- Concept Development
- Technical Requirements
- Definition of the Budgets
- Definition of Technical Standards
- Preparation of the documentation to acquire components
- Performance Modeling
- Verification and Validation
- Assembly, Integration, Testing, and Commissioning (AITC)
- Design Safety

As we are developing the system from scratch, we decided to employ a model for the system development lifecycle that describes the activities to be performed and the results that have to be produced during the development. The most widely used model for this purpose is the V-Model (see Figure 1). The concept, decomposition of the requirements and the creation of system specifications are presented on the left side of the V, while the integration of the instrument and its validation is shown on the right side. We point out that the first leg of the V-Model consists of successive detailed reviews of each system-level design. In order to ensure that any details that may have been overlooked during the previous phases can be identified and the problems are considered, addressed, and remembered, the successive revisions are public and consensual.

Ideally, in the first phase of the project we should deal only with a detailed design of instrument without any hardware implementation. In this way, any changes in the project or changes due to development setbacks can be made without having significant costs. The physical implementation of the system should be made only after the project is approved by consensus and all questions are tackled. Even during the system integration phase, the gradual integration is made with checks of engineering requirements at each level, so that if there is a problem at a certain level, it is possible to avoid expenditure on integration issues at higher levels.

Here, we have not followed strictly this strategy. In order to focus on the development of the spectropolarimeter, we decided to acquire with the funding resources available components that the technology is consolidated and are commercially available. Namely, we have acquire the sensors (sCMOS cameras), the optical telescope, and, the tracking system. One consequence of acquiring these components in the early phase of the project is that we have imposed constrains on the requirements and performance of the instrument. On the other hand, following strictly the model would lead to a significant delay on the implementation of the project due to the characteristic time-scales to acquire components following the institutional process. For example, the delivery of the optical telescope and the tracking system is expected to occur just in 2017. The main risk associated with the delay to implement the project is demotivation of the team and its dissolution.

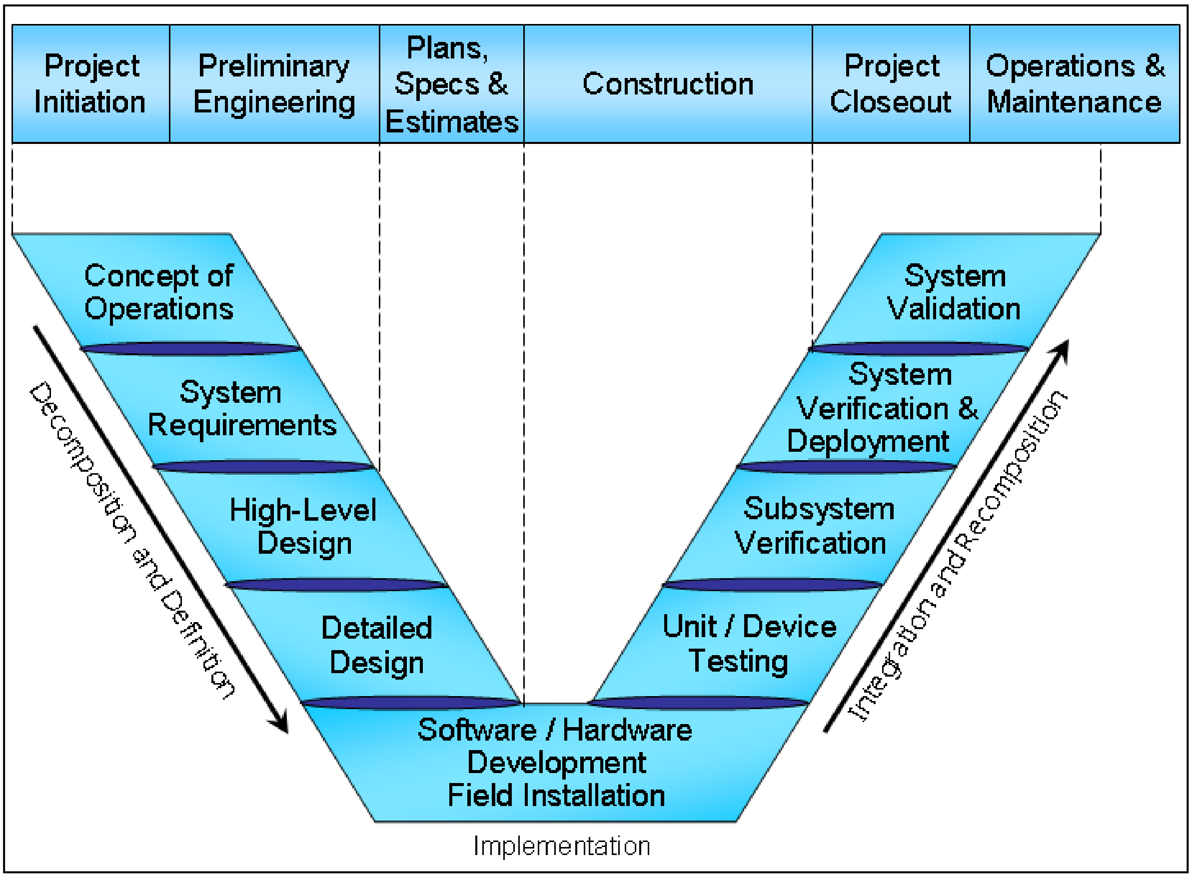


Figure 1: Graphical representation of the V-Model adopted in project development. Source: http://ops.fhwa.dot.gov/publications/regitsarchguide/73useprojimp.htm

The first step was the definition of the overall requirements for the instrument based on team discussions and external consultation to key stakeholders. Subsequently, we elaborated a functional solution in the form of IDF[1] diagrams, which resulted on the identification of the main subsystems. In the next steps, the subsystems were breaking down to the component level. By following this approach, we ensure that if each subsystem or component respects the requirements, the sum of all of them will ensure

[1] *Icam DEFinition for Function Modeling,* where 'Icam' is an acronym for *Integrated Computer Aided Manufacturing.*

the compliance with the requirements of the system as a whole. Additionally, this approach ensures the control development and the adherence to expectations regarding the project as a whole. Furthermore, the distribution of the tasks to team members is facilitated according to their specialties.

Definition of the technical requirements for the system

As the development model adopted is based on the requirements, the first step is the identification of the high-level requirements of the equipment that are expected by the stakeholders (i.e., any institution, group or person involved directly or indirectly in the project). The resulting document summarizing the high-level requirements is sometimes called the customer's voice as it summarizes the customer expectations regarding the project. We have consulted colleagues from INPE, NSO, MPS, APL, UFMG, EEL-USP, the Mackenzie University, the Stanford University, and the University of Alcalá.

Once the requirements were compiled, the team adopted by consensus the requirements for the instrument in an event called Systems Requirements Review (SRR). The requirements adopted encompass some of the stakeholder's requirements, but not necessarily all. The document produced will guide the entire development of the project. The system requirements are listed in Table 1.

We highlight that at this point the project was seen as a black box. The instrument package should contain a telescope for full solar disk observations. A tunable filter is used for scanning of a defined photospheric spectral line (Fe I 630.25 nm), and a polarization modulation package performs the polarization analysis.

Table 1: System requirements

Instrument Performance - Dynamic Range	
Parameter	**Value/Range**
Spatial resolution**	1 arcsec
Cadence**	90 s
Spectral Range	6302.5 Å± 3 Å
Spectral Bandwidth	100 mÅ
B_{LOS}	+-3.5 kG
B_{TRA}	+-3.5 kG
V_{LOS} (long-term)	NA
V_{LOS} (instantaneous)	± 10 m s^{-1}

Instrument Performance – Precision	
Parameter	**Value**
BLOS	50 G
BTRA	200 G
VLOS	20 m s-1
Ic (flat field uniformity)	1%

*Full Disk Telescope

**Value

Comments: (Alexei Pevtsov – 23.11.2015)

- Resolution – you may want to clarify it in terms of pixel size. Most widely used "definition" used nowadays is that you need 2 pixel sampling for a resolution unit (e.g., for 1 arcsecond resolution, you will need 2 pixels – 0.5 arcsec pixels). I do not entirely agree with such definition, in general it makes sense.
- Range in Bl and Bt is reasonable, but there are occasionally fields with stronger amplitudes.
- Precision in V-LOS is too high, and it could be hard, if impossible to achieve given the sampling bandpass (100 mA) in comparison with Doppler width of Fe I spectral lines 6301-6302A.
- Cadence and precision: Full disk, high cadence (90 seconds) and relatively low precision in field strength limit this instrument to study rapid processes in active regions. It would make sense to have additional option to enable study of weaker fields on longer time scales (e.g., polar fields, quiet sun fields etc). This would require higher precision in field strength, but relatively low cadence (e.g., 10 minute or even 1 hour cadence). You may want to include this option in requirements.

Development of the functional solution based on IDF diagrams

The functional system solution using IDF diagrams makes use of diagrams containing inputs, outputs, controls and resources specified at different levels for the system. The first diagram, also called Level 0, includes the equipment as a whole. At this level we analyse which are the inputs, controls, resources and outputs needed for the operation of the instrument without the need to specify the detailed operation of the system. All quantities are defined by the requirements and not by specifications. That is, we just needed to explore what we need, with the freedom to defined subsequently the details of the instrument functioning. Figure 2 shows an example of an IDF0 diagram prepared in the early phase of the project.

At this level, we explored, for example, the requirements for the images to be produced. The requirements for the images is composed by a general requirement which should be common to all images, and specific requirements at different processing levels. Table 2 shows the general requirements for the images. In the zero processing level, Level 0, those images are sampled both in different quasi-monochromatic wavelengths along the absorption line and in different polarization states. The six (6) proposed polarization states that will be explored are shown in Table 3.

We point out that it’s needed at least 5 wavelength points along the chosen line (Fe I 630.25 nm) are needed to reconstruct the Stokes profile and estimate the magnetic field vector. In a preliminary study, we have mainly manipulated the line 6301.5 Å for degradation of the Stokes profiles. We have chosen different sets of line points: 3 wavelengths equally-spaced 0.150 Å; 5 wavelengths equally-spaced 0.086 A, and so on. Figure 3 shows an example of Stokes profiles measured by SP Instrument on board of Hinode Spacecraft. Two lines are clearly distinguished at 6301.5 Å and 6302.5 Å. Effective Landé factor is larger in 6302.50 Å (g=2.5) than 6301.51 Å (g=1.33). A set of possible 4 band-passes points close to the absorption line center and 1 in the continuum to be employed are indicated in the figure. The point distribution in the plots in this report may be risky, as there are two telluric lines (that does not appear in Hinode, as they are formed by the atmosphere and only ground telescopes will see them – see Figure 4). Neverthenless, Telluric lines are useful as wavelength calibrators, since they stand always in the same position, while Fe I lines move by dopplershifts.

The IDF0 diagram was, subsequently, split in internal system blocks (Subsystems). The inputs, controls, resources, and outputs of the Level 0 block are distributed in the inner blocks with the addition of new items interconnecting the blocks. Figure 5 exemplifies the IDF1 diagram for one subsystem. This methodology allows us to work with subsystems that can be fully described in terms of its requirements. In this way, the group responsible for the design and implementation of each block can work independently regardless of the blocks surrounding it. The main assumption here is that each block will fulfill their individual requirements.

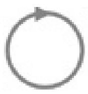
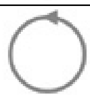
Comments: (Alexei Pevtsov 23.11.2015)

When selecting a minimum number of sampling points, you should remember that the wavelength offsets will be fixed, but the position of spectral lines will change relative to fixed wavelengths due to noise, Doppler shift and field strength. Thus, the sampling points will be rarely if ever symmetric relative to line core. Also, the bandwidth is 100 mA, which means that there will be significant averaging of spectral line profile in each sampling point. All of this should be taken into account when performing such determination. Continuum point between two Fe I lines could be affected when there are significant Doppler shifts (flares?) and strong fields. Continuum on the red-side of this spectral line is much better, but it would require larger tuning range. The tuning range of +/- 3A would allow such tuning. Also, wavelength samling shown in Figure 3 could be prone to significant uncertainties in magnetic field. If you combine Doppler velocities (shift in your Stokes profiles relative to fixed sampling wavelengths) with location of sampling points, you can be in situation when only one V lobe is sampled, and in some extreme cases (5-7 km-s Doppler shifts) even only one side of one lobe is sampled. 5-7 km/s may sound large for the photospheric line, but do not forget that you also have systematic shifts due to solar rotation – large closer to limb, Evershed flows, 5-minute oscillations, and large flows in flaring regions). Thus, I would suggest increasing number of sampling wavelengths to cover both lobes in Stokes V.

Table 2: General requirements for the Images.

Parameter	Value	Comments
Spatial Resolution	≤ 1 arcsec (726 km)	Less than or equal to SOLIS, SVM and HMI resolution.
Image Resolution	≥ 2048x2048 (full-disk)	SVM (1024), SOLIS (2048), HMI (4096),
Exposure Time	300 ms	SVM (100 ms), HMI (125 ms), IMAX (246)

Table 3: The six (6) Polarization States.

Polarization State	Stokes Vector	Description	Representation
I+Q	[1,1,0,0]	Horizontal Polarization	
I-Q	[1,-1,0,0]	Vertical Polarization	
I+U	[1,0,1,0]	+45° linearly polarized	
I-U	[1,1,-1,0]	-45° linearly polarized	
I+V	[1,0,0,1]	Right Hand Circular Polarization (RHCP)	
I-V	[1,1,0,-1]	Left Hand Circular Polarization (LHCP)	

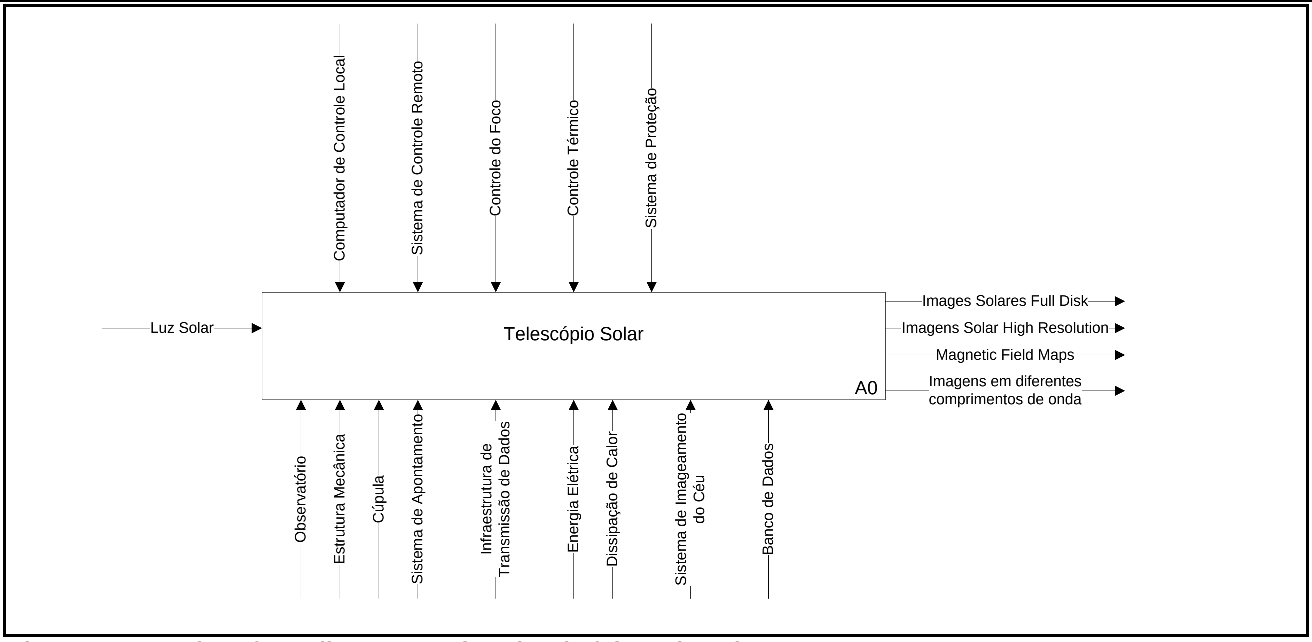


Figure 2: Examples of IDF diagrams to the 0 level of the solar telescope.

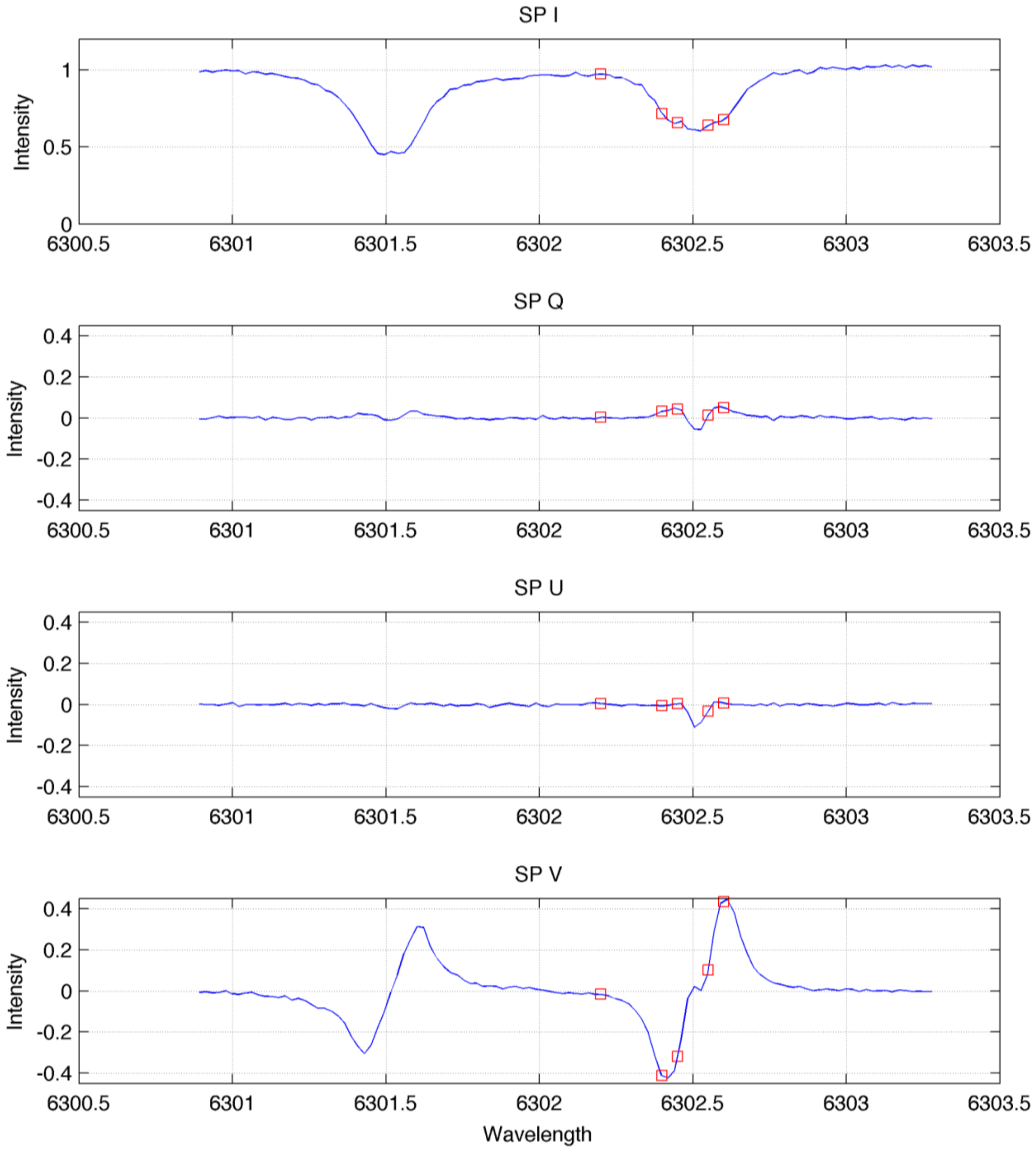


Figure 3: Example of Stokes profiles measured by SP Instrument on board of Hinode Spacecraft. The red squares show the selected wavelengths for the instrument.

