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# IBIS2.0: The new Interferometric BIdimensional Spectrometer

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## ABSTRACT

We present the IBIS2.0 project, which aims to upgrade and to install the Interferometric BIdimensional Spectrometer at the solar Vacuum Tower Telescope (Tenerife, Spain) after its disassembling from the Dunn Solar Telescope (New Mexico, USA). The instrument is undergoing a hardware and software revision that will allow it to perform new spectropolarimetric measurements of the solar atmosphere at high spatial, spectral and temporal resolution in coordination with other ground- and space-based instruments. Here we present the new opto-mechanical layout and control system designed for the instrument, and describe future steps.

**Keywords:** Solar telescopes - Instrumentation: high angular resolution - Instrumentation: interferometers - Instrumentation: polarimeters

## 1. INTRODUCTION

The IBIS2.0 project aims to realize the Interferometric BIdimensional Spectrometer 2.0 for high resolution solar bi-dimensional spectroscopy and spectropolarimetry. IBIS2.0 upgrades the Interferometric BIdimensional Spectrometer (IBIS,<sup>1-3</sup>) that was realized by the INAF–Arcetri Astrophysical Observatory with the contribution of the Universities of Florence and Rome Tor Vergata.

IBIS was installed at the focal plane of the Dunn Solar Telescope (DST) of the National Solar Observatory (NSO) in New Mexico (USA) in June 2003, and it was operated there by the NSO until June 2019. Following changes at DST, the instrument was dismantled for upgrades in light of its re-installation at the German Vacuum Tower Telescope at the Observatorio del Teide in Canary Islands (Spain).

The IBIS instrument basically consisted of two Fabry-Pérot (FP) interferometers and narrow band filters operating in a classic mount over the spectral range 580–860 nm. However, it was made up by more than 40 optical components. Early in 2020 the instrument was remounted in the Optical Laboratory of the INAF Rome Astronomical Observatory with the configuration employed at the DST. This allowed investigating and testing all instrumental components and their movement functions. Some redundancy and obsolescence were found, mostly in electronic parts and interfaces.

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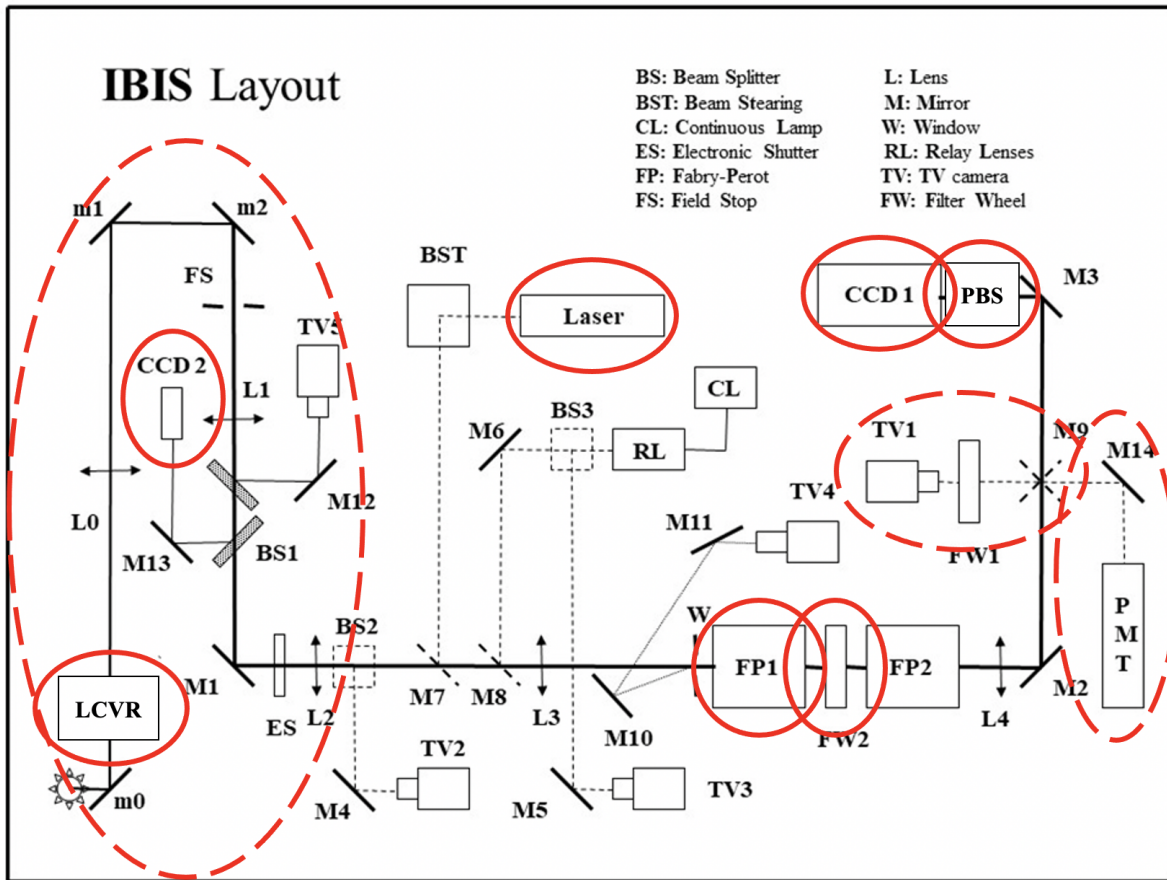


