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CORONAGRAPHY AT PIC DU MIDI: PRESENT STATE AND FUTURE PROJECTS

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Abstract. The Pic du Midi coronagraph (CLIMSO) is a group of four instruments in parallel, taking images of the whole solar photosphere and low corona. It provides series of 2048*2048 pixels images taken nominally at 1 minute time intervals, all year long, weather permitting. A team of $\simeq 60$ persons, by groups of 2 or 3 each week, operate the instruments. Their work is programmed in collaboration with Institut de Recherches en astrophysique et planétologie (IRAP) of Observatoire Midi Pyrénées (OMP), and with Programme National Soleil Terre (PNST).

The four instruments of CLIMSO (L1, C1, L2 and C2) collect images of the Sun as following: 1) L1 : photosphere in H-α (656.28 nm) ; 2) L2 : photosphere in Ca-II (393.37 nm) ; 3) C1 : prominences in H-α ; 4) C2 : prominences in He-I (1083.0 nm).

The data taken are stored in fits format images and mpeg films. They are available publicly on data bases such as BASS 2000 Meudon (`http://bass2000.obspm.fr/home.php?lang=en` and BASS2000 Tarbes (`http://bass2000.bagn.obs-mip.fr/base/sun/index.php`). Several solar studies are carried in relation with these data. In addition to the raw fits images, new images will soon be sent to the data bases: they will be calibrated in solar surface emittance, expressed in $W/m^2/nm/steradian$. Series of mpeg films for each day are presented in superposed color layers, so as to visualize the multispectral information better.

New instrumental developments are planned for the next years and already financed. They will use spectropolarimetry to measure the magnetic field and radial velocities in the photosphere and corona. The data will cover the entire solar disc and have a sample rate of one map per minute.

Keywords: Sun : corona, Techniques: polarimetric, Techniques: spectroscopic

1 Introduction

Coronagraphy started at Pic du Midi thanks to the invention by Bernard Lyot (Lyot 1930), and has continuously been developed since at that observatory. The Pic du midi site (alt 2875m) is well suited for high angular resolution and high dynamic range images, thanks to particularly clear and laminar air conditions, not all the time though: weather allows approximately 2000 hours per year of sunshine, i.e. 45%, based on charts by the French "Agence de l'Environnement et de la Maîtrise de l'Energie" (ADEME). From this clear sky percentage, a relatively large part is free from high altitude cirrus and usable for coronagraphy.

In order to cope with the increasing quality standards set by the space programs for solar observation, and to be complementary to them, the ground-based coronagraphy has evolved. Our most recent implementation of coronagraphy at Pic du Midi is a set of four instruments: CLIMSO, that consists of two 200 mm Lyot coronagraphs and two 90 mm narrowband solar telescopes. They are grouped in a standalone system held on a large equatorial table. This system has started operation in 2009, as an upgrade to the previous coronagraph (HACO) , and in complement to a still operational spectrocoronagraph on the same equatorial mount (MSCO)

This new set of instruments has been developed under the supervision of Jacques-Clair Noëns, with a particular organization regrouping two different groups of people : professional and amateur (although expert) astronomers. The differentiation here between 'professionals' and 'amateurs' holds to the fact that amateurs are not paid a salary for their contribution to Pic du Midi coronagraphs. However, these non-professionals are often working in closely related domains such as optics, computer science, high precision mechanics, and are passionate solar geeks. For example, on the non-professional side David Roumeuf (engineer at Lyon university)

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Fig. 1. The original Lyot coronagraph in the Baillaud dome at Pic du Midi. Picture taken ca. 1974.