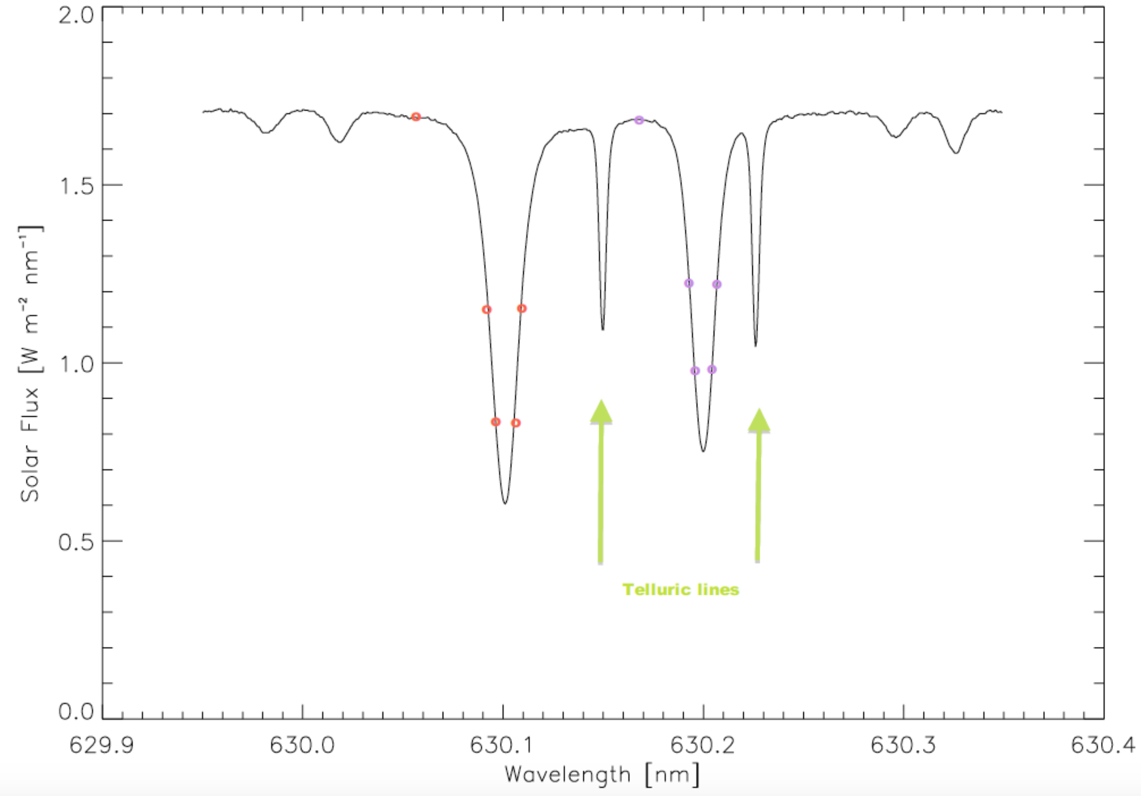


Figure 4: Example of Stokes profiles measured at ground level near the spectral region of interest.

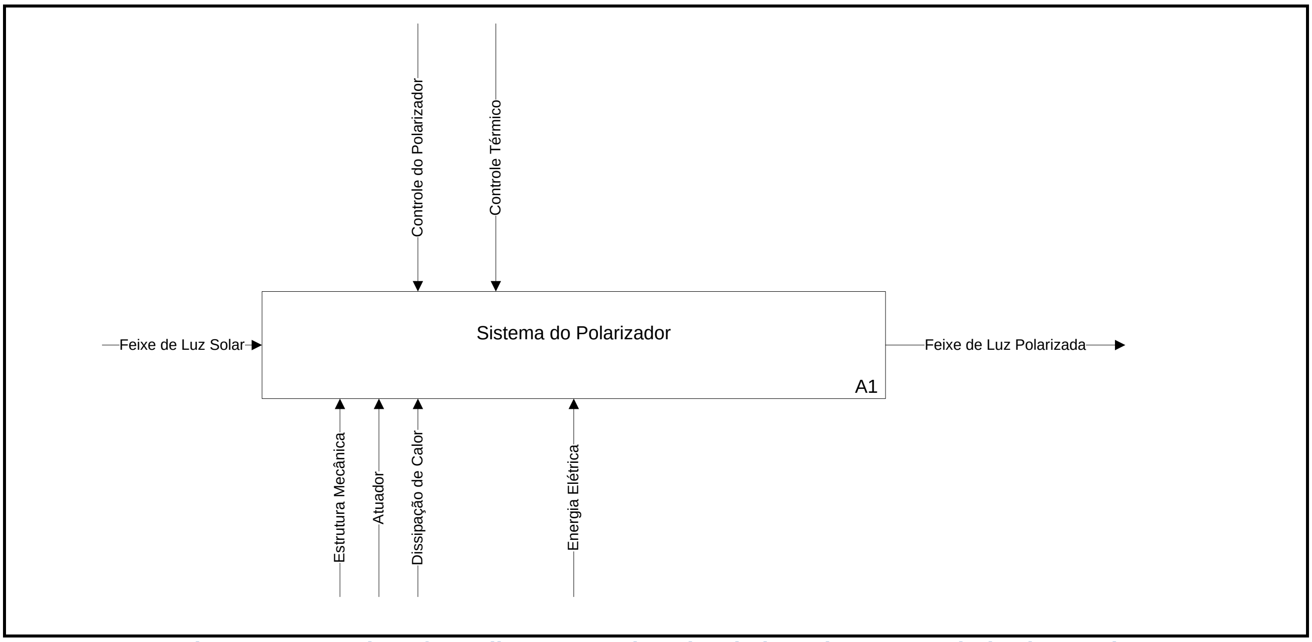


Figure 5: Examples of IDF diagrams to the 1 level, the subsystem polarization package

Development of the basic architecture

The basic system architecture consists of a diagram of simplified blocks, drawn from the initial system requirements. In this block diagram there are just large components that have been mapped from requirements, without any concern in this step on how these blocks are interconnected or which specifications each one has. This diagram gives a general idea of system composition and fosters discussions on the definitions of each of these blocks, which new blocks will be needed and what are the means of connection between them. The diagram of the basic architecture of INPE's Solar Telescope can be seen in Figure 6. Even this diagram shown in Figure 6 has suffered additions compared to its first version presented, as a result of discussions promoted by the use of this diagramming tool.

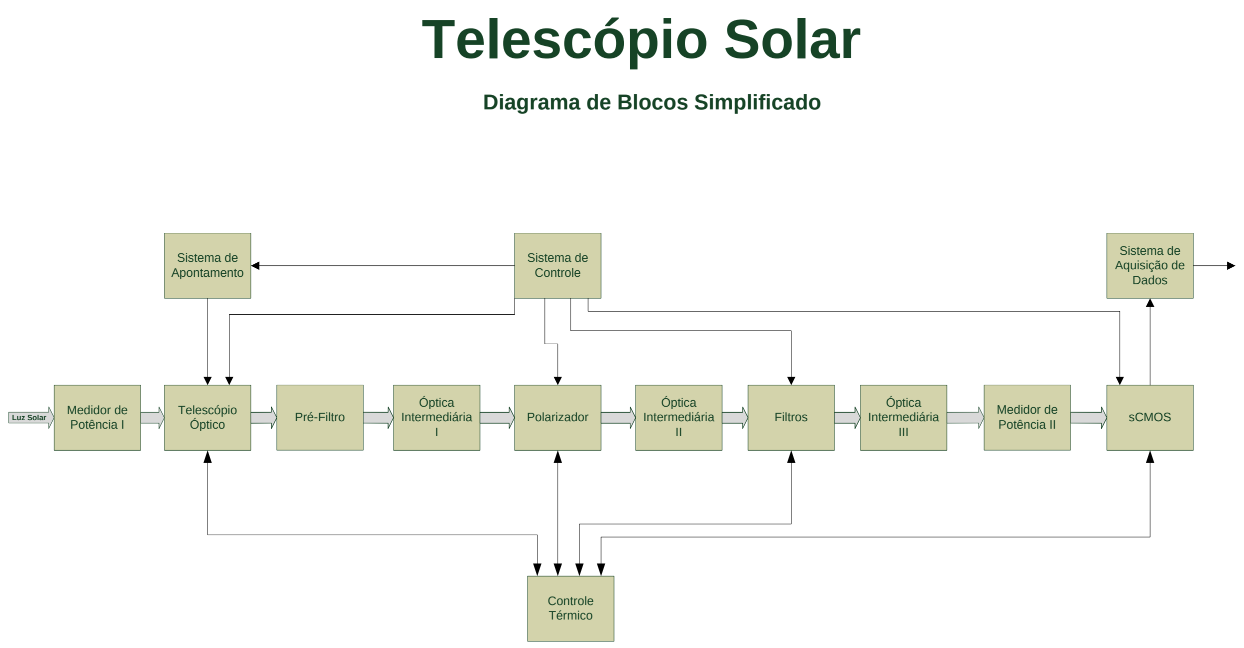


Figure 6: Simplified block diagram of the Solar Telescope. (Text in Portuguese)

Development of high-level architecture

From the discussions, suggestions and comments regarding the diagram of simplified blocks, we started the development of high-level architectural design. At this stage, each block is included in more details and accessories, and one begins to glimpse the interconnections between each block, although only in a generic way, without making a detailed specification of each block or connection.

The diagram in Figure 7 is the High-level Architecture of the Solar Telescope. Note that in this diagram, for example, it is shown the existence of a data bus, without making any specification of the data or how many bits are being addressed.

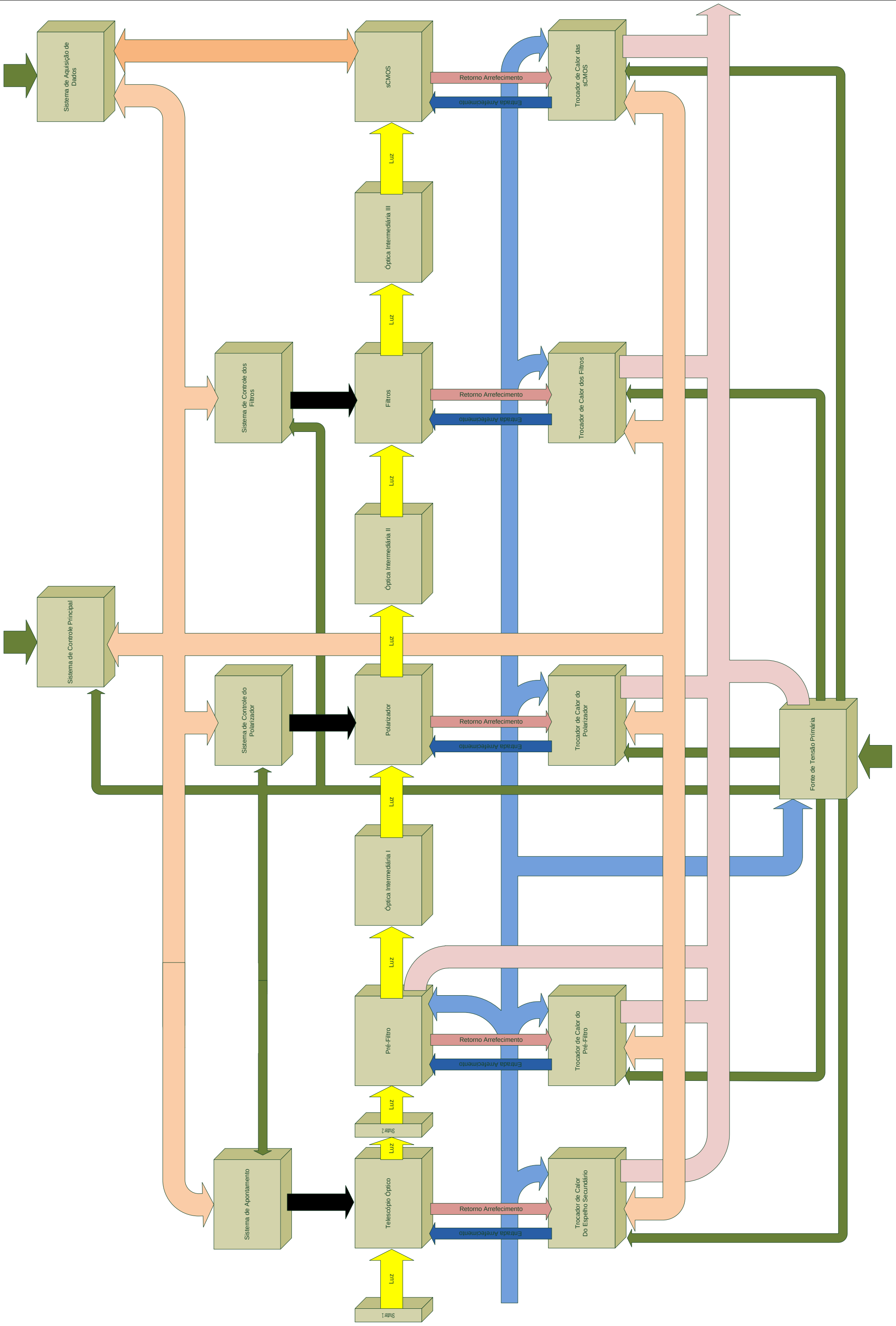


Figure 7: Diagram of the high-level architecture. (Text in Portuguese)

Operating Principles and timeframe

Figure 8 presents the State Machine Diagram, which describes the way the instrument will operate such that each of its subsystems is always in on of the possible states. Additionally, there are well-defined conditional transitions between these states. We suggest that the instrument will operate in the following states:

Idle	The system is in standby. The primary power source is on. The system scans the command for initialization.
Initialization	All elements (filters, polarizer, cameras, etc) are set to the initial state. The operator is asked to define the set points and to confirm the operation temperature of the elements. The operator is asked to perform the manual verification of the system.
Warm-up	All temperature control systems are activated. Wait until all elements reach the operation temperature. Assure that the shutters are closed. Test the individual operation of each element. Active the pointing and tracking system. Release the system to go to the Acquisition sequence.
Acquisition sequence	The operator is asked to select the acquisition sequence to be executed. The cover of the primary mirror is opened. The shutters are opened. The selected procedure is executed. Ask the operator if another routine will be executed. If the yes, the previous step is repeated. Otherwise, the shutters are closed; The cover of the primary mirror is closed. Search for the Cool Down command.
Cool Down	Assure that all shutters are closed. Wait until all components are in the resting temperature. Shutdown all temperature control systems. Set all elements to the initial position. Search the command to total shutdown of the system (idle state).

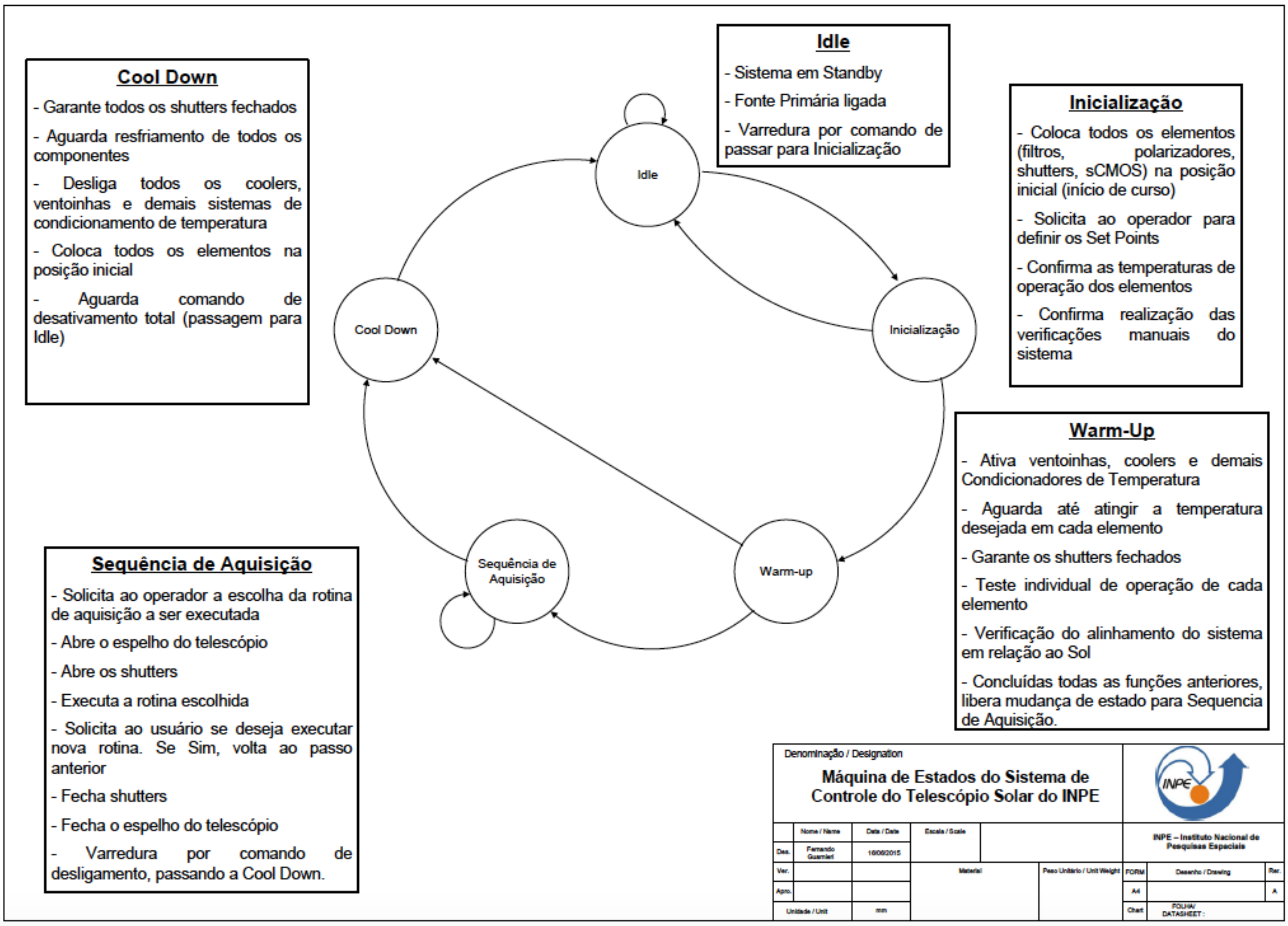


Figure 8: State Machine Diagram. (Text in Portuguese)

Based on the operating principles we analyzed the preliminary specification of the subsystems and components, which are described in the next section, to estimate the execution time for an observation cycle. For the components that we have not yet specified, we have employed the specifications of components employed on similar equipment.