Figure 1. IBIS optical layout at DST. The dashed and solid red lines enclose subsystems undergoing upgrades and replacement, respectively. Adapted from.<sup>1</sup>

IBIS2.0 is expected to continue the high cadence spectroscopic and spectropolarimetric observations of the solar photosphere and chromosphere started by IBIS at DST. A typical IBIS data set consists of measurements taken in sequence over multiple spectral lines (two or three lines, e.g. Fe I at 603.2 nm, Fe I at 617.3 nm, and Ca II at 854.2 nm), with each line sampled at several spectral positions (often between 10 and 30, for the three above lines e.g. 30, 24, and 25 positions) and each position at six polarimetric states (I+Q, I-Q, I+V, I-V, I+U and I-U). The data are characterized by a high spectral ( $> 200000$ ), spatial ( $\approx 0.2$  arcsec), and temporal (8-15 fps) resolution, over a relatively large Field-of-View (FoV  $> 60$  arcsec) and wide spectral range (580-860nm), with a high wavelength stability in time of the instrumental profile (with a maximum drift of the order of 10 m/s over 10 hours), short exposure times to freeze the Earth's atmospheric seeing ( $\approx$  tens of ms), and a diffraction limited resolution on the whole focal plane (image spots inside the Airy disk on the whole FoV).

Here we present the results from the preliminary re-design of the optical layout and control system of the instrument for its installation at the new location with upgraded characteristics. The re-design of the instrument aims to preserve the above mentioned characteristics of the data acquired with the instrument while upgrading its operation by means of an automatic and remote control. The IBIS2.0 project involves researchers at INAF Observatories of Rome, Trieste, Catania, Brera, and at Universities of Rome Tor Vergata and Catania.

