Control and protection of outdoor embedded camera for astronomy.

F. Rigaud*[a], I. Jegouzo[a], J. Gaudemard[a], J. Vaubaillon[b]
[a] GEPI (Galaxie Etoiles Planètes Instrumentation), Observatoire de Paris,
CNRS, Université Paris Diderot,
5 place J. Janssen, 92195 Meudon, France
[b] IMCCE (Institut de Mécanique Céleste et de Calcul des Ephémérides),
Observatoire de Paris, CNRS,
77, Av. Denfert Rochereau 75014 Paris, France

ABSTRACT

The purpose of CABERNET- Podet-Met (CAmera BEtter Resolution NETwork, Pole sur la Dynamique de l'Environnement Terrestre – Meteor) project is the automated observation, by triangulation with three cameras, of meteor showers to perform a calculation of meteoroids trajectory and velocity. The scientific goal is to search the parent body, comet or asteroid, for each observed meteor.

To install outdoor cameras in order to perform astronomy measurements for several years with high reliability requires a very specific design for the box. For these cameras, this contribution shows how we fulfilled the various functions of their boxes, such as cooling of the CCD, heating to melt snow and ice, the protecting against moisture, lightning and Solar light. We present the principal and secondary functions, the product breakdown structure, the technical solutions evaluation grid of criteria, the adopted technology products and their implementation in multifunction subsets for miniaturization purpose. To manage this project, we aim to get the lowest manpower and development time for every part. In appendix, we present the measurements the image quality evolution during the CCD cooling, and some pictures of the prototype.

Keywords: embedded, control command, camera, outdoor, meteor.

1. INTRODUCTION:

After more than 10 years of conducting simulations for the forecasting of the meteors showers, we have decided to start a new program dedicated to continuous observation of meteors. The scientific goal is to measure accurate orbits of meteors to determine their origin. The technical goal is to install three outdoor cameras with a maximum operational availability.

Figure 1: meteor showers.© Jérémie Vaubaillon

* Francois.Rigaud@obspm.fr, phone 33 1 45 07 76 44, http://wwwgepi.obspm.fr

2. INSTRUMENT CONCEPT AND DESIGN:

The trajectory measure of the meteors will be performed with three cameras located on the ground, distant of 100 km and observing the same portion of the atmosphere. Moreover, in order to determine the origin of a meteoroid, a very accurate measure of the velocity is required, since it strongly constrains the semi major axes of its orbit.

The detector and the optics, the elements of the choice:

In order to get a highly accurate trajectory, the detector and associated optics have to provide a high space resolution. Because the trajectory is measured thanks to a weighted photometry (center of gravity), the accuracy will also depend on the number of bits per pixel.

In order to observe as many objects as possible, the field of view has to be wide.

A high space resolution combined with a wide field of view implies a huge number of pixels for the detector. However, today's performances of CCDs, electronics and data link imply a long read time and by such, a low number of frames per second. The solution founded is to add an electronic shutter, combined with a long exposure time (one second). This allows us to measure many points along the trajectory of the meteor. In order to control the speed accuracy, this shutter is electronic and is piloted by a Quartz. The details on camera are described in Atreya et al. (2012) [1].