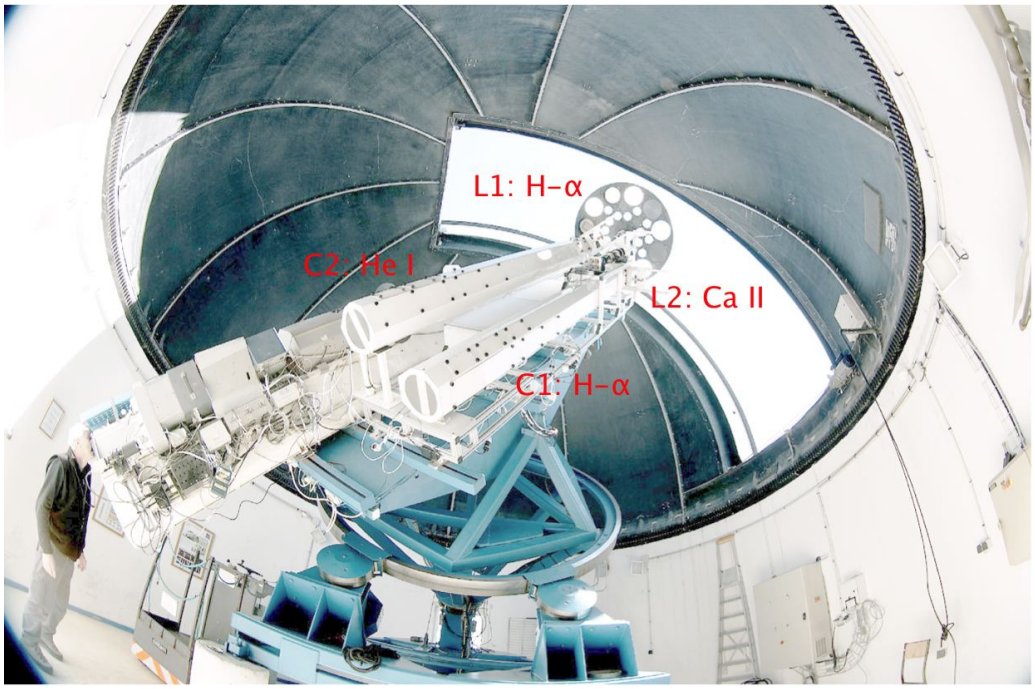

Fig. 2. The set of four instruments: CLIMSO. These two Lyot coronagraphs and two solar refractors at Pic du Midi are placed on the same equatorial table in a new dome built ca. 1999. The large instrument on the East side (left) of the equatorial table is MSCO, a spectro-coronagraph. The wheel with holes in front of CLIMSO is used for calibrations and pointing. Photo credit : OA

took in charge the overall conception and computer monitoring, Luc Dettwiller the optical design, Maurice Audejean the image processing. Many others "observateurs associés" (OA)contributed to decisive actions on the instrument, and contribute to the scientific publications.

The CLIMSO optics, computers and mechanics have been funded with large donations by Fiducial (a private

company), thanks to the action of Serge Rochain and the members of the OA non-profit organization directed presently by Franck Vaissiere.

On the "professional" side, Observatoire midi Pyrenees contributes to the project by defining the scientific program with the IRAP scientists and PNST, as well as the present data acquisition procedures and the future instrumental developments. Observatoire midi-Pyrenees is financing all the base equipment : equatorial mount, buildings and done, and pays the work of a significant number of people for their maintenance in this high altitude site.

In fact both groups are closely interacting as Observatoire Midi Pyrenees staff are involved also in the optics and mechanics, such as Raphaël Jimenez, or the image processing and data base management, such as Martine Lafon. Several science studies are carried presently using these data, see (Romeuf et al., 2007). My role as a newcomer in this field is to continue the work of astronomer J.C.Noëns: link the OA and the scientific community, contribute to the the elaboration of new science programs and instrumental developments.

The coronagraphs are also contributing the the outreach of astronomical research at Pic du Midi, as 20 to 100 persons visit the instrument each day, and hear detailed explanations on the solar studies undergone. High level education is also concerned, as groups of Master-2 students from Université Paul Sabatier in Toulouse (14 in 2011 and 15 in 2012) trained for 5 days internships at Pic du Midi. Their work includes acquisition, processing and scientific use of the coronagraphs' images.

In this paper I describe the recent developments of the instruments, their operation, the type of solar data sent to databases, the ways to retrieve them, and the planned developments in instrumentation for the next three years.