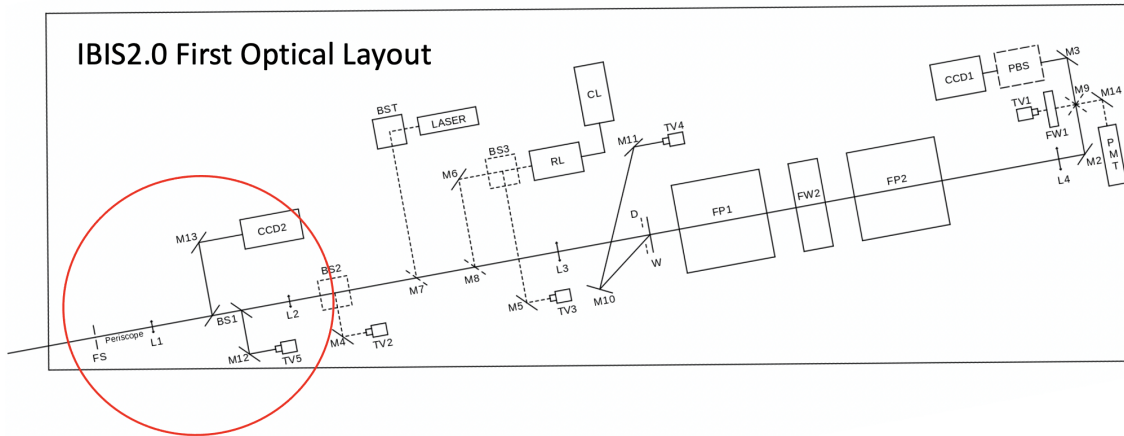


Figure 2. The first optical layout designed for the IBIS2.0. See Section 2 for details.

## 2. OPTICAL LAYOUT

Figure 1 shows the optical layout of IBIS at DST. We refer the readers to the original description of the instrument in<sup>1</sup> for details. The instrument, in brief, was basically composed by two Fabry-Pérot interferometers (FP1 and FP2) and narrow band filters, which were positioned in a filter wheel (FW2) in between FP1 and FP2, operating in a classic mount. However, it consisted of more than 40 optical components, including 5 lenses (L0-L4), 3 beam-splitters (BS1-BS3), 14 fixed mirrors (m0-m2, M1-M2, M4-M6, M10-M14), 4 moveable mirrors (M3, M7, M8, M9), 2 filter wheels (FW1, FW2), 2 CCD cameras (CCD1, CCD2), 5 TV cameras (TV1-TV5), 1 He-Ne laser, 1 halogen continuous lamp, 1 photomultiplier (PMT), 1 Liquid Crystal Variable Retarders system set (LCVRS) and other components counting several narrow-band filters (NB with FWHM $\approx$ 0.3nm) and broad-band filters (BB with FWHM $\approx$ 5-10nm). The components were arranged to form a main optical path, which is represented in Figure 1 with solid line, and a few secondary channels, which were employed for instrumental calibrations and reported in Figure 1 with dashed lines. All the above components were anchored in an optical table through holders on X95 rails. The mechanical stages employed on the rails allowed for the fine tip/tilt regulation and three-axis translation of the components by using micrometers. Find more details on the instrument also in<sup>2</sup> and<sup>3</sup>.

IBIS at DST was employed to perform both spectroscopy and spectropolarimetry, the latter by applying instrumental changes to the scheme in Figure 1. These included replacement of the circular FS employed for spectral measurements with a rectangular one, activation of a LCVRS system between m0 and L0, which are the elements used to redirect the light from the telescope to the instrument path and form the image of the FoV on the instrument field stop (FS), movement ahead of L4 and CCD1, and positioning of a polarizing beam splitter (PBS) between M3 and CCD1.

The dashed red lines in Figure 1 show the regions in the IBIS optical scheme undergoing a significant re-design, while the solid red lines enclose the elements requiring either replacement or maintenance. The re-design aims to get a simpler optical scheme for the instrument, and a fully automatic control for the remote operation of the instrument. Indeed, instrumental changes to switch between spectroscopic and spectropolarimetric operations, and most of the calibration procedures of IBIS at DST were performed manually. To overcome this approach, the re-design of the optical layout for IBIS2.0, and development of its control system consider the needs for full control of the instrumental functions and for automation of calibration procedures.