For the polarization package we employed the specification of the LCC1221C liquid crystal, manufactured by Thorlabs, Inc. The total cycle time (rise/fall time) is about 27 ms/510 µs at 25 ° C. Assuming the worst case, the cycle time is about 27 ms.

For the Fabry-Perot Etalon, we considered the specification of the Etalon used by the instrument Imax/Sunrise. In this case the device needs to do a scan from -3000 V up to

4000 V, using a maximum slew rate of 1500 V/s. Note that not all wavelengths setting positions are not equally spaced. Whereas wavelengths 1 to 5 are equally spaced, the interval between the continuous wavelength setting position and the next one is twice the interval between the other wavelengths setting positions.

Comments: (Alexei Pevtsov – 23.11.2015)

I am confused by your (conflicting?) reference to Fabry-Perot etalon and scanning speed (in V/second) used LiNiO3 etalon on Imax/Sunrise. These are principally different devices. What is the purposed of such comparison? Also, if you aim at studying rapid processes, you may want to consider a non-sequential tuning sequence for FP (e.g., alternate between opposite wings and do continuum the last. This will minimize the effect of changes in spectral line profile position during the tuning).

The frame rate of the acquired sCMOS cameras is 50 fps at full resolution employing the global shutter mode. This corresponds to a sample interval of about 0.02 s. Here, in a conservative way, we assumed an interval of 0.1 s between each image.

Table 4 presents a summary of the setting times of the considered components. As can be seen, the polarization package response time is much smaller than the Etalon filter response time. Thus, the best operation sequence should be: (a) the selection of wavelength; and, (b) for each polarization state, we should acquire a number of images needed to improve the signal-to-noise ratio (SNR).

Table 4: Summary of the setting times of the considered components

Component	Setting Time
Polarization Package:	0,027 s
Fabry-Perot Etalon	0,93 s
sCMOS Camera	0,1 s
Reset	5 s

Following the propose sequence, we can estimate the timeframe to complete an observation cycle. The panel (a) of the Figure 9 shows the execution time for each of the states of the components for the data acquisition for the continuum wavelength setting position. In the first step, the system is reset. The wavelength is adjusted to the continuum wavelength setting position, λ_C, and the polarization package is adjusted to position 1, P_1. Then, a sequence of images is acquired (six in this example). In the next step, the polarization package is adjusted to the position 2, P_2, and a second set of images is acquired. The sequence repeats until all polarization states are acquired. The complete observation cycle is presented in the panel (b) of Figure 9, while the panel (c) shows the cumulative execution time. Note that for this example, the whole cycle would take about 30 s. The number of images acquired would be 180.

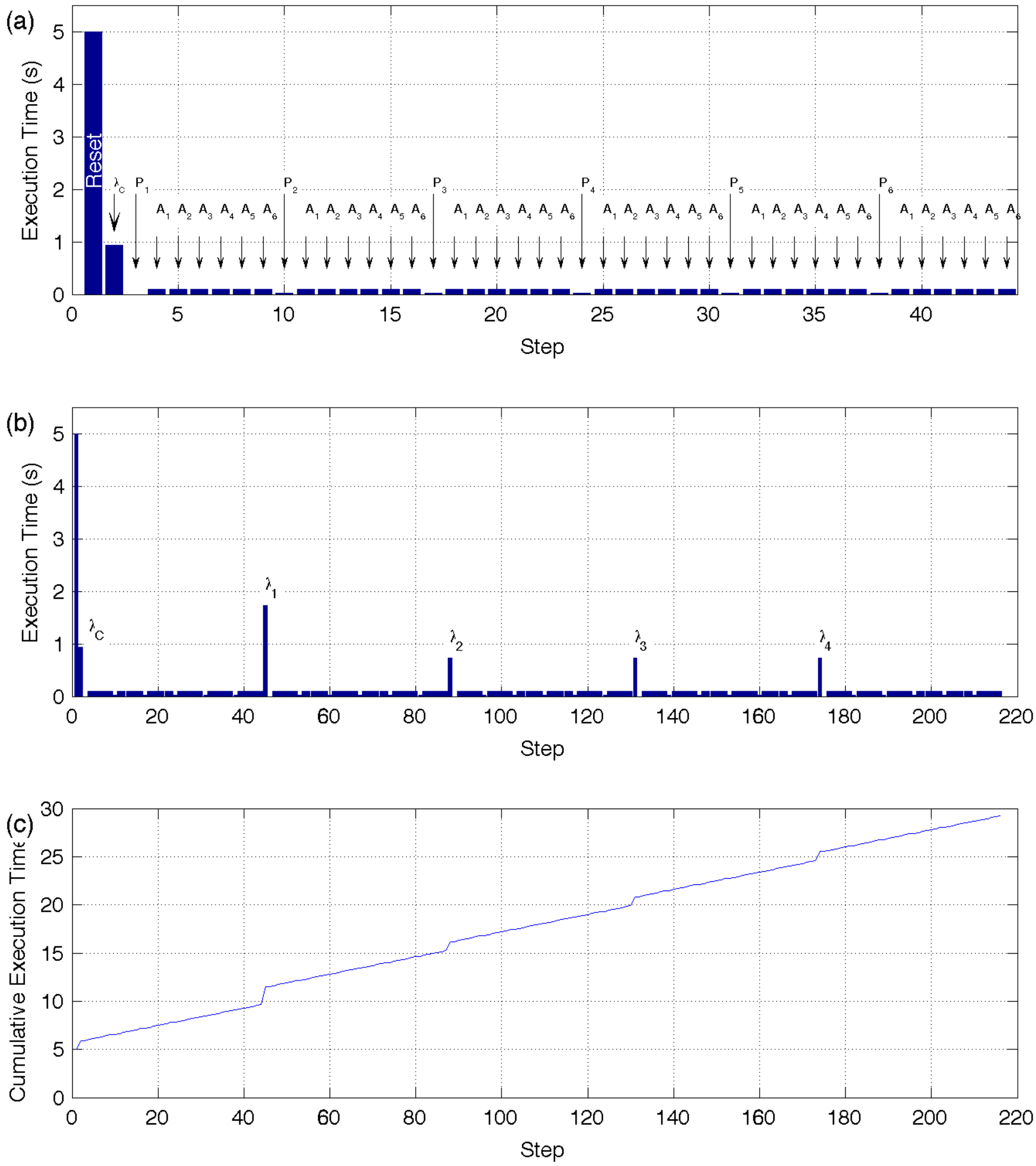


Figure 9: The figure shows and example of timeframe for an observation cycle.

Data acquisition architecture

In order to increase the Signal-to-noise ratio (SNR) it is necessary to accumulate several images for every wavelength position and polarization state. For the operation described in the previous subsection, the total number of images to be acquired is at least 180 for each estimate of the distribution of the magnetic field on the solar surface. For a resolution of 2048x2048 pixels and a resolution of 16 bits, we would have to store about 1,509,949,440 (1.5 Gigabyte) per observation cycle.

Figure 10 presents the proposed data acquisition architecture. The main subsystems are: (a) the subsystem responsible for the control of the solar telescope and spectropolarimeter; (b) the subsystem responsible for the image acquisition; (c) the subsystem responsible for the data bank; and, (d) the subsystem for post-processing and product generation.

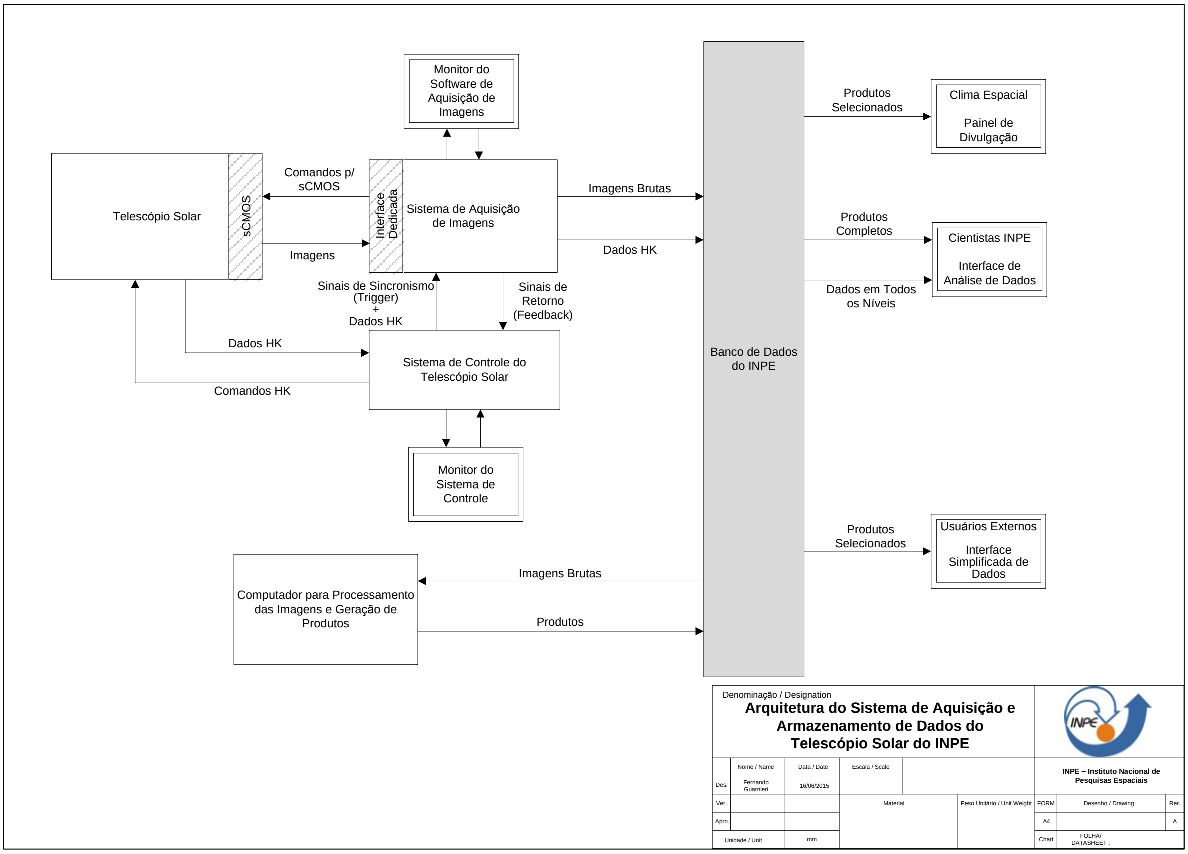


Figure 10: The diagram presents the proposed data acquisition. (Text in Portuguese)

Preliminary design of the Solar Telescope Project

This stage of the project is carried out on the High-Level Architecture and is one of the most important phases of the project, because herein are defined some of the equipment major features. This stage starts with the analysis of the system output, in this case, the images to be generated according to the requirement. It is then passed to the last block and it makes the block to meet this specification, i. e., this output. This process follows successively block by block toward the system input, setting each block or flow or connection between them. It is important to note that at this stage, most of the memorials of the design calculations are developed where they actually happen. This phase arises the specifications of the components to be acquired or developed throughout the project.

At the end of this stage, all the specifications of each block should be clearly defined, so that it has a global map with all system features. Each block specified graphically in the diagram is accompanied by a formal document specification and, if necessary, a calculation memory showing how it came to certain specification.

The preliminary optical layout of the instrument from the telescope to the image formed on the camera is shown in Figure 11. A detailed analysis of the design is discussed in the document TS-ET-0011 (text in Portuguese), which is attached to this report.

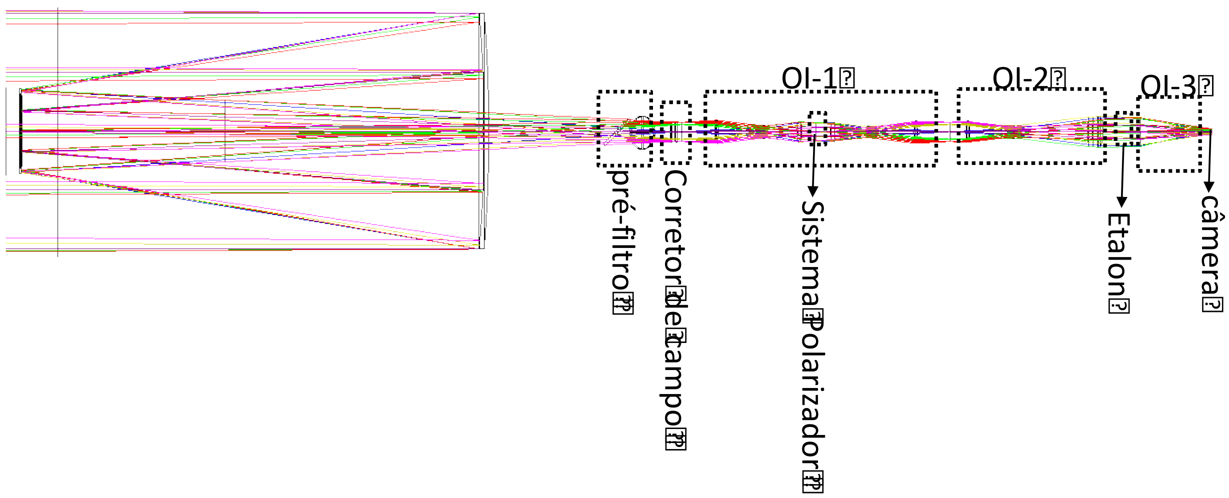


Figure 11: Preliminary optical layout of the instrument from the telescope to the image formed on the camera. (Text in Portuguese)

Preliminary specification of the subsystems and components

These preliminaries technical specifications were developed taking into account the stakeholder requirements and requirements of the INPE's Solar Telescope. The analysis started by the output of the results (images) ending the system input (light from entering the telescope). Below are the specifications for each instrument of the block, assuming the architecture formed by a sCMOS camera and one Fabry-Perot Etalon filter.

Optical Telescope

The layout of the Ritchey-Chrétien telescope is presented in Figure 12, while the specifications for the optical telescope are presented in Table 5.

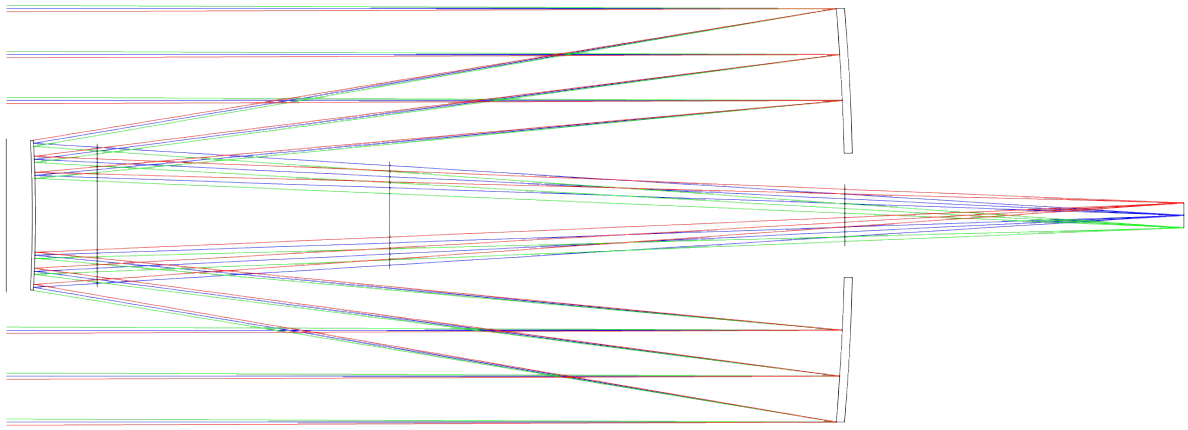


Figure 12: Layout of the Ritchey-Chrétien telescope.

Table 5: Specifications for the Ritchey-Chrétien telescope.

Optical System	
Parameter	**Value/Range**
Model	Ritchey-Chrétien
Aperture	500 mm
Focal Length	4000 mm
Focal Ratio	F8
Back Focus	365 mm
Field of View	69 arc minutes
Coating	Coating with 96% Reflection
Surface quality	Wave front higher than 95 Strehl
Material for the primary and secondary mirrors	A lithium aluminosilicate glass-ceramic material with thermal expansion coefficient lower than 0.05×10^{-6} /K between 20^{o}C and 300^{o}C
Main mirror optical diameter	500 mm
Main mirror diameter	510 mm
Main mirror thickness	60 mm
Secondary mirror optical diameter	181 mm
Secondary mirror diameter	186 mm
Secondary mirror thickness	35 mm
Mechanical structure material	Aluminium and carbon fiber.
Optical elements	Corrector for image flat fielding
Cooling	Cooling system controlled by software
Focus	Hardware and software control

Pre-filter

The pre-filter is one of the most critical components of the entire Solar Telescope system. This device shall function, preferably using the principle of reflection of the undesired wavelengths. If necessary, the system must have its own cooling system. The pre-filter should have a spectral window 50 Å, centered on the selected line (6302.5 Å).

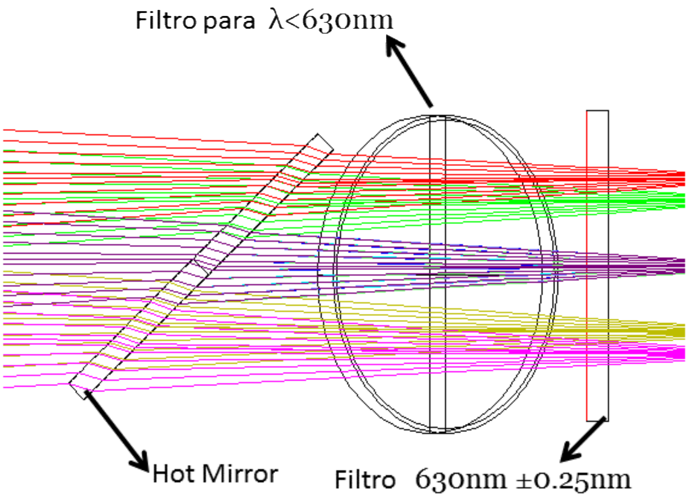


Figure 13: Preliminary optical layout of the pre-filter.

Polarization Package

The polarizer should have a linear response in the range of wavelengths of 6302.2 Å 6302,6Å. The polarizing windows should have a minimum diameter of 40mm. The package must be able to select 6 modes of polarization: horizontal polarization, vertical, 45 Linear, Linear -45º, circular polarization to the right and circular polarization to the left.

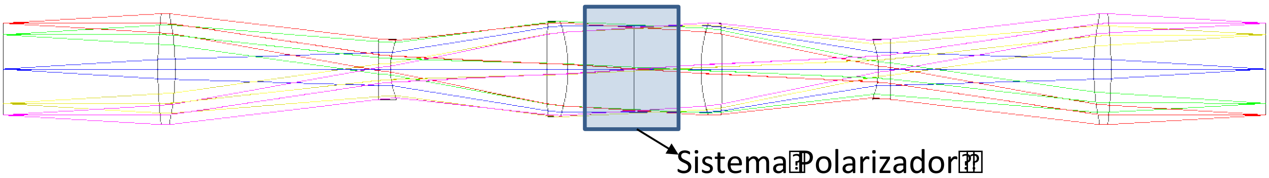


Figure 14: Layout of the intermediate optics I project (OI-1).