2 Design

2.1 Optics

The two photosphere telescopes are 90 mm commercial "Coronado" refractors equipped with narrowband H-α (656.28 nm) and CA-II (393.37 nm) filters respectively placed before the objective lens. The non-uniform transmission of the Coronado H-α filter across the field causes image degradations, but they can be corrected to a large extend by using the 5 flat fields taken every day. The Ca-II filter has a more uniform transmission.

The two coronagraphs are 200 mm custom designed refractors, equipped with conventional Lyot optics (i.e. adjusted field mask and pupil mask) and narrowband H-α and He-I filters respectively, placed in a parallel beam downstream.

2.2 Mechanical interface

In order to keep parallel the optical axes of both coronagraphs to a high precision, one of them has two additional degrees of freedom in rotation, and a computer controlled adjustment. Due to mechanical flexions and dilatations, this adjustment needs to be made periodically during the day, every 5 minutes on average. This adjustment is performed manually at present. The focusses of the four instruments are adjusted by remote control. They stay within good tolerances for several weeks without requiring action.

3 Operation

The instrument is operated by "Observateurs Associés": a nonprofit organization regrouping approximately 60 active members, who take turns for one or two weeks per year by groups of two. The deal is the following : non-professional astronomers are offered one week of comfortable accommodation at the Pic du Midi site, in exchange of qualified work for data acquisition. The candidates are trained for one or two weeks before being eligible to operate the instruments by themselves, and a senior member of the association is reachable (if not present) when necessary to solve technical problems that may arise.

In a coronagraph, the Lyot mask must exactly cover the photosphere, thus constraints in position and radius are strict. The set of field masks used to cover the photosphere has 0.05 mm steps, which correspond to 4 arc second increments being given the 2.478 and 2.511 m focal lengths of the H-α and Ca-II coronagraphs, respectively. These masks are changed every ten days on average (8 to 20), in order to match the variable angular diameter of the Sun, due to the ellipticity of Earth's orbit.

During the acquisition, from one hour after sunrise to one hour before sunset, weather allowing, an image every minute is taken at the four instruments. If the sky is not clear enough for the operation of coronagraphs, only the two photosphere images are stored.

The equatorial mount used at present is still the one used previously to support the original Bernard Lyot coronagraph. It's drive is precise to a few arc minutes per hour, and manual guiding is the only solution to achieving the arc second precision required. Depending on the operators skills and on the seeing conditions (atmospheric tip-tilt), this precision is reached, or not. It is one limit now for image quality, and it concerns a fraction of the images sent to the databases. This will be improved in the next future by two actions : an automatic guiding system to be ready by the end of 2012 and a sieving of images before sending them to the databases, as it is already the case for the images that are selected to make the mpeg "films of the day".These films are sent onto the BASS2000 databases daily and one of them (with extension CL12) regroups the H-α corona with a composite RGB image of the photosphere in Ca-II (green channel) and H-α (red channel).