Figures 2 and 3 show the two optical layouts investigated during the preliminary phase of the IBIS2.0 project. These layouts were designed with Zemax to comply with the conditions at VTT and further additional constraints.<sup>4</sup> For example, in order to maintain the micrometer regulation of the position of components that is required for the accurate set-up of the instrument, all the elements are still assumed to be anchored in the optical table through the existing holders and X95 rails. Besides, conditions at VTT imply insertion of a periscope of

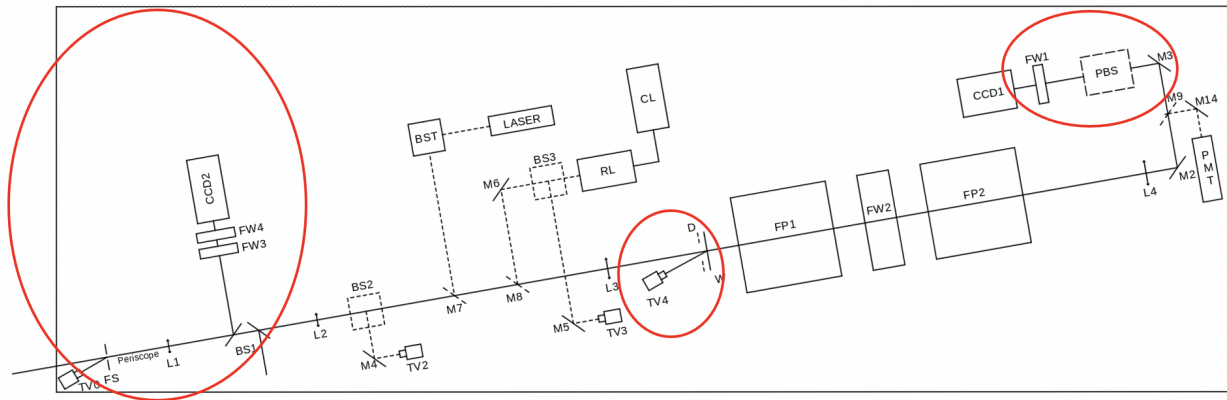


Figure 3. The second optical layout designed for the IBIS2.0. See Section 2 for details.

two mirrors between FS and L1 to raise the height of the optical beam from the telescope to the one of the main optical axis of the instrument. The latter is also expected to be placed diagonally on the optical bench available at the telescope, in order to avoid spurious instrumental polarization from folding mirrors and to simplify the optical alignment of the instrument. Ongoing laboratory tests will lead to the final optical design of IBIS2.0, which is expected to be close to the second layout presented in the following.

Figure 2 shows the optical layout of the instrument as operated at DST with the revisions needed to adapt it to the conditions at VTT. This layout minimizes the instrumental revisions with respect to the optical scheme of the former version of the instrument. It also makes use of all the components of the previous version of the instrument, with the re-arrangement of the elements before L2 that are enclosed in the solid red circle in Figure 2. The re-arrangement of those components allows to avoid application of folding mirrors, and to fit the dimension of the optical table and encumbrances of the mechanical parts. The re-arranged components also include those forming the so called white light channel (M13+CCD2) and the M12+TV5 channel, which receives the light passed by BS1 still positioned near the pupil between L1 and L2. All the components in the optical path across L2 are unchanged with respect to IBIS at DST.

Figure 3 displays the second optical layout designed for IBIS2.0. This layout simplifies the optical scheme of the instrument with respect to the one of the former version, and automates functions of components in the calibration channels, by introducing new elements. The re-arranged elements are enclosed by the solid red lines in Figure 3. As in the layouts presented above, the core elements of the instrument, i.e. the FP1 and FP2, and the FW2 holding narrow-band prefilters, are placed in the pupil plane between L3 and L4. In the second layout, the white-light channel that includes BB filters comprises a reduced number of optical components with respect to the same channel in the former version of the instrument. The calibration channels involving BS2+TV2 and BS3+TV3, which are used to check the orthogonality of the solar beam and continuous lamp (CL) beam with respect to the plates of both FPs respectively, is upgraded with motorized linear stages. The TV1+FW1 channel, which is employed to check the parallelism of the FPs plates with the laser beam, is integrated into the main optical path after M3, in order to use the scientific camera in place of TV1. The PMT+M9+M14 channel, which is employed for the spectral tuning of the two FPs, shall also be integrated into the main optical path, by using the scientific camera for the spectral tuning in place of the obsolete PMT.