Fabry-Perot Etalon

The Etalon to be used should have a minimum diameter of 40mm window. The construction and general features should be equivalent to the Etalon filter used in Imax (Imaging Magnetograph eXperiment). Table 6 presents the preliminary specification for the Etalon. The filter should be 5 able to select the operating wavelengths (Å 6302.40; 6302.45 Å; 6302.55 Å, Å 6302.60; 6302.20 Å), with a bandwidth in each channel, the maximum 100m Å.

Comments:

Page 38.

There are some inconsistencies with previous requirements. The table lists spectral lines separated by at least 60 A, but the prefileter bandwidth is only 50A. Also, aperture of Fabry-Perot here is listed as 60mm, but on previous pages it is referred to as 40 mm. Also, prefileters and other optics also listed as 40mm in diameter.

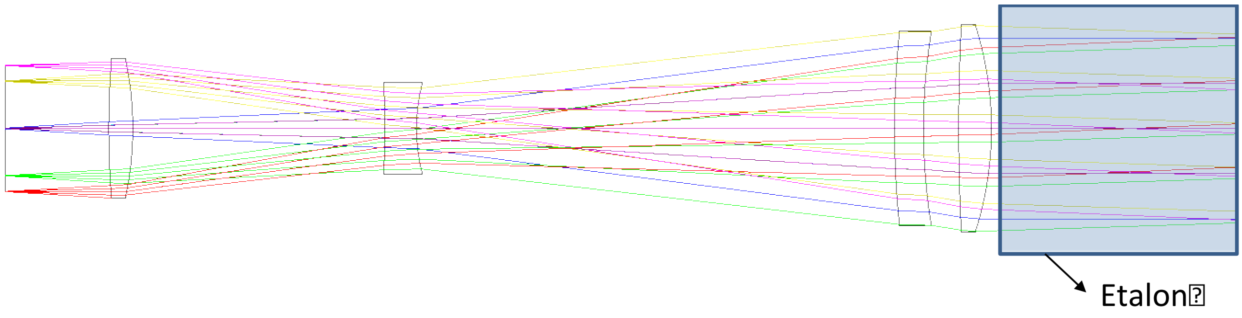


Figure 15: Layout of the intermediate optics II project (OI-2).

Table 6: Preliminary specification for the Etalon

Parameter	Value/Range
The wavelength range of interest	6563 &? 6301.5 and 6302.5 Angstroms
Required finesse	30
Reflectivity	95%
Thickness	TBD
Free Spectral Range (FSR)	2.5 Angstroms
The number of etalons you will require for your project	1
Required working aperture	60 mm
Temperature range	15-35 C
Physical diameter	74 mm

Sensors

The output of the data acquisition system with the full specification of the images is described in the document TS-TE-0004. The specification of data acquisition hardware must take into account the high rate of acquisition of sCMOS (frame rate) and the high size of the images (due to high resolution). Previous experiences have shown that ordinary computers cannot acquire and write to HD images from cameras with these caracterísiticas, especially taking into account the response times of the buses. Therefore, it is recommended to check the computer specification recommended by Zyla, manufacturer of the cameras, to meet sCMOS. The Table 7 contains the specifications of CMOS camera as purchasing specification sCMOS.

Table 7: **Specification for the sCMOS cameras.**

Parameter	Value/Range
Active pixels	2560 x 2160 pixels (5.5 Megapixels)
Pixel size	6,5 µm x 6,5 µm
Exposition mode	Global Shutter
Sensor size	16.6 mm x14,0 mm
Frame rate	50 frames per second in the 2048 x 2048 resolution
Interface	10 tap
Pixel readout rate (slow mode)	200 MHz
Pixel readout rate (fast mode)	500 MHz
Quantum efficiency between 500 and 700 nm	50%
Quantum efficiency between 500 and 700 nm	60%
Linearity	Better than 99%
Dynamic range	25.000:1
Dark current	0.04 (electrons/pixel)/s
Read noise median [rms] (slow mode)	2.4 [2.7]
Read noise median [rms] (slow mode)	2.6 [2.9]
Data acquisition	12 and 16 bits
Pixel binning	2x2, 3x3, 4x4, 8x8
Trigger modes	Internal, External

Timestamp accuracy	25 ns

Mount, Pointing and Track System

The specifications for the mounting, pointing and tracking systems are presented in Table 8.

Table 8: Specifications of the mounting, pointing and tracking systems.

Mount and pointing	
Mount	German-Equatorial mount
Load	250 kg
Motors	Noiseless high torque direct drive
Pointing accuracy	8" RMS
Tracking accuracy	0,25" RMS in 5 Minutes
Encoder resolution	0,007"
Moving speed	13° per second
Pointing system control	Hardware and software

Shutter

The system must contain one or more shutters systems to prevent light from entering the solar telescope when not in operation. Preferably, it should be included at least two shutters, one at the entrance of the optical telescope and another just after the pre-filter.

The shutter must be able to completely prevent the passage of light and at the same time withstand the temperatures that will be exposed.

MANAGEMENT

Long-term management

The long-term management was implemented employing several technics, such as strategy meetings, schedules, and task lists. The meetings were carried out at the INPE's Building CEA II (room 23; see Figure 16). To monitor the evolution of the project, we have elaborated a schedule based on a Work Breakdown Structure (WBS). The schedule was elaborated during strategy meetings with the participation of the team involved, including remote participation of member outside INPE's campus. It was based on a detailed analysis of the effort need to develop the instrument, its main blocks, their sequencing, and dependencies.

This schedule includes the phases related to the implementation of the conceptual development, intermediate prototype, and advanced prototype (see Figure 17). Although we decided not to include in the scope of the current project, we explored also the timing to start the activities related to the installation of the instrument in a suitable observatory.

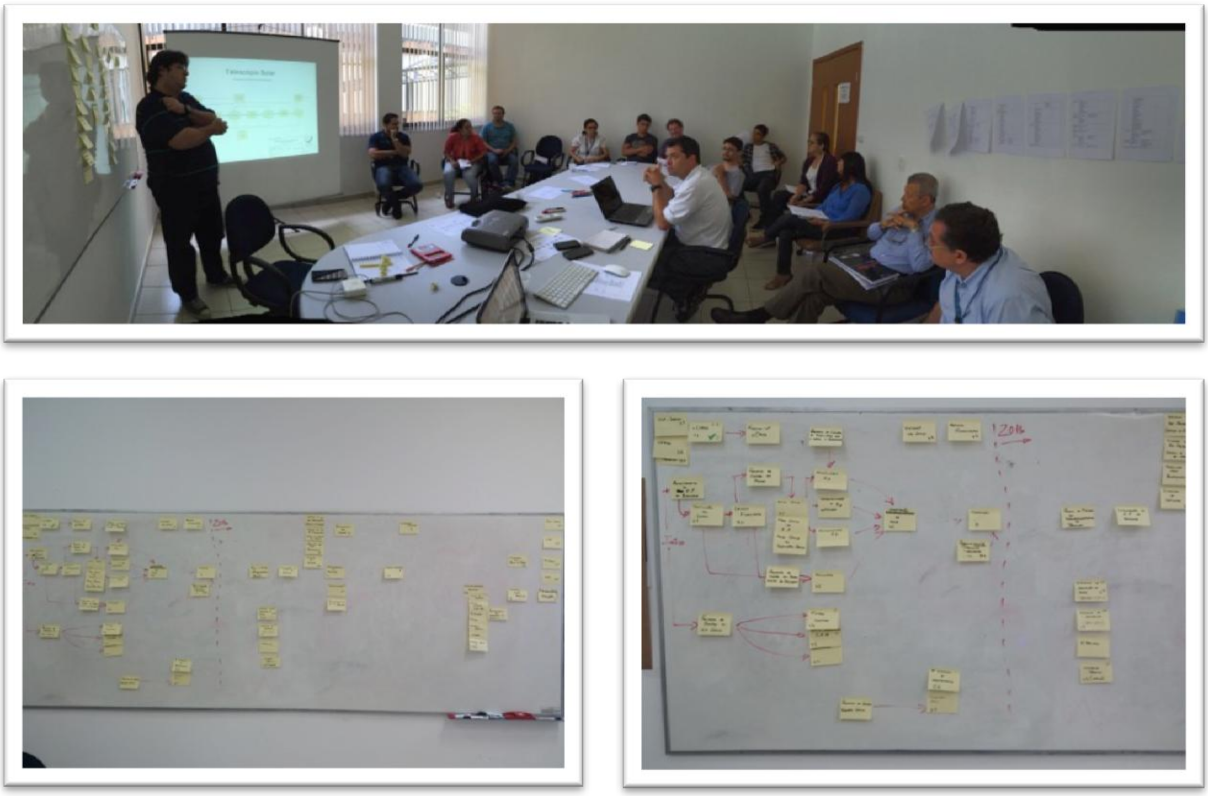


Figure 16: Image of a strategy meeting carried out on March 12, 2015.

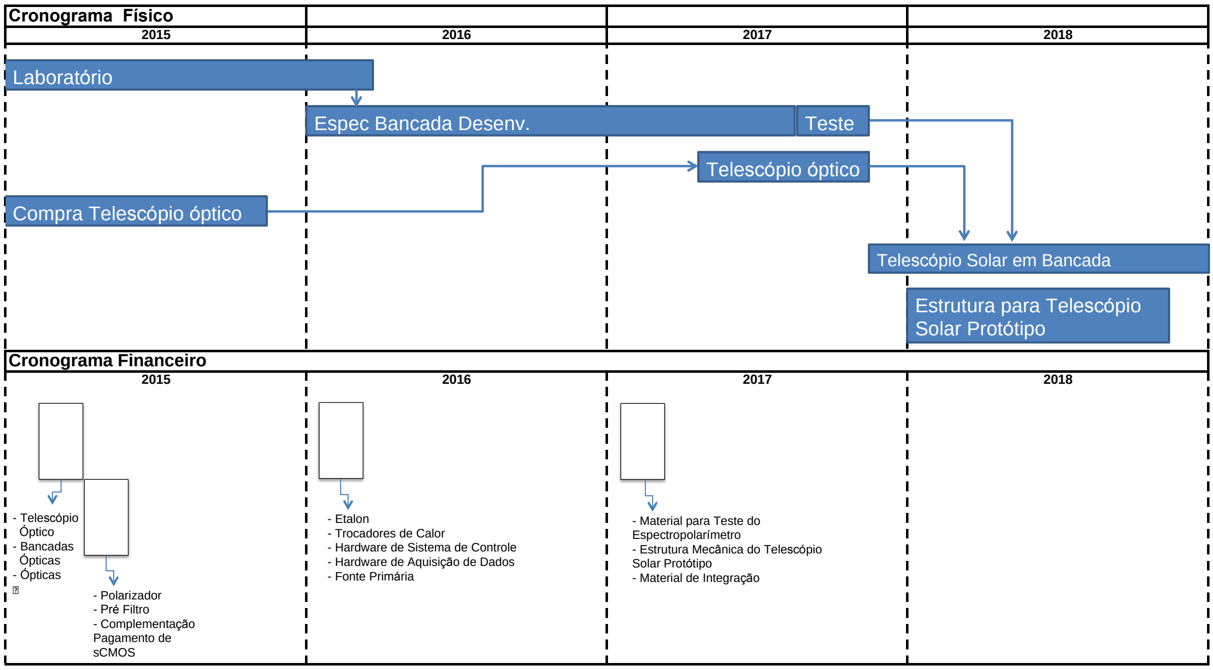


Figure 17: Chronograms. (To be Revised)

Short-term management

Figure 18 shows the Scrum strategy adopted in the project for short-term management. In this approach, the team works as a unit to reach a common goal. Based on the long-term schedule, we held weekly meetings to define the tasks and attribute them to the team members. Additionally, during the weekly meetings we evaluated the progress of the execution of the activities previously attributed. This strategy was very important for the discussions about the system requirements and the preparation of the paperwork need to open the call for international bidding processes and the subsequent follow ups. Comparing the expected and observed delivery of the results of the activities, we have been able to monitor the progress in a quantitative way.

Figure 18: Panel employed to follow the Scrum strategy for short-term management.

Document Repository

As the number of documents generated within the project increased, we decided to implement a document repository. The preservation of the project's memory, calculations, designs and decisions is a key element for the development of the project. However, as important as the documentation itself is its organization. In this section, we briefly describe the set of standards for the preparation of the documents for this project. Specifically, we indicate the correct classification of each document, the nomenclature used, and, file formats.

We point out that the language to be used in the technical documentation must be direct and concise. The aim is reporting even small activities without expending long time in its preparation.

The first step was the implementation of a document management system (specifications, drawings, memories, calculations, etc.) that could be accessible to all involved in the project. A free document sharing system with cloud storage (cloud drive) where the documents were stored following a structure, indexed system was used.

Thus, each document receives a record in the form TS-XX-ZZZZ, where XX describes the folder according to the document type and ZZZZ is the sequential number of documents in each category. The document categories represented by XX can be:

Management documents (DG)	These are documents related to project management, and communication plans, schedules, newsletters, etc.
Technical specifications (ET)	These are documents that contain technical information defining a system, subsystem, or component part. They not only define parts that are being developed, but also specify which parts are being acquired or manufactured externally.
Memorials Calculation (MC)	These are documents containing the description and/or methodology used in parts of the project. Specifically, they are generated to record the rational used in a particular part of the project specification. These documents can be made in Microsoft Word (doc or docx), Microsoft Excel (.xls or .xlsx), MathCad , MatLab , IDL , etc.

Testing Plans (PE)	These are documents that describe, in detail, test or trial that will be developed in systems, subsystems or components. The main emphasis of this document should be given to the methodology to be used in testing or form of testing that can be traced directly by the person performing the task.
Test reports (RE)	These are documents that describe the tests or trials carried out according to a previous plan (the document must be related to a Test Plan). In this document, there are the reports, analyzes and conclusions of the tests. The collected data can be described in this report, but must be filed as dataset (DS).
Datasets (DS)	These are files that contain the data collected in a particular test or observation. The format of these files can be variable, although it should respect of numbering. The data should be stored in raw format. If some processing is done on this data should be generated a new Dataset with the processed data.
Technical drawings (DE)	These are files related to technical drawings of all levels (conceptual, preliminary and detailed) project parties. Whenever possible, the document should be recorded in source format and a copy of the same name in PDF format (for easy access).
Manuals and procedures (MN)	These are files related to documents drawn up as user manuals, operation, maintenance, or system assembly, subsystem or components of the Solar Telescope. This section shall also be filed safety procedures, operating, maintenance, system or infrastructure related to the development of the project.
Bibliographic documents	This folder contains documents that might be of interest to all project participants. This folder, because it is merely informative, it does not have naming or numbering system, thus names follow a freeform.

In this way, based only on the document number we can identify easily which project it belongs (TS indicates Solar Telescope) and that document category within the project.

Document Format

The documents, whenever possible, should be stored in Microsoft Word format (.doc or .docx). The document should be prepared using the model in TS-DG-0002 file. The author must be careful to include, both on the cover and in the headers and footers of the pages, the correct number of the document.

It is important to note the approval of the document flow, which should have one or more authors, a verifier and an approver. The dates of verification and approval must be empty and to be filled only by the data field when performing the step. Only with the fields filled should the document be stored in the documentation system.

Naming Files

The file name should be in the following format:

TS-XX-YYYY–ZZZZZZZZZZZZZZZZ.doc

Where TS refers to the design of the Solar Telescope, XX are two letters designating the area of the document, YYYY is the sequential number of document control and ZZZZZ is the document title (included in the name file for easy searches of documentation system).

Numbering Control

At the root of the documentation system there is a spreadsheet called Indice.xlsx containing document types and fields to fill.

Each author must fill in the fields related to his/her document allocating thus a sequential number, which is unavailable to other authors. This sequence number must be included on the cover and header / footer of the document in preparation.

Mapping of Purchasing Processes

In October 31st, 2013, a committee assigned by the General Coordination for Atmospheric and Space Sciences (CEA) at INPE, composed by Dr. Mangalathayil Ali Abdu, Dr. Severino Luiz Guimarães Dutra and Dr. José Williams dos S. Vilas Boas has received the duty to evaluate "CEA proposals" for projects with budget within 1.5 million Brazilian Reals (equivalent of 600,000.00 USD, at a 1USD=2.50BRL from the period). The solar telescope proposal was approved in its scientific merit and received recommendation for partial funding.

In general terms, first the purchasing process is instructed within the institute, which gathers all specs, documentation, justifications, quotations, etc.. Following that, an external and independent legal evaluation is required. When all legal demands are met, the institute announces the bid, which is followed by several deadlines for proposals, evaluation of providers, clarifications, etc. The winner is the proposal that meets all specs and offers the lowest price.

International Bidding Process for the purchase of two (2) sCMOS Cameras

PROCESS: CI 177/2014	**Object: Purchase of two 5.5 Megapixels sCMOS to be used in the Solar Telescope.** Category: permanent material Price estimate: 122,464.78 BRL Budget origin: "CEA proposals" assigned budget

The "CEA proposals" committee has awarded an amount of 122,464.78 BRL to the Solar Telescope project, aimed at the purchase of two 5.5 Megapixels sCMOS cameras. In early 2014, the team started the planning and execution of the purchase process. At first, it was identified that there were no national suppliers, thus demanding an International Bidding process. The legal and administrative process for a International Bidding at a government institution is somewhat complex and time demanding, as well as personnel work time demanding in several levels, including external to the institution.

In details, the milestones of the International Bidding process for acquisition of 2 sCMOS (CI 177/2014) are listed in the Table 9:

Table 9: International Bidding milestones for the case of the CI 177/2014.

#	Date	Action
1	Jan. 1st – May 5th (2014)	a) preparation of the documents that compose the bidding process: “preliminary study and risk evaluation”, “basic project”, “Document specific to IT or Automation acquisitions”; b) gathering 3 quotations from 3 independent suppliers, with representation offices in Brazil.
2	May 6th (2014)	Presentation of the demand via “purchase requisition” (RC - requisição de compras), from the Space Geophysics Division at INPE.
3	May 8th (2014)	First evaluation from the “Permanent Group of Bidding” (GPL - Grupo Permanente de Licitações), inside INPE. During this phase, several corrections are requested by the GPL to the solar telescope group, mostly technical corrections related to legal aspects or formatting of documents.
4	July 2nd (2014)	Sent to “Budget Sector” at INPE (COF), for inspection and approval.
5	July 23rd (2014)	Sent to the external legal evaluation at the Federal Government Legal Affairs (CJU - Controladoria Jurídica da União)
6	August 14th (2014)	Process returns to INPE with recommendations from the CJU and is evaluated by a technical group at INPE’s administration (GAT - Grupo de Assessoramento Técnico)
7	Aug. 15th (2014)	Process sent back to GPL which asks for inputs from the solar telescope group to provide corrections required by the lawyers at CJU. After all points are addressed, both by the solar telescope group and by GPL, a draft of the “announce of opportunity” is prepared, soon to be published in official journals.
8	Sept 1st (2014)	back to COF
9	Sept. 8th (2014)	Publication of the “announce of opportunity” for an International Bid (CI 177/2014) in the official government journal. This announce establishes a 30-day (deadline on Oct. 8th) period for proposals to be hand in by any interested supplier.
10	Oct 3rd (2014)	Extension of the deadline published on the official government journal, to Nov. 7th. (This extension was granted after one of the interested suppliers argued that there was some delays in paperwork by one of the international suppliers, Andor. This extension was granted in the spirit of

		maximizing the competition by allowing the maximum number of competitors).
11	Nov. 7th (2014)	Receiving of the proposals at INPE.
12	Nov. 12th (2014)	Meeting with the proponents, scientific staff of INPE and INPE's administration in order to evaluate the fiscal health of the proponents. At this point, only fiscal health is evaluated and proof of previous successful delivery of similar goods. (at this phase, no proposal is opened yet).
13	Nov. 13th (2014)	Official announcement of habilitated proponents, published in the Official government journal.
14	Nov. 24th (2014)	Meeting with the proponents, scientific staff of INPE and INPE's administration in order to open their proposals. Only those habilitated proponents are allowed to have their proposals opened.
15	Nov. 25th (2014)	Winner of the BID is announced via publication in the Official government journal.
16	Dec. 4th (2014)	Blocking of the budget to honor the payment (EMPENHO). Final deadline for this event was Dec. 5th (2014).
17	Dec. 9th (2014)	Process goes to GAT for preparing the draft of the contract with the winner.
18	Dec. 10 to 17th (2014)	Internal bureaucracy until preparation for the Director General of INPE to sign the contract.
19	Dec. 19th(2014)	SIGNATURE OF THE CONTRACT
20	Dec. 22nd(2014)	Internal details are arranged.
21	Dec. 24th (2014)	Publication of the contract in the Official government journal (contrato 1.210/2014 no Diário Oficial da União, seção 3, pag. 19).
22	Aug. 5th (2015)	Delivery of the sCMOS at INPE. Initial inspection demonstrated that the cameras were not the correct ones. The purchase order referred to "water refrigerated" model while the delivered ones were "air refrigerated" models.
23	Aug 6th (2015)	The supplier starts the procedures to change the sCMOS by correct ones.
24	Oct. 16th (2015)	FINAL RECEIPT OF THE sCMOS AT INPE.