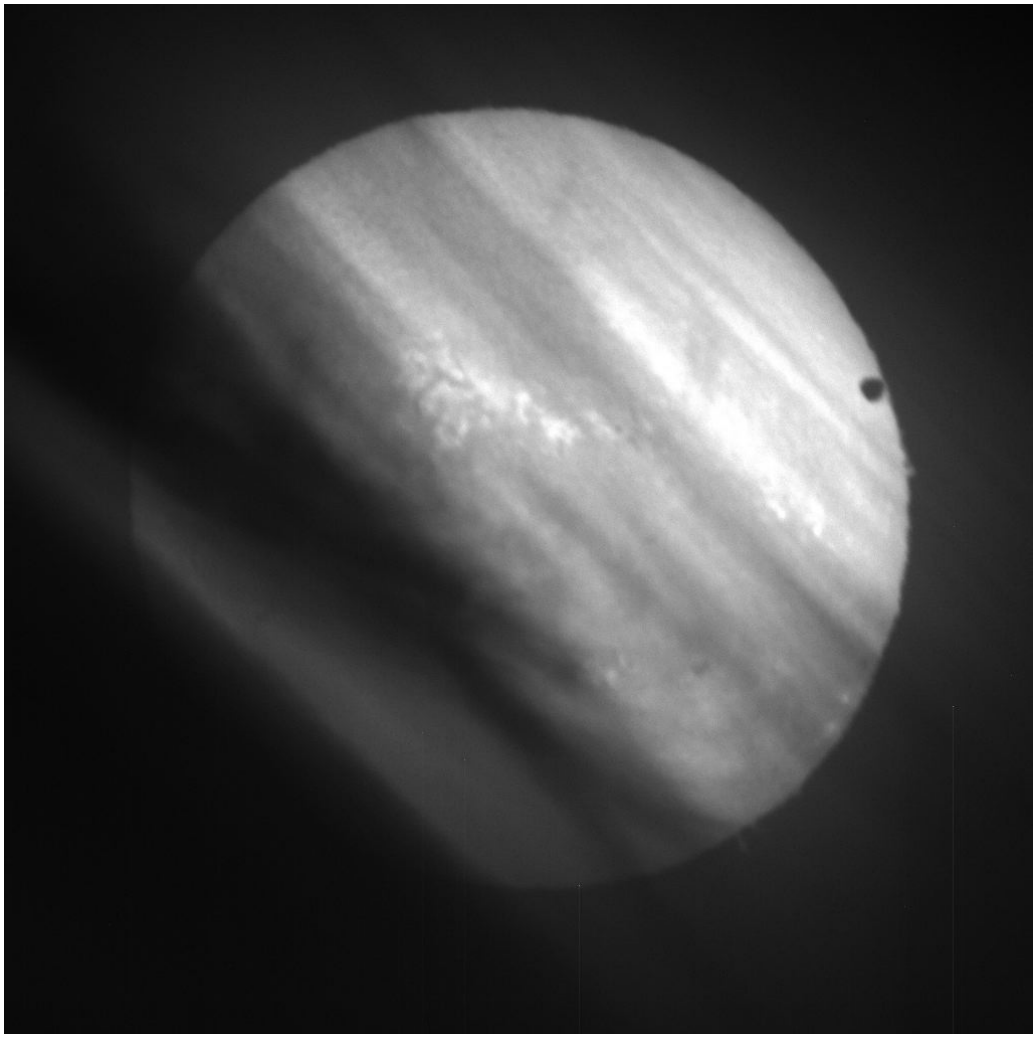

Fig. 3. Venus transit taken at Pic du Midi by the H-α telescope L1, 2012 06 06 at 04:38:28 TU. Cirrus clouds and atmospheric refraction in addition to seeing, did not allow to use the coronagraphs that morning. Photo credit : Z.Challita and P.Muller

Flat fields, darks, biasses and calibrations are taken each day in the morning. All images are stored in fits format, direct from camera reading. At present it is up to the data-base user to calibrate and reorient the images downloaded, using the references associated: series of five darks, five biasses, five flats, and two calibrations made with a relative East-West displacement, to retrieve photometry and precise field orientation. In the near future, the image orientations in the databases will be already corrected from instrumental camera disorientation.

Fig. 4. Combined image of the solar disc and prominences in H-α taken at Pic du Midi by the L1 refractor and C1 coronagraph. Additional images are available in combined colors, from L1, L2 and C1. One can notice that the the photosphere appears brighter in the lower part of the field, due to non uniform transmission (in space and in time) of the Coronado H-α filter, despite the flat fielding applied from calibrations made the same morning.

The calibrations may also be used to intercalibrate the H-α coronagraph with the H-α photosphere telescope, as the images are taken quasi-simultaneously and at the same wavelength. Knowing the solar constant for that date (which is given by satellite data and varies slowly) one can divide out the contribution of the atmosphere and instrumental transmission from the data. Although this can be computed independently since calibrations are provided, we will upload in the next few months the emittance maps computed for each image, expressed per pixel in $W/m^2/nm/steradian$ at the surface of the Sun.

4 Future improvements

For the next three years we prepare two new instruments : a larger 150 mm H-α photosphere telescope, with several narrowband channels across the H-α line, providing radial velocities, and furthermore, polarimetric data with four Stokes parameters. We aim to provide magnetic field data. The associated filters should be developed jointly by Arturo Lòpez Ariste, from Teneriffe observatory, and Silvano Fineschi, from Torino Astrophysical Observatory, in collaboration with IRAP and the OA. Once the solar telescope is tested, a new coronagraph with equal or higher spectropolarimetric performances will be built, exploring the corona in a Fe XIII line.