### 3. INSTRUMENT CONTROL

The former version of the instrument consisted of several types of devices, with only a subset of them being controlled by software. Most of the devices were controlled manually, either by a mechanical control or by an electrical function operated via keypads and switches. The IBIS control system at DST was based on a Main PC covering the tasks of low level device control and high level instrument control. The control software was



based on the Virtual Engineering Environment (VEE) framework. The Main control PC used Ethernet, Serial and USB interfaces to control the devices. Part of the devices used a GPIB (also known as IEEE 488) bus.

The first optical layout designed for IBIS2.0 implies the continuation of the manual control of all the instrument components on site by trained operators, for the set up and operation of the instrument as done for IBIS at DST. The upgrade of the control system (CS) for the first layout only considers the replacement of the VEE control software employed to control IBIS at DST, with an updated and more maintainable system. The changes applied to the Instrument Control Electronics (ICE) are also minimal with respect to the former version of the instrument, and only include a General Purpose Interface Bus (GPIB) to Local Area Network (LAN) interface for the CS100 controllers, CCD focus motor and Frequency counter, and a gateway device for controllers of FW1 and FW2. Concerning the framework employed for the control software, adoption of LabVIEW offers the possibility for a smooth update of the system, since the programming paradigm is very similar to VEE. However, a scripting language (e.g. Python) could also be used for the implementation of all the software procedures formerly employed at DST.

The control architecture designed for the second optical layout includes two options that aim to realize either a partial (Level 1) or full (Level 2) automation of instrument functionalities, the latter excluding optical elements that are fixed or moved only for instrument alignment. The instrument control architecture proposed for the instrument is based on the control software developed by the European Southern Observatory (ESO) for the control of the ESO Very Large Telescope (VLT) instruments. The VLT software (VLTSW) is a software framework ranging from the control of the low level functions to the tools to implement in an easy way the Graphical User Interfaces (GUIs). It is worth noting that, although the first versions date back to the end of the nineties, the VLTSW has been regularly extended to include the latest technology and industry standards (e.g. Programmable Logic Controllers (PLC) for the hardware control and use of the OPC-UA communication protocol). The proposed ICE for IBIS2.0 is based on PLC Beckhoff, which is compliant with the VLTSW baseline. The Beckhoff brand offers many solutions to develop a fully automatic control system as the one expected for IBIS2.0. Indeed, the main CPU can be equipped with Analog and Digital I/O control modules, Analog modules for the PT100 monitor, and many options for the control of low power motors (DC and stepper). Beckhoff PLCs are programmed via TwinCAT Software System and can be equipped with the OPC-UA library employed by the IBIS2.0 hardware to communicate with the VLTSW.

The core of the IBIS2.0 ICE is represented by the PLC CPU. The baseline for IBIS 2.0 CS is the Beckhoff CPU of CX2030 series. The functions to be controlled include motorized functions, digital I/O functions, analog I/O functions, temperature sensors. The Beckhoff CPU can be equipped with several series of modules. The communication between the PLC modules is via EtherCAT interface. In case of necessity the modules can be decentralized from the CPU thanks to EtherCAT interfaces.