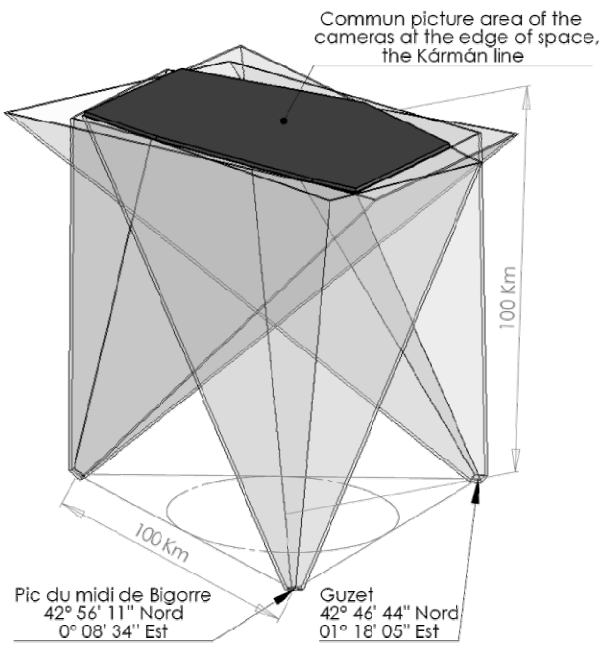

Figure 2 : concept

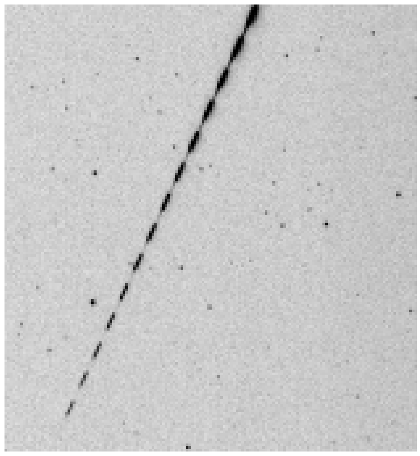

Figure 3: trajectory of a meteor.

Shutter to 50% period 20 ms

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3. INSTALLATION SITES:

The three cameras (called “Cabernet” for camera for better resolution network) will be ground-based. The distance between the cameras is 100 km, and they are set up to observe the same portion of atmosphere at 100 km of altitude.

The elements guiding our choice for the installation sites are:

-a low light pollution caused by large cities,

-the connection to the electrical and Internet networks

-the installation of the prototype will require numerous human interventions. The presence of a technical staff will greatly help during this test phase.

-a good weather statistics.

The optimal choice is hard. The French Pyrenean Mountains, in particular around the Pic-du-midi observatory fits the criteria. The observatory staff is used to manipulate and install astronomical observation device so this site will be used to develop the prototype. The two other installation sites will be managed by local administrations.

4. CAMERA INTERFACE:

One camera set includes three major interfaces, a source of energy, a communication device to transmit the images, a fixation point as well as the light coming from the spotted sky.

The outdoor use of the camera needs to take into account the contradiction between a variable weather environment and the stability needed to get the desired metrology accuracy.

4.1 Outdoor environment:

Weather conditions:

an outdoor camera observing the sky is subject to the wind, the rain, the snow, hail storms, the sunlight as well as huge temperature variations caused by the seasons and the night and day alternation. Exceptionally, lightning can fall in the vicinity of the camera and destroy it because of induced high voltages. Moreover birds can use the box as a perch and smear the window.

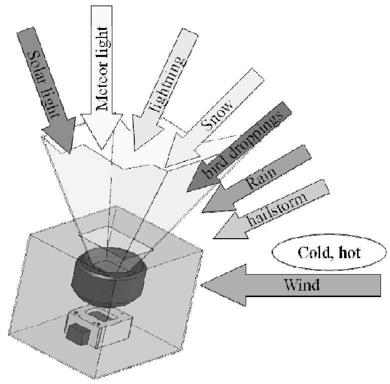


Figure 4: Schematic representation of outdoor environment.

Climatic conditions:	Requirement	Remarks
Outdoor temperature Range	-20 to 40°C	
Maximum wind speed for operation	100 Km/h	Increase number of meteor observations
Humidity, cloud and rain	Protect.	
Direct solar light may burn the detector	Protect.	
The ice and snow on the windows	Automatic melt	Increase number of meteor observations
A camera would be installed at the "pic du midi" observatory, lightning regularly strikes the Lightning rod, near the camera	Protect	
Occasionally, hailstorm or bird droppings can falling on the windows	Day protect	

4.2 Technical constraints and installation conditions:

Dimensions:

The specifications regarding the observation (high wind near the floor, producing vibrations because of turbulences, to melt the snow and the ice) let us to design a small dimension camera with a small CX. Moreover, because the camera will be installed on the wall of a public building, a small box is less inclined to have a negative effect on the overall look of the architecture, and is less likely to attract badly intentioned people.

Detector signal over noise ratio:

In order to observe dim meteors, the signal to noise ratio has to be the best as possible and as a consequence, the detector will be cooled down.