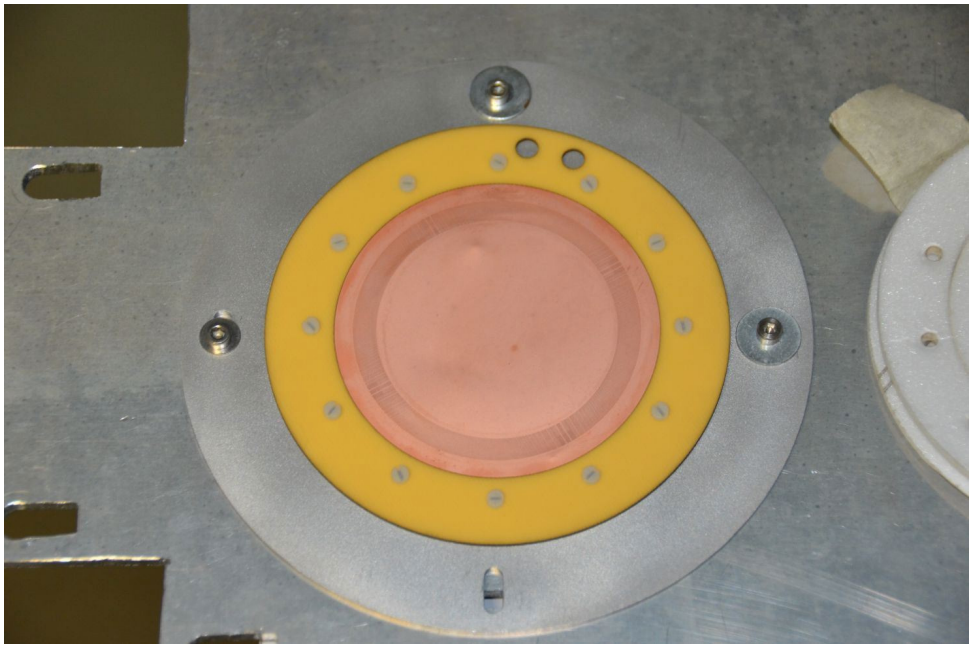

Fig. 5. The diffractive optics objective of the future autoguiding system. It is a 62 mm diameter Fresnel array carved into a thin copper foil with a large central obturation to block the order 0 of diffraction, leaving a 2.6 m focal length for the order 1 image. No chromatic correction will be necessary, as a 0.1 nm bandwidth filter is used, centered at 632.8 nm.

5 Data bases and scientific use of the data

The images taken in three spectral channels by the four instruments are sent to data bases BASS 2000 Meudon and BASS2000 Tarbes, also visible from NASA databases. The data are publicly available immediately, free of charge and with no embargo period. They can be downloaded from `http://bass2000.obspm.fr/home.php?lang=en` and `http://bass2000.bagn.obs-mip.fr/base/sun/index.php`.

The images are 2048x2048 pixels, in fits format. They are currently available as soon as they have been sent from the acquisition computer to the data base, i.e. usually the night after observation. The total amount of data per year grew from 287 Gb in 2007 to 825 Gb in 2011, and should reach 1 Tb for the year 2012. A few additional images per day are sent in quasi real-time onto `http://bass2000.obspm.fr/home.php?lang=en`.In addition to the solar studies that are under way at Observatoire Midi Pyrenees use these data (e.g. Roudier 2012), although we are not necessarily aware of all the use made of these images, we would appreciate some return information regarding their use, by mail and/or by citation in the published papers for which these data have been useful.

6 Conclusion

We presently provide images complementary to space data and to other ground based instruments. In order to improve them, we would appreciate any remark or comment that may help us improve them.

This scientific instrument and its operation are funded respectively by the Fiducial company and by French government funds through Université Paul Sabatier and Centre National de la Recherche Scientifique. A vital contribution is also the highly qualified work-power offered by the $\simeq$ 60 “Observateurs Associés” who run the instrument for image acquisition 7 days a week, almost all year long.

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