It is worth mentioning that the motors employed in the former version of the instrument need to be replaced in order to obtain a better degree of uniformity, to improve performance and to be completely compliant with the PLC control system. In a few cases of translation movements, specifically those pertaining to FP1, FP2, M7 and M8, the functions will be upgraded to also provide a feedback to the CS of the position. In all the other cases, the motors and stages are expected to be of the stepper type. Figure 4 displays the motorized functions in the IBIS2.0 second layout with Level 2 automation. Besides, the original TV cameras will be replaced with either CCDs or CMOS cameras that offer a digital interface, while still maintaining the Type-C attachment on the optical side allowing a straight replacement. At automation Level 1, the ThorLabs DCC1545M with a  $1024 \times 1048$  sensor and maximum 25 fps are proposed. These cameras offer a USB connection and an additional USB hub will be provided for the connection to the Instrument Workstation (IWS). The purpose of this camera is only to show a real-time image to the operator on the control system monitor, replacing old TV monitors. At automation Level 2, the Allied Vision Technologies Manta G-235B with  $1936 \times 1216$  sensor and maximum 50 fps is proposed. These cameras have a Gig-E compliant Ethernet interface with PoE that allow a connection to the IWS through LAN. With better specs and higher frame rate they should be better suited for closed loop control of the functions via image analysis.

The IBIS 2.0 CS architecture follows the standard model for the VLTSW based instruments, which includes the following standard packages:

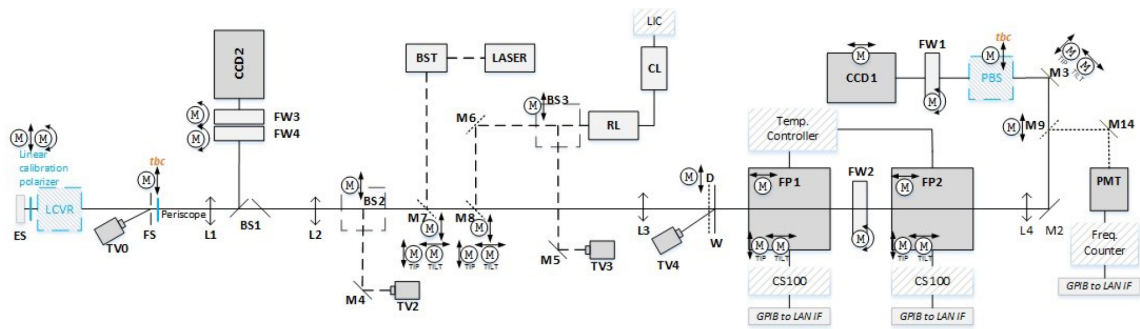


Figure 4. Overview of the motorized functions in the IBIS2.0 second layout with Level 2 automation. See Section 3 for details.

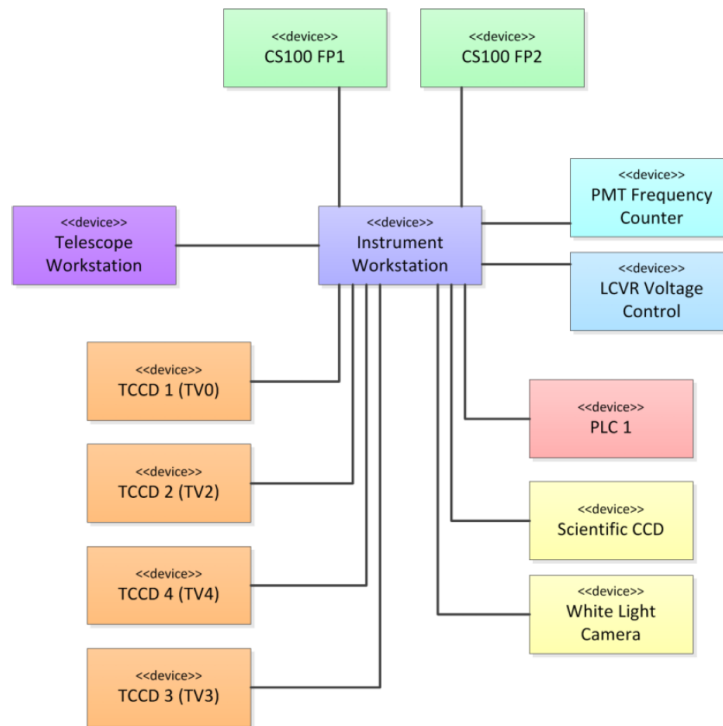


Figure 5. Control architecture for the IBIS2.0 second layout with Level 2 automation. See Section 3 for details.