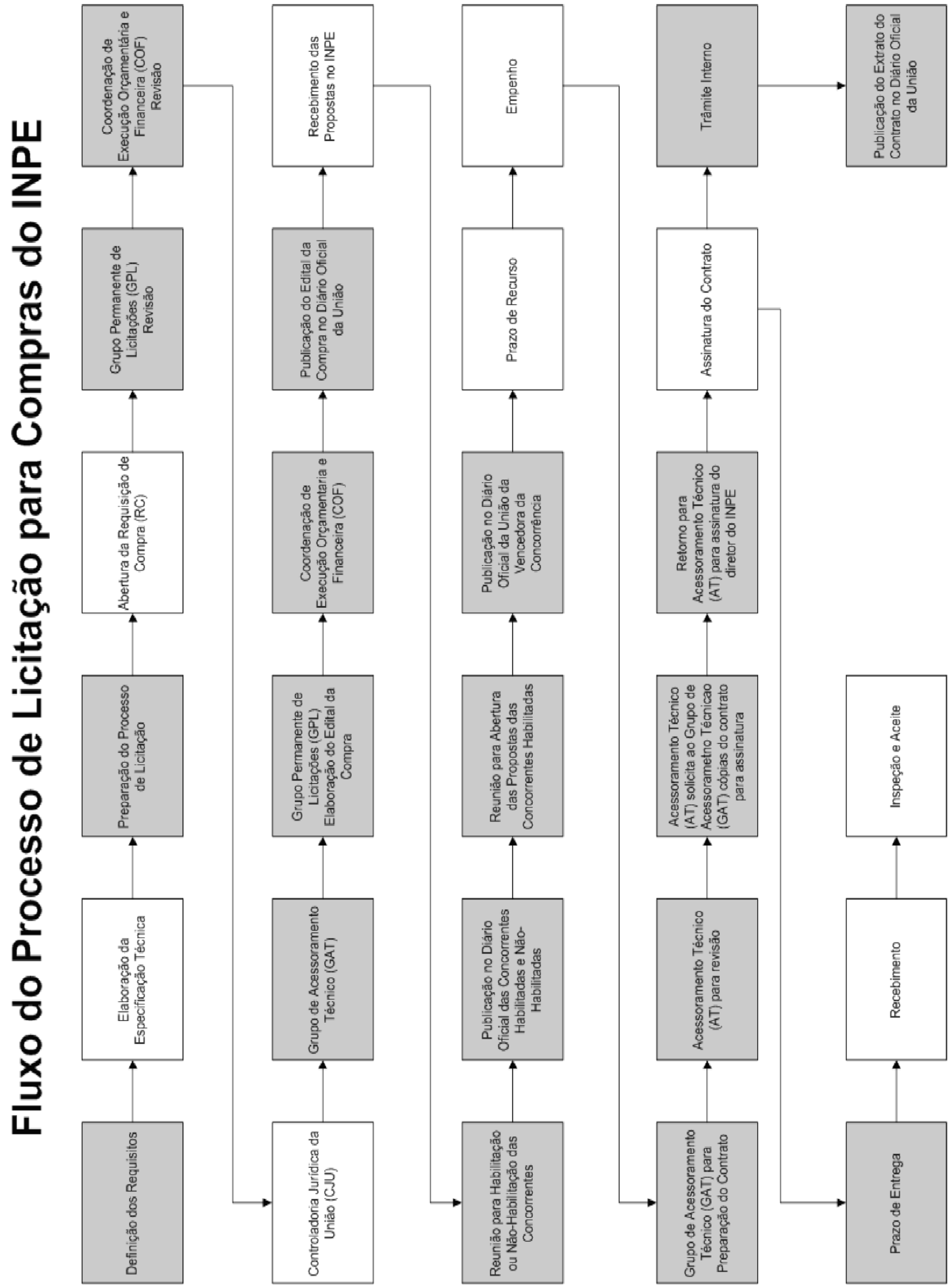


Figure 19: Main milestones observed during the International Bidding Process of the 2 sCMOS of the Solar Telescope. (Text in Portuguese)

In conclusion, the purchase of the 2 sCMOS to be used in the solar telescope via International Bidding was successful.

The delivery of the 2 sCMOS purchaized with the 2014 "CEA Proposals" budget occurred on October 16th (2015). Figure 20 shows one of the cameras.

Figure 20: One of the 2 sCMOS purchaized via 2014 budget of "CEA Proposals".

Lessons learned

From the experience of the International Bidding processes, we learned few lessons that were helpful to guide future purchase processes. Below, we list the main recommendations to be followed:

- Before or during Phase #1 of the Table above, it is important to conduct a evaluation of the project proposal, such as the "CEA proposals", which will be important to answer lawyer requests later. From our experience, in all International Bidding processes, lawyers asked for the "internal study that lead to the need for the acquisition of the specific item". In all cases we presented the official report from the committee assigned by CEA for the "CEA proposals", in which there was an evaluation and recommendation of the project.
- Phase #1 in the Table above needs to be carefully prepared, both by setting specs and finding quotations for the goods to be purchased. In some cases, it is not possible to find 3 quotations for the item to be purchased, so it is needed to prove, sending request e-mails to possible providers, which might be added to the process to prove the inexistence of all three providers.
- Phase #2 marks the start of the process in the government system. Planning of Bidding processes need to pay attention to this date in order to evaluate the conclusion of Phase #16, to which there is a deadline, typically sometime around the first week of December of each year.
- Phase #5 is a key one, because it is the only external evaluation, by government lawyers. Lawyers pay attention to several aspects, which sometimes are already present in the model forms available at INPE. However, many times one needs to provide extra clarification to parts of the process, like the "internal study that lead to the need for the acquisition of the specific item".
- Phases #12 and #14 require the presence of the person who is responsible for the process (scientist or employee who signed the RC). It is very important to have more people together in order to assist this person in the evaluations

he/she needs to do, both for accepting proof of previous sells or the meeting of specs.

- Phase #16 is the most important date, which needs occur before the "Blocking budget" deadline ("Data Limite para Empenho"). If this deadline is missed, the process will be lost. In the case of CI 177/2014, the phase was met only one day before the final deadline.

Figure 21: Meeting with the scientific staff of INPE and INPE's administration in order to open their proposals for the optical tables bidding.

The CI 177/2014 had a 25 days extension for receiving proposals and it took 2 weeks to provide inputs to the lawyer requests. Both these time intervals were optimized for the International Bidding processes that followed this one.

In conclusion, we have established that International Bidding processes need to have their "purchase requisition – RC" (Phase #2) in late April each year.

Prospects for International Biddings in progress (2015 budget)

Currently, three other International Bidding processes are underway, related to the Solar Telescope, with the 2015 budget.

PROCESS: CI 117/2015	**Object: Purchase of a 500mm Ritchey-Chrétien optical telescope**, focal length = 4000mm, with pointing system. Category: permanent material Price estimate: 437,626.73 BRL Budget origin: "CEA proposals" assigned budget Milestones: • Phase #5: Sent to CJU on June 10th (2015) • Phase #9: Publication of the "announce of opportunity" on Aug. 21st (2015) • Phase #14: Opening of proposals on Oct. 8th (2015)
PROCESS: CI 172/2015	**Object: Purchase of two active stabilized optical tables.** Category: permanent material Price estimate: 40,558.18 USD Budget origin: Space Geophysics Division budget Milestones: • Phase #5: Sent to CJU on July 7th (2015) • Phase #9: Publication of the "announce of opportunity" on Sept. 8th (2015) • Phase #14: Opening of proposals on Oct. 23rd (2015)
PROCESS: CI 344/2015	**Object: 70 optical laboratory items.** Category: spendable material Price estimate: 31,029.90 USD Budget origin: Space Geophysics Division budget Milestones: • Phase #5: Sent to CJU on Sept. 22nd (2015) • Phase #9: Publication of the "announce of opportunity" on October 23rd (2015)

A progress evaluation of 3 processes shows that 2 of them are doing well for conclusion in terms of schedule. These 2 are those for which we had the budget since beginning of 2015.

The third process (CI 344/2015) used a left over budget, only available on August 12th (2015). Also, this CI is for spendable materials, which account for 70 items, for which 3 times 70 quotations were required. This process was much more time consuming than the previous ones. Although we knew form the beginning that this CI had little chance to be concluded in time, we took the decision to try because the external evaluation can be used for future acquisitions, which was already a plus in this process.

In conclusion, all current International Biddings (CI) that were planned since early 2015 are in better conditions to be concluded, when compared to the 2014 CI. An extra non planned Bidding is also in place, with less chances to be concluded, but already obtained the approval from the external lawyers (CJU).

Implementation of the Solar Polarimetry Laboratory (LPS)

Location settings and arrangements of the laboratory for the development of the Solar Telescope

The partial implementation of a laboratory dedicated to the development of the project was a key milestone achieved in 2015. We started to search for the place to install the laboratory in the beginning of the year. Several possibilities were explored. For the choice of the laboratory we took into account several factors such as the available area, laboratory position in relation to the building structure (in order to minimize vibrations), access to the ceiling or position that allows access to a pipeline of a heliostat, disposal furniture and internal structures of the laboratory facilities and adaptations to the room to operate effectively as a laboratory.

The consensus of the team was that the implementation of a join laboratory for optics in collaboration with the INPE's Space Weather Program. A proposal was submitted to the Space Weather Council and accepted. The location of the laboratory was in second floor of the INPE's Building CEA II (room 10).

Following the acceptance of the proposal, Dr. Renato Dallaqua (LAP/INPE) loaned several optical components, including lens, mirrors, supports, a Fabry-Perot Air-gap Etalon, a monocromator, and, an optical table. A List of equipment and materials is presented in Table 10. The Fabry-Perot Etalon, which is an important component of the instrument, was acquired under the FAPESP grant agreement no. 96/07170-1[2]. The instrument model is RC-150 manufactured by Burleigh (Model RC-150). Additional components of the system are a ramp generator, thermal box and RC mirrors. Later, Dr.

[2] Source: Diagnóstico de plasma com interferômetro Fabry-Perot em uma centrífuga de plasma iniciada por arco no vácuo. Year 1999. http://www.bv.fapesp.br/pt/auxilios/13070/diagnostico-de-plasma-com-interferometro-fabry-perot-em-uma-centrifuga-de-plasma-iniciada-por-arco-n/

Odim Mendes Jr. loaned a high-speed camera (Kodak Motion Corder Analyzer) acquired under the FAPESP grant agreement no. 98/03860-9[3].

The loan of the components and equipment was very timely for training purpose of the team members, which is working on the development of an optical instrument for the first time. Figure 22 shows a very simple setup for the projection of the Sun on a cabinet employing the optical components loaned.


Figure 22: The images show a very simple setup for the solar projection on a cabinet at the room 10 in the second floor of the INPE's Building CEA II.

Also following the acceptance of the proposal, we started the evaluation of the adaptations needed to employ the laboratory for the development of the project. Among the changes needed, the installation of a Heliostat was the most challenging. Our first

[3] Source: Análise observacional e modelagem numérica dos relâmpagos do Sudeste do Brasil (projeto via lux). Year: 1998. http://www.bv.fapesp.br/pt/auxilios/14526/analise-observacional-e-modelagem-numerica-dos-relampagos-do-sudeste-do-brasil-projeto-via-lux/

approach was a direct access to the roof of the building through a hole for the passage of the solar beam. However, the institute's maintenance engineering pointed out some technical infeasibility for carrying out an opening in the pre-stressed slab used in the building. The alternative was the construction of a structure that would allow us to bring the solar beam through a window of the laboratory. Figure 23 shows the building structure that we considered for the installation of the heliostat. After a long-period developing a conceptual model of such structure, we realized that its implementation following the INPE's rules to contract a company to design and build the heliostat as planed would demand a lot of time and resources.

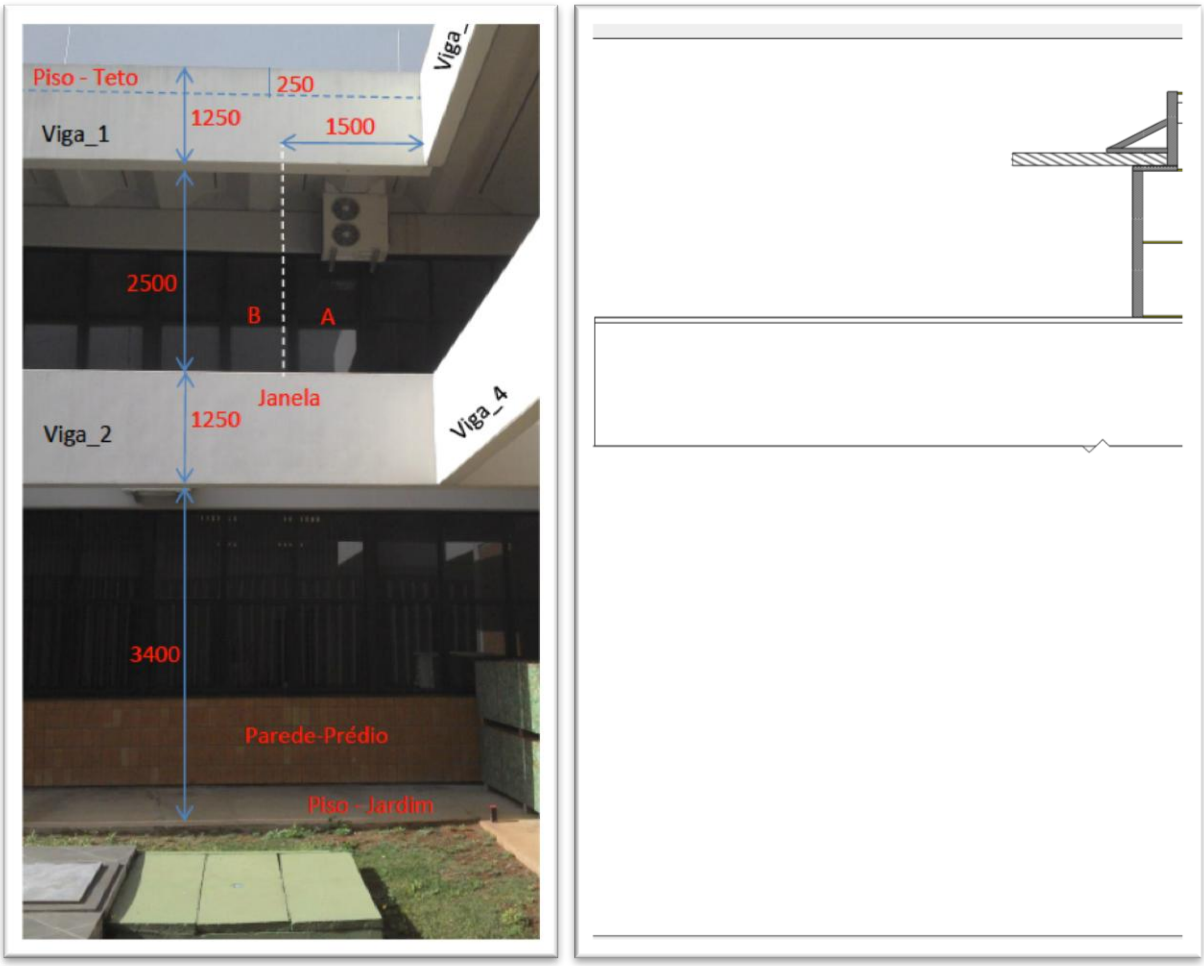


Figure 23: The building structure that we considered for the installation of the heliostat. (Text in Portuguese)

As the laboratory in the second floor of the INPE's Building CEA II (room #10) was not viable, we decided to explore other possibilities. We found that the best option was the room #4 at the ground floor of the INPE's Building CEA II.

In order to implement the laboratory, we prepared several sketches with the location and layout of furniture, components and adaptations necessary for the new laboratory. The final sketch, meeting all the demands of engineering and contemplating sharing with other areas of interest is found in Figure 24. Figure 25 shows some images of the laboratory.