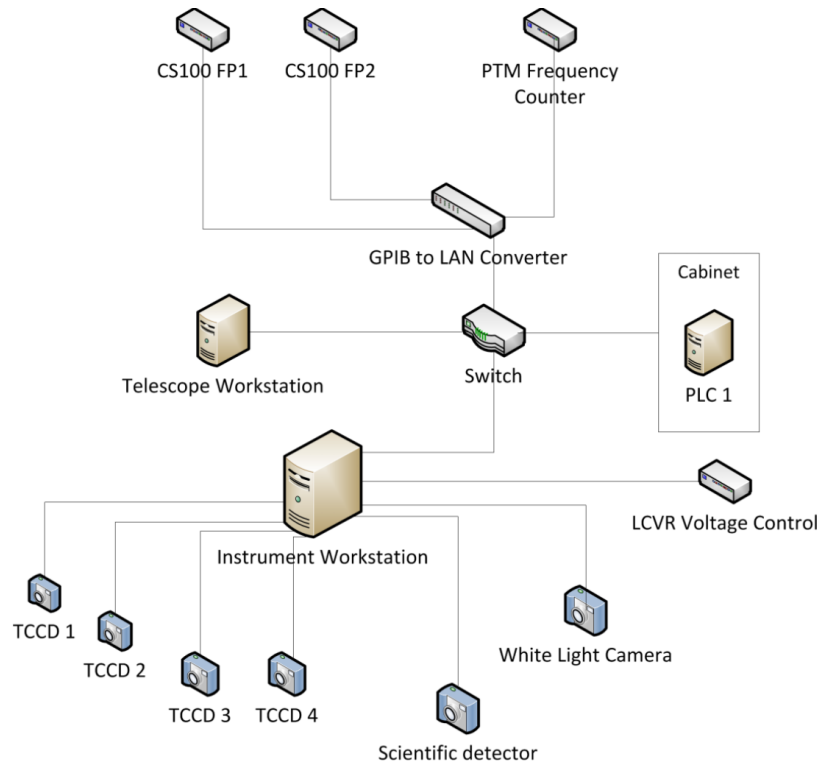


Figure 6. ICS network layout for the IBIS2.0 second layout with Level 2 automation. See Section 3 for details.

- Instrument Control Software (ICS): it is responsible for the control of all the vital, low-level functionalities of the instrument (motors, lamps, sensors).
- Detector Control Software (DCS): it takes care of the control of scientific detector systems (scientific detector and white light camera).
- Observation Software (OS): it is responsible for the coordination of activities of the DCS and ICS. It also interfaces with the telescope control system if needed, and with the instrument data flow, in particular with the Broker for Observation Block (BOB) that delivers the next observation block to be executed, and the Archive, which saves the results at the end of each observation.
- Maintenance Software (MS): it provides tools to maintain the configuration of the instrument and to check the instrument health.

Figure 5 gives an overview of the control architecture for the IBIS2.0 realized with Level 2 automation, which means the full automation option. On the IWS runs the high level control software that controls the instrument devices and detectors. At the VTT the IWS is expected to be located in the optical laboratory near the optical bench. Figure 6 shows the planned network layout.

Finally, the original power supply system will be completely reworked as part of the PLC system, since all the devices will be connected to this unit in the new designed instrument.