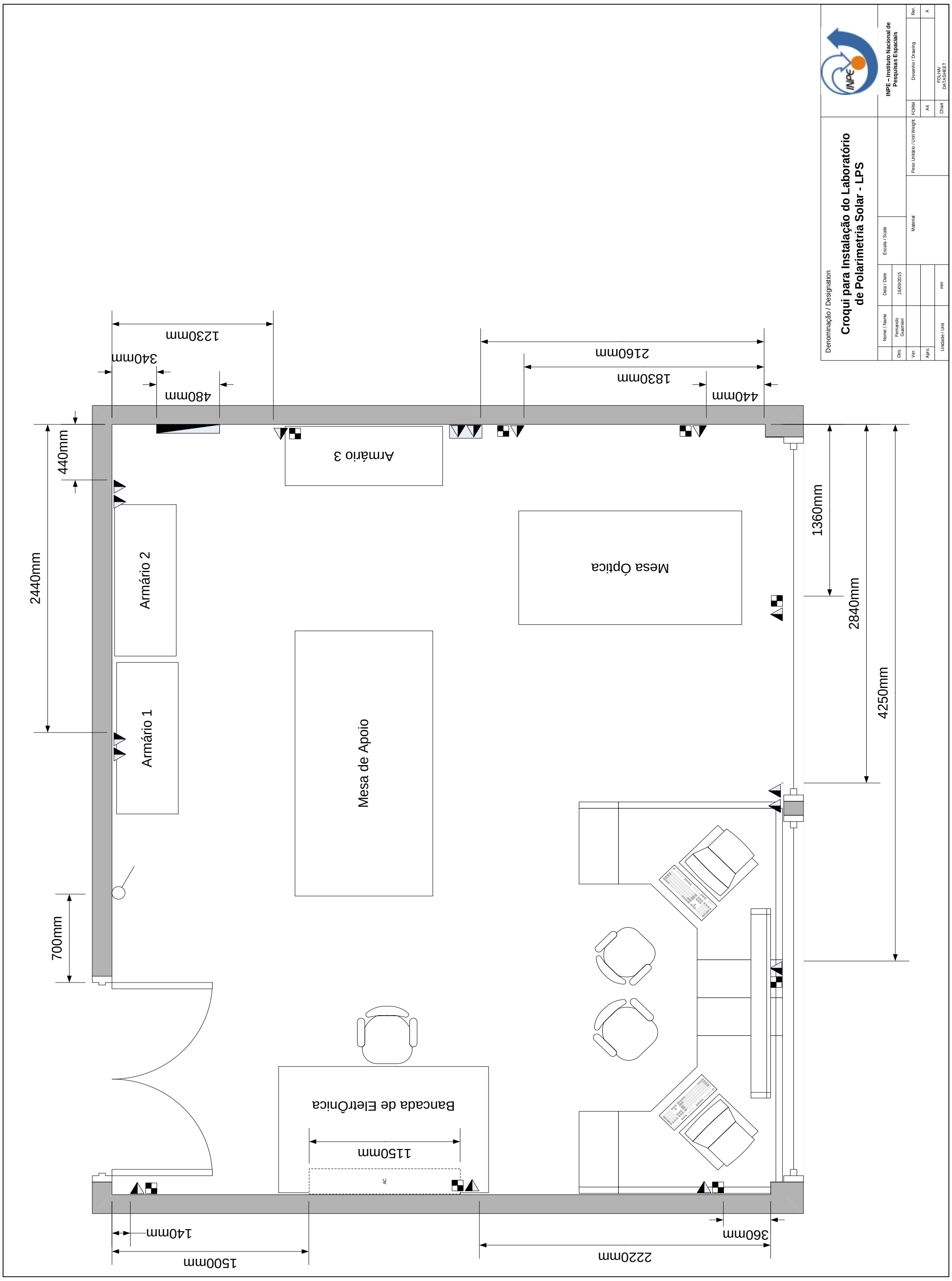


Figure 24: The diagram presents Final sketch of the implementation of the Solar Polarimetry Laboratory - LPS.

Figure 25: Darkening of laboratory windows of the room 4 at the ground floor of the INPE's Building CEA II.

Table 10: List of equipment and materials. (Text in Portuguese).

Patrimônio	Item	Descrição	Nome
85229	Cadeira	Cadeira cinza	Alisson Dal Lago
85227	Cadeira	Cadeira cinza	Alisson Dal Lago
14728	Cadeira	Cadeira preta	José Raimundo
98085	Cadeira	Cadeira Verde	Fábio Becker Guedes
98092	Cadeira	Cadeira verde	Alisson Dal Lago
85233	Cadeira	Cadeira Cinza	Alisson Dal Lago
9265	Cadeira	Cadeira preta	Alisson Dal Lago
98463	Mesa	Mesa em L	Alisson Dal Lago
Sem identificação	Mesa	Mesa em L	
6026	Mesa	Mesa de madeira	José Raimundo
17955	Mesa	Mesa ótica	Renato Sergio Dallaqua
98462	Mesa	Mesa pequena	Alisson Dal Lago
2593/25406-1	Bancada	Bancada	José Raimundo
000533/202009	Armário		Alisson Dal Lago
15105/25723-2	Armário		José Raimundo
98180	Armário		Alisson Dal Lago
022490/34475	Heliostato		Luis Pascote
002717/34470	Base Heliostato		José Raimundo
82479	Monitor	LG	Alisson Dal Lago
98154	Monitor	LG	
87394	Monitor	Samsumg	José Raimundo
99280	Telefone	CISCO	Alisson Dal Lago
98152	PC	ORO	
505279	Estabilizador	SMS	Polinaya Muralikrishna
78039	Monitor	AOC	Alisson Dal Lago
100422	PC	HP	Alisson Dal Lago
88497	PC	ORO	Alisson Dal Lago
47943	Notebook	HP	Adriano Petry
70925	Nobreak	Simustriad	José Raimundo
84649	PC	Megaware	Alisson Dal Lago
95559	Nobreak	SMS	Alisson Dal Lago
99561	Nobreak	SMS	Alisson Dal Lago
99292	Telefone	CISCO	Airam Jonatas Preto
80506	Fonte do Laser	Voltex	Renato Sérgio Dallaqua
23826	Monocromador	Jobin Yvon	José Raimundo
8055	Fonte da	Newpoet	José Raimundo
29806	Câmera	Odim	Odim Mendes Junior

Formalization of the collaborations

From the beginning, we expect that this project would be the starting point to establish a strong program on Solar System Research at INPE, which would also foment the development of research groups on the Brazilian Universities. Two partners are contributing to the development of the project since its early moments: The Federal University of Minas Gerais (UFMG); and, The Engineering School of Lorena /Sao Paulo University (EEL-USP). Since February/2015, the National Laboratory for Astrophysics (LNA) joined the initiative. On the other hand, several foreign institutions, such as The Stanford University (USA), The National Solar Observatory (NSO/USA), Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E/CNRS/France), and, The Max-Planck Institute for Solar System Research (MPS/Germany), have been contributing directly or indirectly to the development of the project by advising on of the architecture of the instrument, the specification of the components, post-processing of the data, and modeling. More recently, we have started to collaborate with a colleague from the California State University Northridge. However, until now we have not established with any institution a formal agreement for cooperation on the development of this project.

During 2015 we explored the steps needed to establish a formal cooperation with Brazilian institutions. The first step was the contact with INPE's administration to understand the legal procedure and the requirements to establish a formal collaboration with Brazilian Institutions. We found that there are several models that we could follow based on the legal, technical and scientific requirements of each institution. Considering a bilateral cooperation focusing on scientific interaction and no transfer of financial resources or permanent equipment, the instrument that best meets the goals, in principle, is the "Partnership Agreement". However, this may not be the most adequate approach for the establishment of an agreement to install the instrument in an observatory, for example.

From INPE's side, the procedure would include the following steps: a document describing the project and the requirements for the external partner; preliminary analysis of the document from INPE's administration; agreement with the external partner about all aspects involved in the agreement; analysis of the INPE's lawyers; final adjustments; and, signature of the agreement. We point out that the agreement should consider elements such as copyright, patents or innovations as well as the interaction with foundations.

We have already started informal talks with the National Laboratory for Astrophysics (LNA/MCTI) to discuss about the possibility to propose a formal agreement for the development of this project. Recently, INPE and LNA established a framework agreement that would facilitate the discussions for the elaboration of the specific agreement for the Solar Telescope. The upper panels of Figure 26 show images from a visit of our team to LNA. The bottom panel presents a possible spot that we are exploring to install the instrument.

We have also investigated the requirements to institute an agreement with the Engineering School of Lorena /Sao Paulo University. However, it seems that in this case a formal agreement should focus on the scientific interaction.

Figure 26: The upper panels show images obtained during a visit of the working group to the LNA. The satellite image presents a possible spot for the installation of the advanced prototype at the Pico dos Dias Observatory is indicated in the figure.

PRELIMINARY RESULTS

Preliminary characterization of the loaned Air-Gap Fabry-Perot Etalon

Overview

The proposed magnetograph must provide a map of the magnetic field vector at the photosphere over the full solar disk. To achieve this aim, one of the requirements (TS-ET-0006 - Requirements for the Solar Telescope) is a spectral bandwidth of 100 mÅ in the spectral range of 6302.5 Å± 3Å. Here we characterize an already existing Fabry-Perot available at the Laboratory for Solar Polarimetry (LPS/CEA/INPE), which was provided by Dr. Renato Dallaqua. The instrument was acquired under the FAPESP grant agreement no. 96/07170-1[4]. The instrument model is RC-150 manufactured by Burleigh (Model RC-150, see Figure 27). Additional components of the system are a ramp generator, thermal box and RC mirrors.

It is important to state that this existing Fabry-Perot is not optimal for the final goals of the project, but it will serve for preliminary assemblies and training in laboratory. A customized etalon will be required for the final assembly of the instrument.

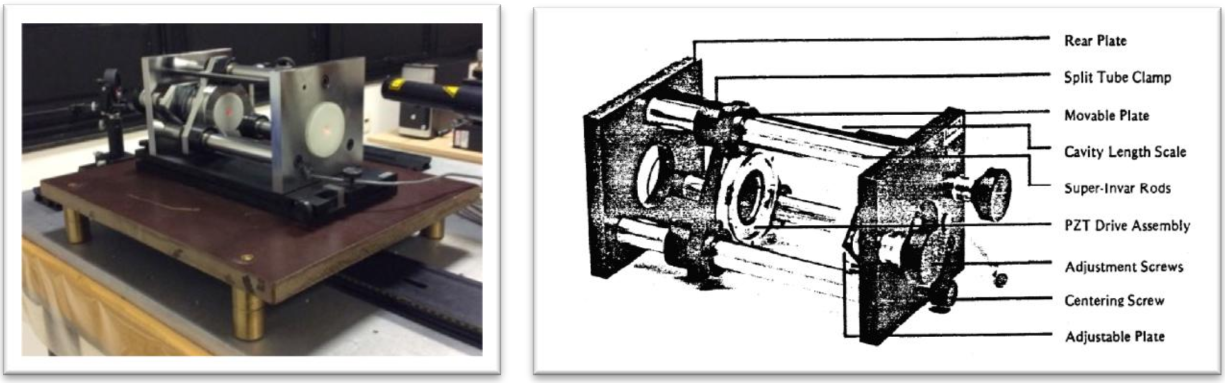


Figure 27: The figure shows an image of the RC-150 Model with the main elements indicated in the figure.

[4] Source : Diagnóstico de plasma com interferômetro Fabry-Perot em uma centrífuga de plasma iniciada por arco no vácuo. http://www.bv.fapesp.br/pt/auxilios/13070/diagnostico-de-plasma-com-interferometro-fabry-perot-em-uma-centrifuga-de-plasma-iniciada-por-arco-n/

Objective

In order to employ the Fabry-Perot etalon as an optical element of the Solar Telescope, we need to characterize the unity. Our main aim is determining the reflectivity of the mirrors near 630.25 Å, the beam quality, and the optimal bandpass, free spectral range and finesse for the Solar Telescope. Here we investigate specifically the sensibility of the bandpass, free spectral range and finesse to the distance between the mirrors (d0). Additionally, we verify the dependence of these parameters on the diameter of the beam. Furthermore, we aim to check to stability of the electronics of the ramp generator.

Setup

For the characterization of the Etalon, we followed the procedure proposed by Dr. Renato Dallaqua, which is detailed describe along with experimental results in a notebook. Dr. Braulio Albuquerque prepared the optical setup and Drs. Fernando L. Guarnieri, Vitor Moura, Luis E. A. Vieira, and MSc. Tardelli Stekel carried out the Etalon alignment and configured the data acquisition system. Images of team members working on the alignment of the Fabry-Perot Etalon are shown in Figure 28.

Figure 28: The images show team members working on the alignment of the Fabry-Perot Etalon.

Figure 29 shows the laboratorial setup employed. We have characterized the Fabry-Perot (FP) using a collimated configuration. A He-Ne laser of a central wavelength 633 nm was used as a source to perform the experiment. The beam was expanded and collimated using a spatial filter assembly and a lens system before passing through the FP.

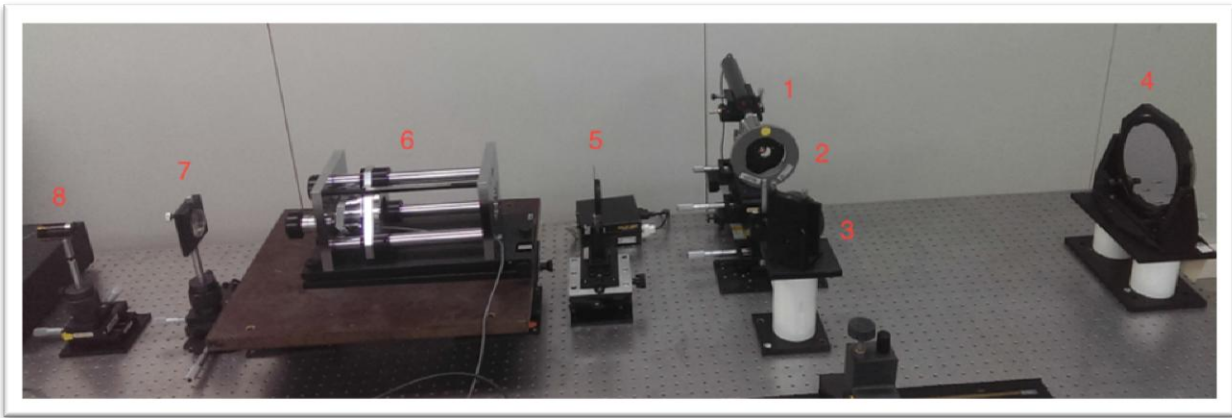


Figure 29: Setup to characterize the Fabry-Perot Etalon. Components: (1) laser; (2) microscope; (3) Folding mirror; (4) Parabolic mirror (collimator); (5) Diafragma; (6) Fabry-Perot Etalon; (7) Lens; and, (8) Sensor.

One example of the measurements performed is presented in Figure 30. The panel (a) shows the ramp voltage (proportional to the distance between the mirrors), while the panel (b) displays the sensor voltage. The Finesse estimated is approximately 25.9. The beam diameter was adjusted to 45 mm and the distance between the mirrors to approximately 0.3 mm. The maximum amplitude is about 0.7 V and the parameter rate of changed of distance between the mirrors per voltage is about 193 nm/V.

The preliminary output of a simple model of the experiment is presented in the panel (c) (red line). For reference, the blue line shows the measurements. The free parameter in the model is the distance between the mirrors, which is not precisely known from the mechanical setup at this point. The difference between the model's output and the measurements is displayed in panel (d). The best fit of the model indicates that the distance between the mirrors is approximately 0.28 mm and the bandwidth is estimated to be about 0.278 A. The estimated free spectral range (FSR) is approximate 7.20 A. Note that it is a very first estimate of the etalon parameters and the team is acquiring know-how on the alignment of the mirrors. Additionally, we are not employing the thermal enclosure.

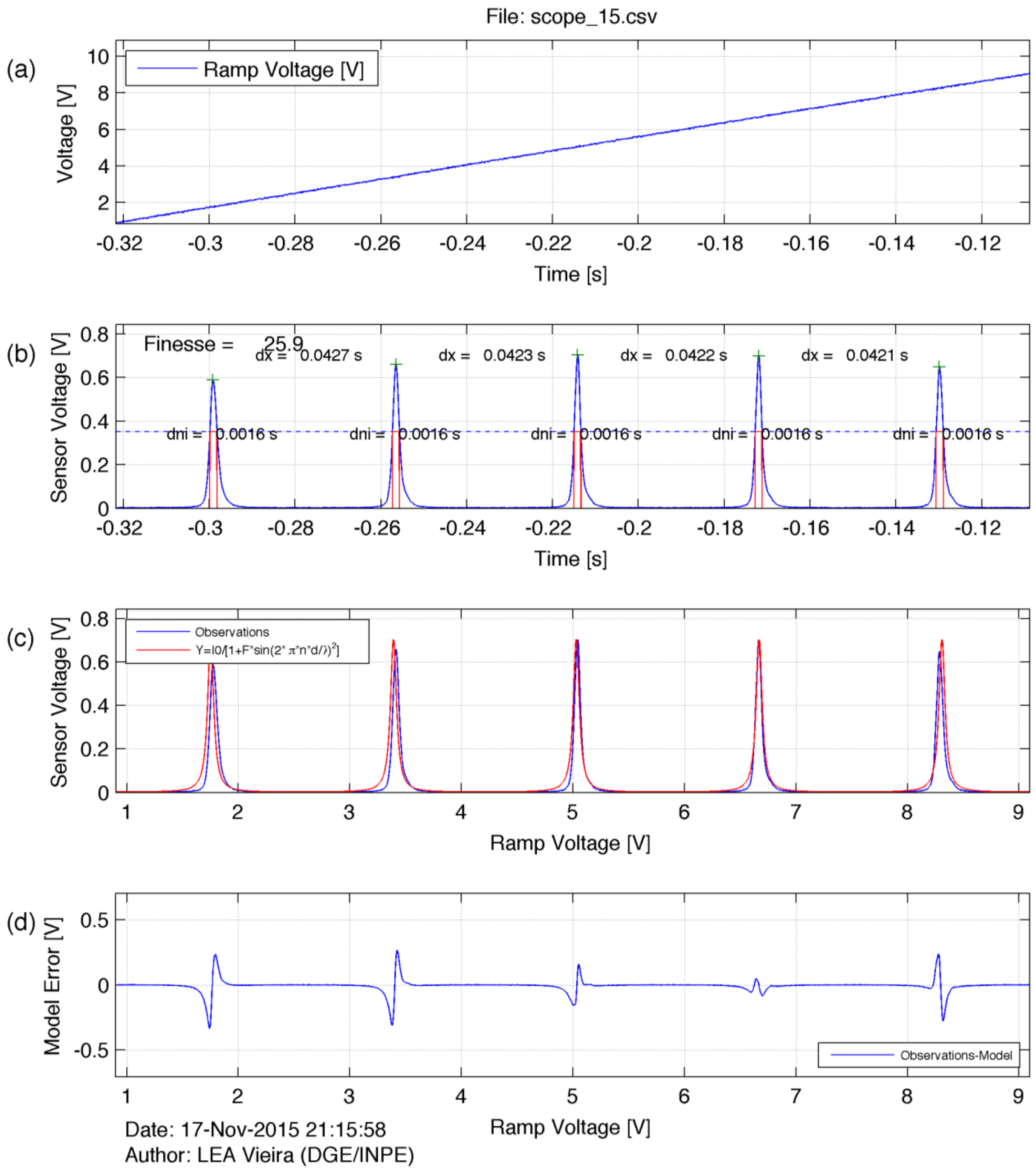


Figure 30: Modeling of the experiment Scope_13. Panel (a) shows the ramp voltage. Panel (b) indicates the sensor voltage measurements (the blue line). The blue line in panel (c) presents the measurements, while the red line shows the model's output. The last panel shows the difference between the measurements and the model.

Preliminary characterization of the sCMOS Cameras

Here we investigate the technique to improve the quality of the digital images produced by the sCMOS cameras (Zyla 5.5, water-cooled version). The problem is the identification of variations in the pixel sensitivity of the detector. We do not deal here with distortions in the optical path introduced by the optics of the instrument.

The corrected image, C, is obtained by

$$C = \frac{R - D \ \ * m}{(F - D)} = \ R - D \ \ * G$$

where C is the corrected image, D is the dark image, F is the flat field image, m is the average value of $F - D$, and, G is the gain.

Dark Image

We aim to characterize the sensitivity of the cameras detector, due to electrons that are detected in the device that are not photon dependent, that is, thermal ones added up to other noise sources. It is also useful for locating dead or hot pixels and other local inhomogeneities.

We studied a simple setup to obtain the dark image (D) under two different conditions: (a) active dissipation of the sensor heat; and, (b) passive dissipation of the sensor heat. In the first case, the sensor's temperature was set to about -10.4 ^{O}C, while in the second case the sensor's temperature was about 22 ^{O}C. In both situations, the sCMOS sensor was covered, the room lights were shutdown, and all built-in filters and correctors were turned off. Additionally, we investigate the dependence of the dark image statistics on the camera's operation parameters such as the exposition, frame rate, binning, etc. For each set of parameters, we obtained 100 frames (about 1.4 GigaBytes).