#### 4. CONCLUSIONS

The IBIS2.0 project aims to update and upgrade the Interferometric Bidimensional Spectrometer, in order to operate it at the focal plane of the German Vacuum Tower Telescope (Tenerife, Spain) after its disassembling from the Dunn Solar Telescope (New Mexico, USA). The preliminary phase of the project has designed two optical layouts for the instrument. The first one minimizes the instrumental revisions with respect to the optical

scheme of the former version of the instrument at DST. In this layout, all the components of the previous version of the instrument are employed. The second layout leaves almost unchanged the main optical path of the former version of the instrument, but widely re-arranges and upgrades the calibration channels. This is to allow either a partial or fully automatic control of the components of the instrument and its remote operation. In this layout, some of the components of the previous version of the instrument are replaced with new elements. Ongoing laboratory tests will allow to define the final optical design of IBIS2.0 that is expected to be close to the second layout with Level 2 automation presented above. The final design of the instrument is await within Spring 2021. Integration of the instrument and test in the laboratory are planned to occur right after, in order to get the IBIS2.0 first light in early 2022 at the latest.

IBIS2.0 will be used to acquire high cadence spectroscopic and spectropolarimetric images of the solar photosphere and chromosphere in coordination with other ground- and space-based instruments, while waiting for the observations with unmatched resolution by the European Solar Telescope (EST) and next generation solar telescopes. Indeed, among others focal plan instruments, EST<sup>5-7</sup> will include a narrow-band tunable-filter imaging system based on Fabry-Pérot interferometers, similarly to IBIS2.0.

Find updated information about IBIS2.0 at [www.ibis20.inaf.it](http://www.ibis20.inaf.it).

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## REFERENCES

- [1] Cavallini, F., "IBIS: A New Post-Focus Instrument for Solar Imaging Spectroscopy," **236**, 415–439 (July 2006).
- [2] Reardon, K. P. and Cavallini, F., "Characterization of Fabry-Perot interferometers and multi-etalon transmission profiles. The IBIS instrumental profile," **481**, 897–912 (Apr. 2008).
- [3] Righini, A., Cavallini, F., and Reardon, K. P., "Imaging performance of multi-etalon bidimensional spectrometers," **515**, A85 (June 2010).
- [4] Viavattene, G., Baldini, V., Ciraami, R., Coretti, I., Del Moro, D., Di Marcantonio, P., Giorgi, F., Giovannelli, L., Pedichini, F., and Piazzesi, R., "IBIS-04 System Design Description," INAF Technical Reports Rapporti Tecnici INAF 51 (2020).
- [5] Collados, M., Bettonvil, F., Cavaller, L., Ermolli, I., Gelly, B., Grivel-Gelly, C., Pérez, A., Socas-Navarro, H., Soltau, D., and Volkmer, R., "European Solar Telescope: project status," in [*Ground-based and Airborne Telescopes III*], Stepp, L. M., Gilmozzi, R., and Hall, H. J., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **7733**, 77330H (July 2010).
- [6] Schlichenmaier, R., Bellot Rubio, L. R., Collados, M., Erdelyi, R., Feller, A., Fletcher, L., Jurcak, J., Khomenko, E., Leenaarts, J., Matthews, S., Belluzzi, L., Carlsson, M., Dalmasse, K., Danilovic, S., Gömöry, P., Kuckein, C., Manso Sainz, R., Martinez Gonzalez, M., Mathioudakis, M., Ortiz, A., Riethmüller, T. L., Rouppe van der Voort, L., Simoes, P. J. A., Trujillo Bueno, J., Utz, D., and Zuccarello, F., "Science Requirement Document (SRD) for the European Solar Telescope (EST) (2nd edition, December 2019)," *arXiv e-prints*, arXiv:1912.08650 (Dec. 2019).
- [7] Quintero Noda, C., Collados, M., and EST Team, "The European Solar Telescope (EST): Recent developments," in [*Contributions to the XIV.0 Scientific Meeting (virtual) of the Spanish Astronomical Society*], 207 (July 2020).