One example is presented in Figure 31 for the configuration with the active dissipation of the sensor heat. Panel (a) shows the average field. The color limits of the color code are set to 2 times the standard deviation. While panel (b) displays the row average values, the column average values are presented in panel (c). Finally, the histogram of the pixel values is exhibited on panel (d). Figure 32 shows the results for one example for the configuration with a passive dissipation of the sensor heat. The format of the figure follows the one of the previous figure.

Flat field Image

Our goal is to characterize the spatial non-uniformity and differential sensitivity of the camera's detector to a quasi-uniform source of radiation. Specifically, we study a setup to obtain the flat field image (F). To produce a quasi-uniform illumination, we employ an integrating sphere manufactured by Labsphere. The theory on the integrating sphere is presented in the document 'Integrating Sphere Theory and Applications', by Labsphere.

The upper left panel of Figure 33 shows schematically the setup investigated. The integrating sphere is presented on the left, while the sensor is on the right. The parameter D represents the diameter of the sphere's exit, d is the length of the detector, and x is the distance from the sphere to the sensor. The other panels of the Figure 33 display the actual laboratorial setup of the system. To quantify the parameter x, we employ as reference the mechanical structure of the sphere and the camera frame as indicated in the figure.

Note that the sensor cannot be positioned exactly at the sphere's exit because of the camera's mechanical structure (seen Figure 34). The average field obtained from 100 frames capture at the closest position (approximately 13 mm) is shown in Figure 35. In this case, the field is saturated at the center and present lower values near the corners. This configuration results from the dependence of the uniformity (E_e/E_0) on the distance from the sphere to the sensor (see Figure 36). Note that there is a minimum about d/D equal to 0.4. This dependence can be seen in the fields presented in Figure 37 to Figure 39, where the distances are 35 mm, 80 mm, and 100 mm, respectively. Even so, we have not obtained a flat field needed to characterize the spatial non-uniformity and differential sensitivity of the camera's detector. We are planning in the forthcoming weeks to employ a larger integrating sphere (diameter: 1 m) to obtain a more uniform field.

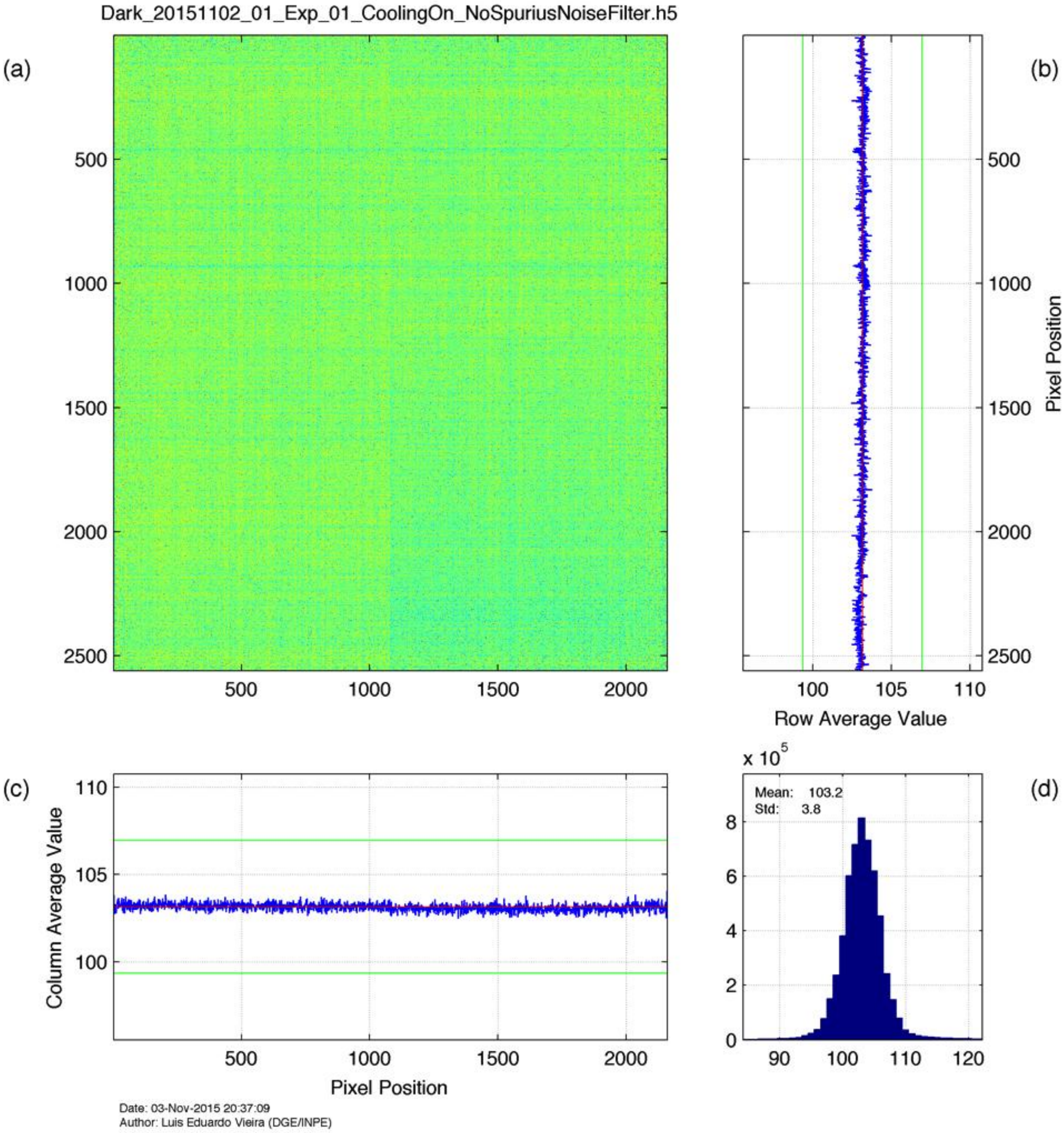


Figure 31: (a) Average field for the setup #1. (b) Rows average values. (c) Columns average values. (d) Histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

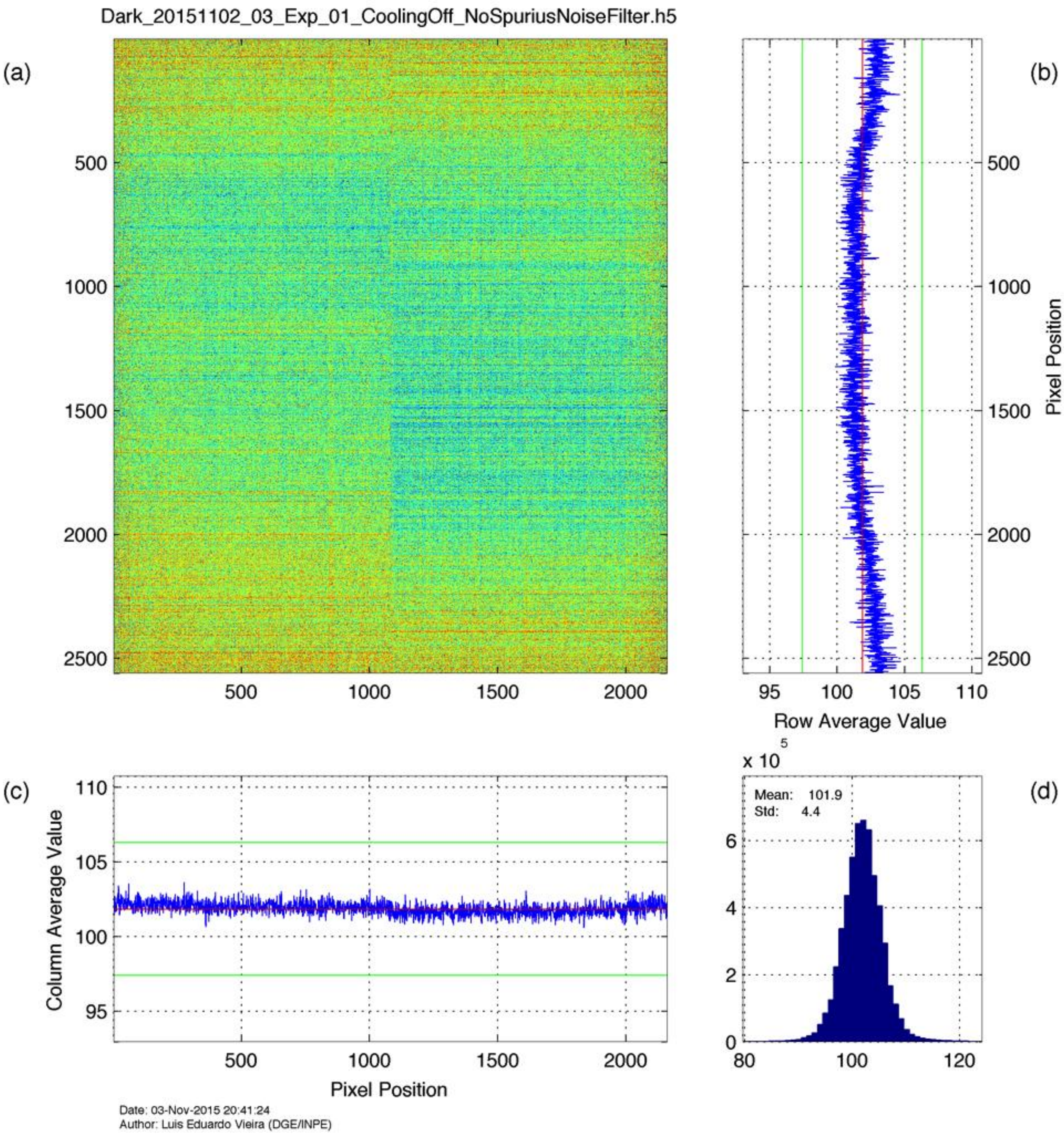


Figure 32: (a) Average field for the setup #2. (b) Rows average values. (c) Columns average values. (d) Histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

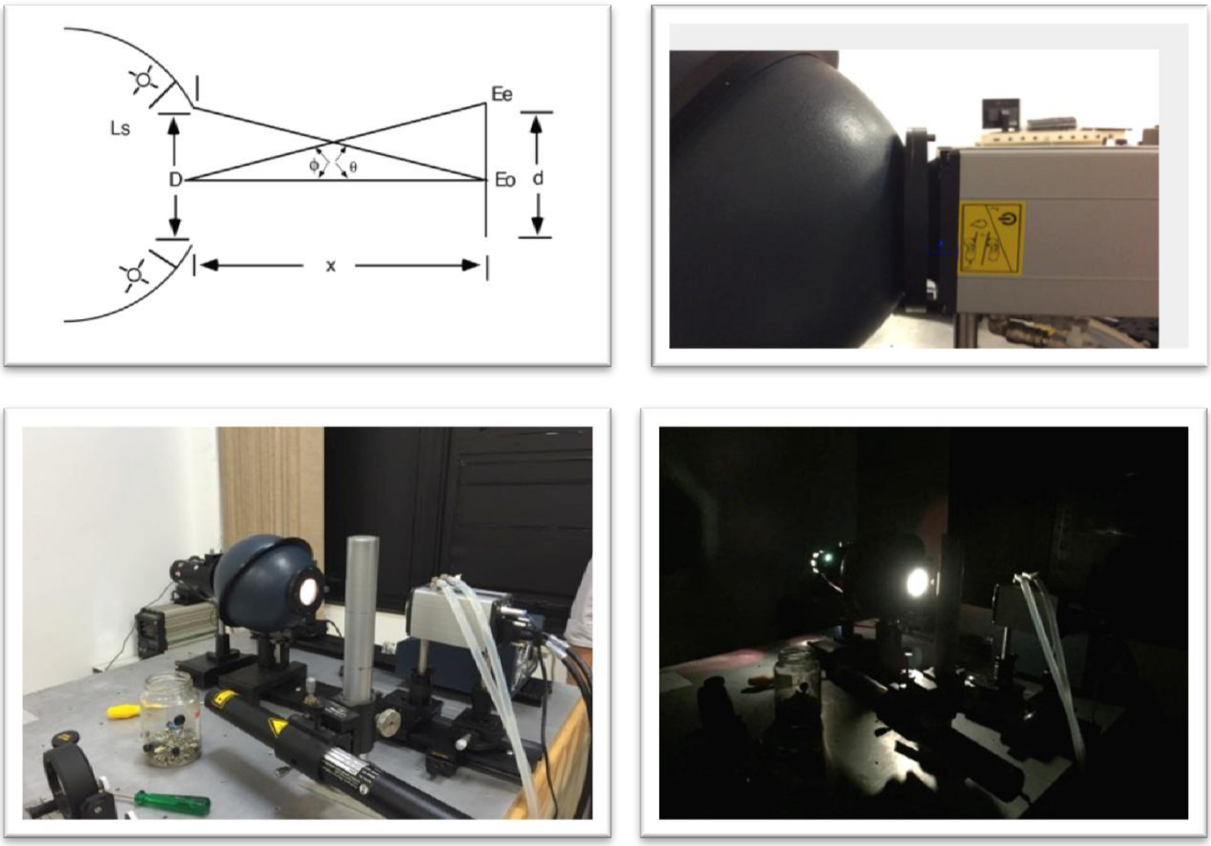


Figure 33: The figure presents the elements to be considered in the setup. Source: Integrating Sphere Theory and Applications', by Labsphere.

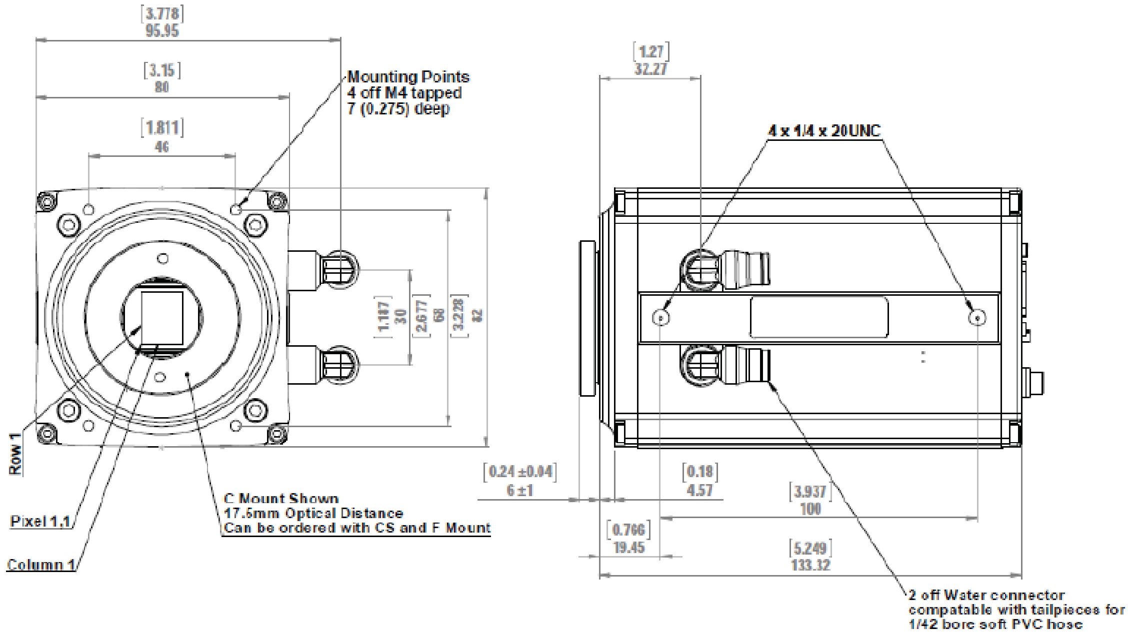


Figure 34: The figure shows the mechanical drawings for the water-cooled versions of Zyla 5.5. Source: Zyla_hardware_user_guide.pdf.

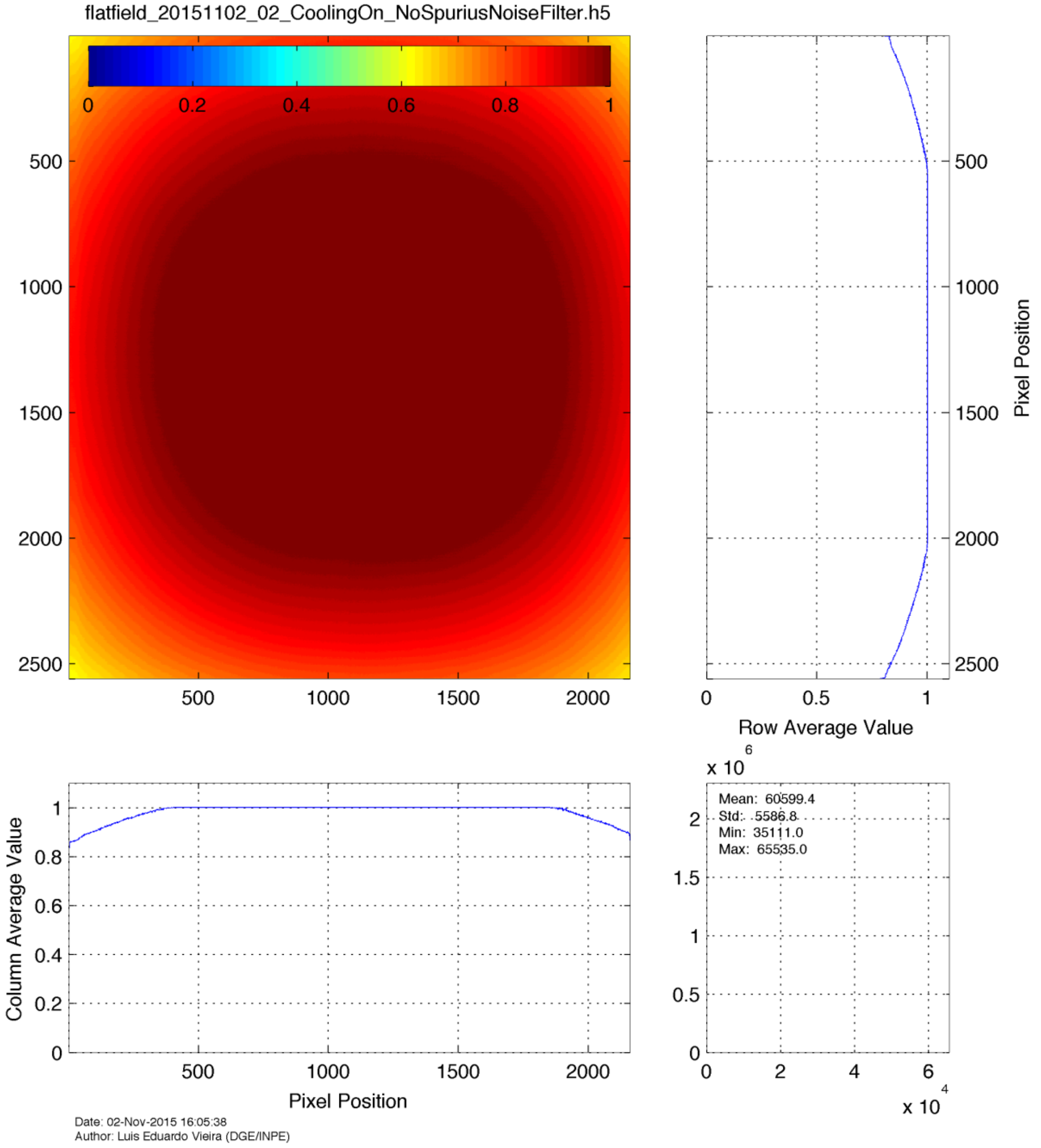


Figure 35: The left upper panel shows the average field for a setup with a distance of 13 mm of the sensor to the exit frame of the sphere. The right upper panel shows the rows average values. The bottom left panel shows the columns average values. The right bottom panel shows the histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

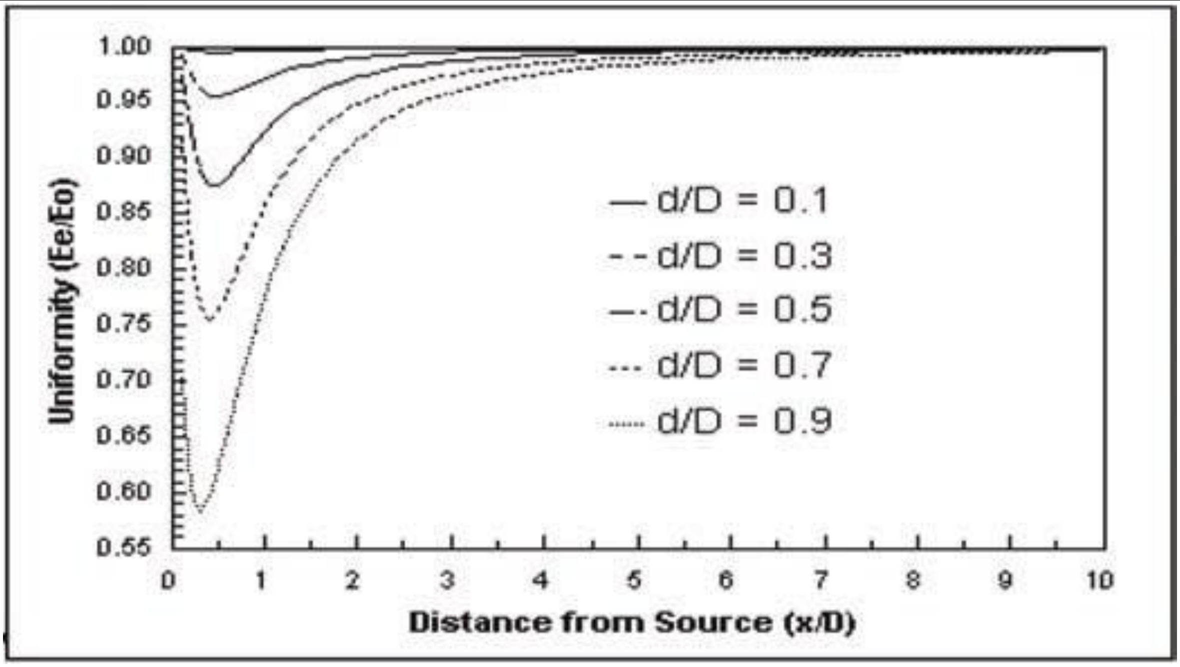


Figure 36: The figure shows the distance from the source versus uniformity. Source: Integrating Sphere Theory and Applications', by Labsphere.

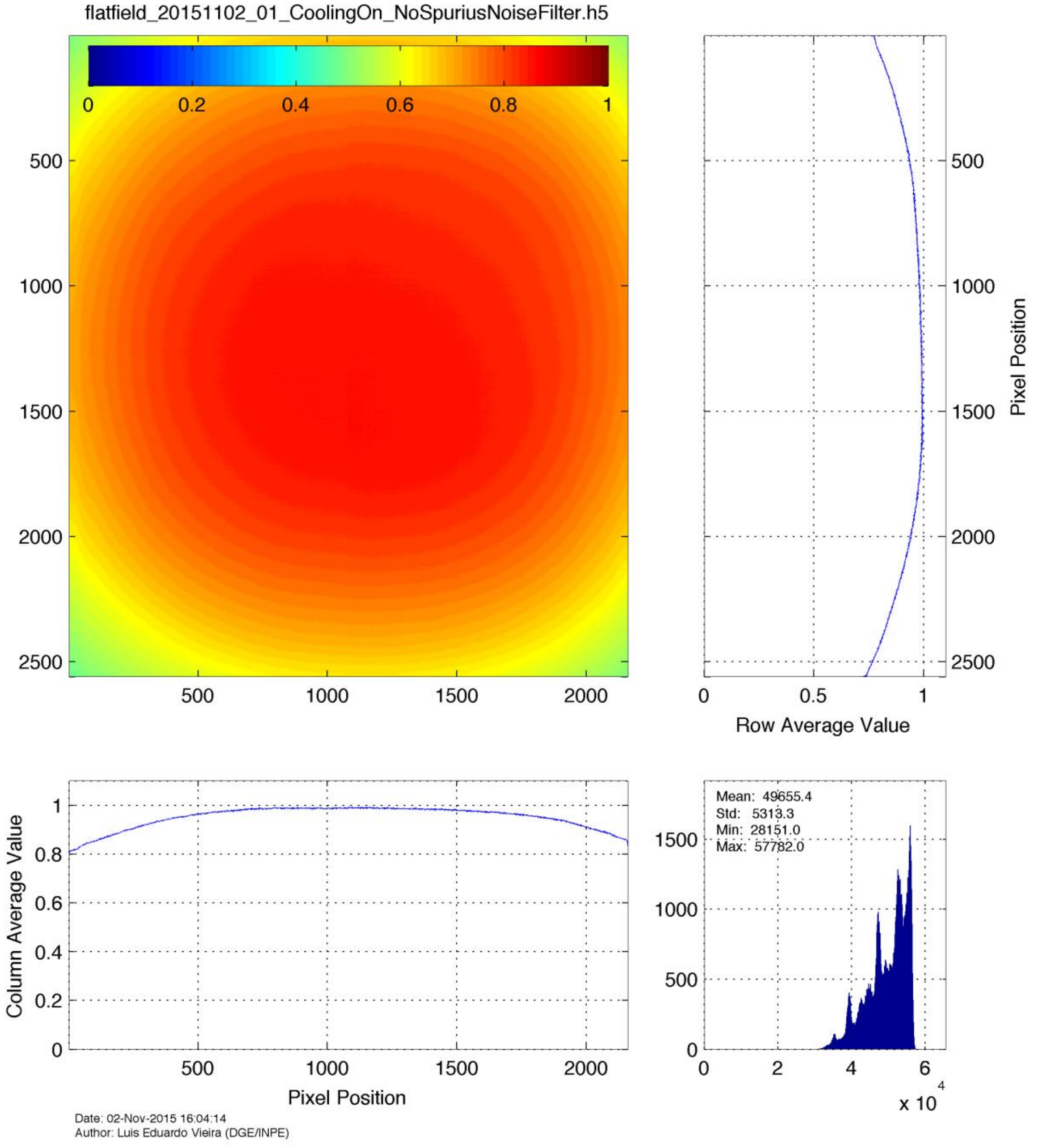


Figure 37: The left upper panel shows the average field for a setup with a distance of 35 mm of the sensor to the exit frame of the sphere. The right upper panel shows the rows average values. The bottom left panel shows the columns average values. The right bottom panel shows the histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

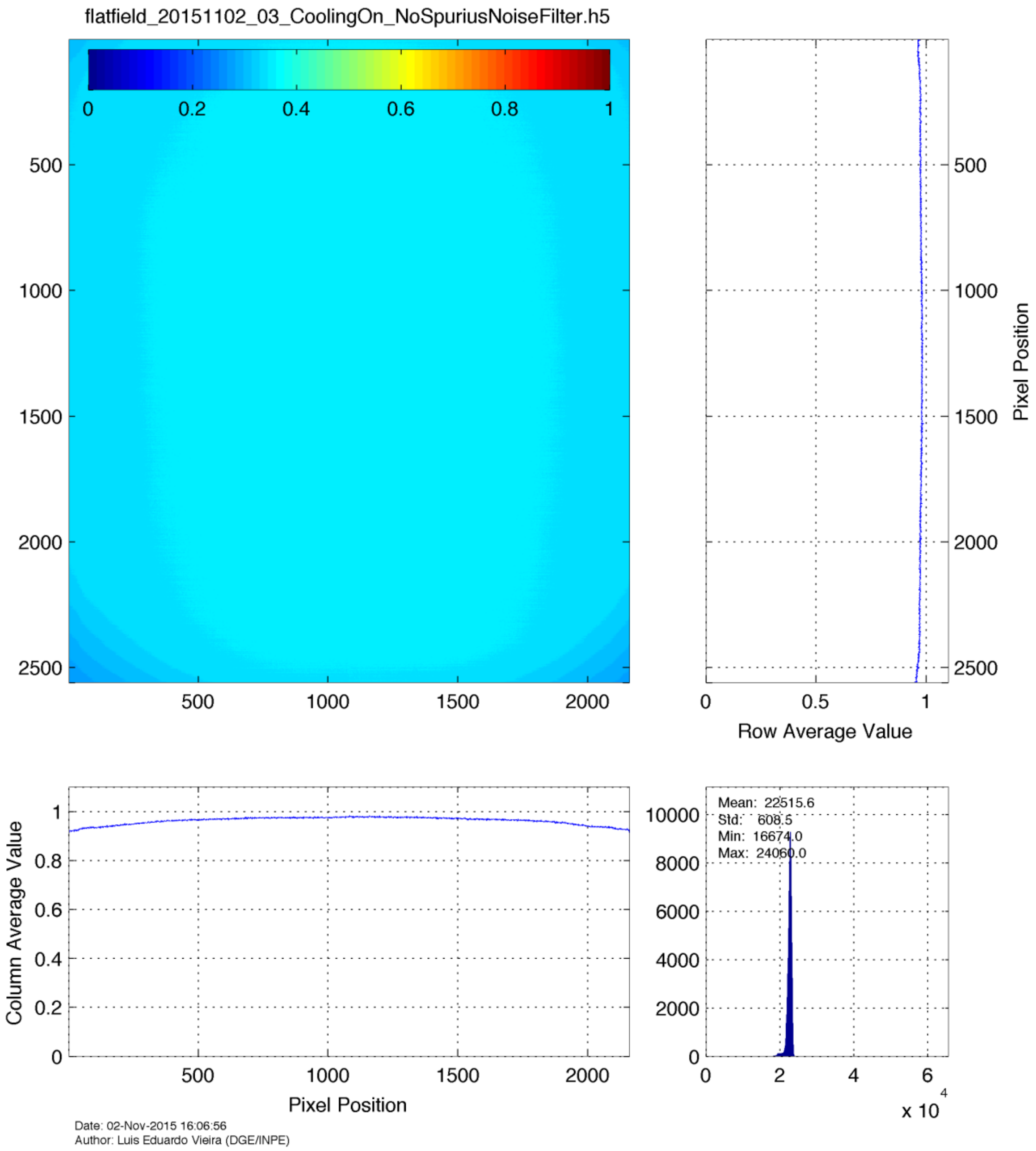


Figure 38: The left upper panel shows the average field for the setup with a distance of 80 mm of the sensor to the exit frame of the sphere.. The right upper panel shows the rows average values. The bottom left panel shows the columns average values. The right bottom panel shows the histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

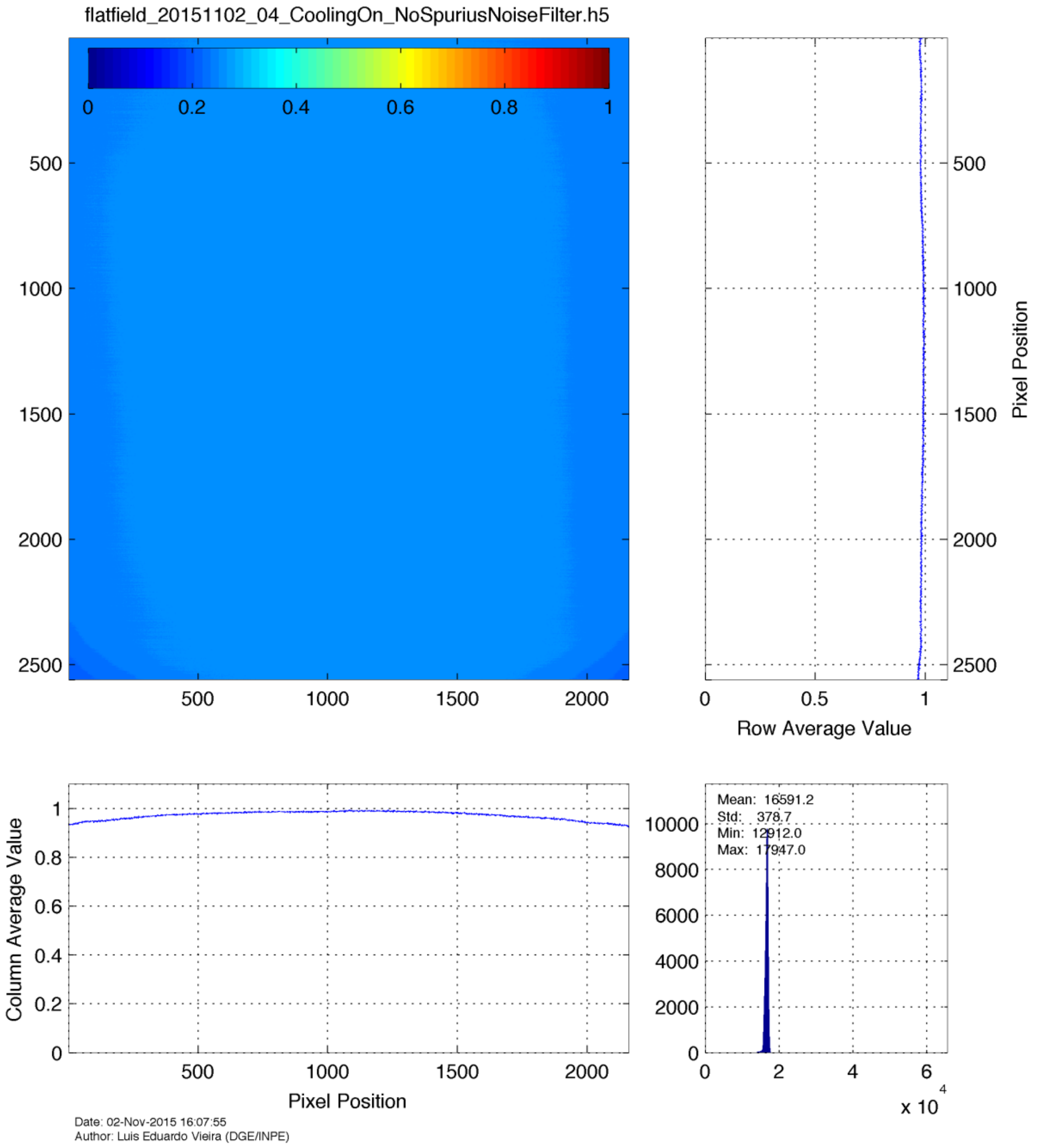


Figure 39: The left upper panel shows the average field for the setup with a distance of 100 mm of the sensor to the exit frame of the sphere. #3. The right upper panel shows the rows average values. The bottom left panel shows the columns average values. The right bottom panel shows the histogram for the average field. The mean, standard deviation, minimum and maximum values are presented in the figure.

Publications/Conferences

Title	Preliminary design of the INPE's Solar Vector Magnetograph
Authors	Vieira, L. E. A.; de Gonzalez, A. L. Clúa; Lago, A. Dal; Wrasse, C.; Echer, E.; Guarnieri, F. L.; Cardoso, F. Reis; Guerrero, G.; Costa, J. Rezende; Palacios, J.; Balmaceda, L.; Alves, L. Ribeiro; da Silva, L.; Costa, L. L.; Sampaio, M.; Soares, M. C. Rabello; Barbosa, M.; Domingues, M.; Rigozo, N.; Mendes, O.; Jauer, P.; Dallaqua, R.; Branco, R. H.; Stekel, T.; Gonzalez, W.; Kabata, W.
Publication	Proceedings of the International Astronomical Union, Volume 305, pp. 195-199
Publication Date	10/2015
Keywords	Sun: photosphere, magnetic fields, techniques: polarimetric
DOI	10.1017/S1743921315004767
Observation	Paper presented during the Symposium S305 (Polarimetry: From the Sun to Stars and Stellar Environments), Punta Leona, Costa Rica, 30/Nov/2015-5/Dec/2014. Presenter: Judith Palacios

Title	Design review of the Brazilian Experimental Solar Telescope
Authors	L.E.A. Vieira, A. Dal Lago, B. Albuquerque, B. Castilho, F. Guarnieri, F. Cardoso, G. Guerrero, J. Rodríguez, J. Santos, J. Costa, J. Palacios, L.A. da Silva, L. Alves, L. Costa, M. Sampaio, M.D. Silveira, M. Domingues, M. Rockenbach, M. Aquino, M.C. Soares, M.J. Barbosa, O. Mendes, P. Jauer, R. Branco, R. Dallaqua, T. Stekel, T.S.N. Pinto, V.M enconi, V. Souza, W. Gonzalez
Conference	AGU Fall Meeting. Session: Thermal and Magnetic Structure of Solar Active Regions from the Photosphere to the Corona
Period	14/Dec/2015-18/Dec/2015
Keywords	photosphere, magnetic fields
Link	https://agu.confex.com/agu/fm15/meetingapp.cgi/Paper/85069
Observation	Paper to be presented on Monday, 14 December 2015 13:40 - 18:00 Format: Poster Presenter: Alisson Dal Lago

CONCLUDING REMARKS

This report summarizes the activities related to the INPE 's Solar Telescope project, also named Brazilian Experimental Solar Telescope, from years 2014 and 2015. Special attention was given to year 2014, because at this point, we are 2 years past the initial budget delivery. Below, we list the milestones achieved until this stage of the project.

Project Charter	A Project Charter was built in which several aspects were brought to light: current status, goals, future scenarios, stakeholders, products, and risks, among others. Besides the organizing power, this development had the advantage of aligning all the team with the mental concept of the project. Often this aspect was neglected in our past experiences, but it proved a challenge to overcome.
Systems Engineering	Development of Systems Engineering for the project, where requirements, architecture among others, were established more clearly than before.
Managing strategy	Adoption of a managing strategy, were deliveries were planned and controlled in a weekly-based fashion. Since the beginning, in early 2014, the team has meetings every week. However, the adoption of a more efficient systematics was necessary, in order to make each member aware of his short-term deliveries. Every few months, a general realigning meeting was held, to correct focus and make any necessary adjustments.
Execution of the 2014 budget	2014 budget was executed correctly, with success. Two sCMOS detectors were acquired via international bidding process. A lot has been learned from this experience, which allowed future processes to be correctly conducted.
Execution of the 2015 budget	2015 budget is on time at this point.
Solar Polarimetry Laboratory	A Solar Polarimetry Laboratory was created and is already in use for the project.
SCMOS Cameras delivered	Preliminary tests were performed with the sCMOS, following a pre-defined procedure, developed throughout these two years.
Preliminary optical design	• Details of the optical design were reviewed by specialized team members.

As a general conclusion, the project is running in a very satisfactory fashion. We, however, still have a lot of work to do, for which the whole team will need to keep working hard.