Distance between the camera and the connection point:

The amount of data from the detector is huge. The upload network connection speed is limited by ADSL, that is 256 kB per second (French standard). A software running on a computer will be in charge of selecting those images showing a meteor and to transfer them to the lab in Paris, where the trajectory and velocity will be computed independently. This connection point will provide the energy required by the camera. It will be located inside a building for protection purposes. The maximum distance between this connecting point and the camera is 50 m.

Fixation interface:

It would be better to install the camera at a height greater than 2 meters above the ground. So badly intended people or animals will not smear the windows by touching it by curiosity. Because of the numerous constraints for the selection of the installation sites, it is mandatory that the camera mounts are flexible enough so that they have to be adapting to the location. As a consequence, it will be possible to mount the camera in many different ways, horizontally or vertically.

5. COMPONENT SPECIFICATIONS:

5.1 System components:

Image acquisition chain:

The image acquisition device includes a CCD camera equipped with its proximity electronics module, as well as a wide angle optic lens. LHeritier CCD cameras equipped with a Kodak KAI11002 detector allowed to take 4008x2676x14 bits images. A test on the modification of the camera electronics (FPGA) allows us to get an electronic shutter. The camera link cable is limited to 20 m. With a camera Link to Ethernet adapter (IPort Pleora), we can connect the camera up to 50 m.

Detector cooling system:

The detector is cooled down by use of Peltier modules. The whole electromechanical set linked to the embedded detector is cooled down.

Protection against the sunlight:

The sunlight could be focused on the detector by the camera lens. This would irremediably damage the detector. A screen, closed day allow us to mask the light. It automatically shuts down in case of power failure or if the ambient light is too bright.

Protections against the weather and humidity.

The whole set is protected by a protection box. This box isolates everything from the weather and the humidity. It still allowing some interfaces such as the night sky observed by the camera, the computer connections to transfer the images and the control of several accessories, the power and the dissipation of the heat generated by the inside component.

5.2 Technologically constrained components:

Thermal isolation of the detector:

A thermal isolation box equipped with a window will embed the detector set in order to limit the cooling power. The Peltier are fixed on the wall, since they have a hot and cool surface. Because of water condensation always happens on the coolest zones, the camera is embedded in a waterproof box including drying material (Molecular Sieve).

The box window:

The box window allows us to isolate the inside of the whole set from outside humidity. In order to melt the snow during the winter, heating resistance is as well as temperature sensors are installed on the periphery. The window temperature is always greater than the ambient temperature thanks to the heating components inside the box. As a consequence, the dew will quickly dissipate. The window is built in optical quality glass (BK 7, lambda / 10), with anti-blooming coating. It is a thick enough to resist hail.

The window screen:

When the camera is not working, a motorized window screen protects the window against the dust, insect, bird dirt etc. Because it is located outside the box, and as a consequence can be blocked by the ice, it cannot efficiently protect again the sunlight.

Fixation and pointing support:

The fixation and pointing support allows us to orient the camera along three axes and to install the whole set it whatever its orientation (wall, terrace, and roof). The orientation of the camera has allowed us to optimize the atmospheric area covered by the three cameras, even the rectangle field of view. This support is rigid enough so that the camera stays stable even by high-speed wind (100 km/h).

Heat evacuation:

The camera and its communication interface, the thermal electric Peltier effect, as well as the screens all generate heat. The hotter the whole set, the more heat the box will transfer. The dissipation of the power has to be as efficient as possible. A finned heat sink associated to a fan keeps the inside temperature as low as possible. An electronic circuit stops the fan if the temperature is less than 4° C in order to limit the power needed to melt the ice on the observation window.

Protection against electric fields generated by the lightning:

The Pic du midi observatory is located in the mountains of southern France. It is especially exposed to lightning and the camera will be installed a few meters from the lightning shelter lines. The link between the camera and a connection point is shielded, and all that metallic masses are connected. High tension protection component are located on each side of the cables (diode TVS and varistance).

Control and command electronics:

All the electromechanical or thermal devices are controlled or piloted by an electronic card. A communication between this card and the computer allows to remotely knowing the state of the camera. Because the length connection is 50 m, and it is necessary to read sensor, actuators state and failures of the prototype, the electronic card includes a software on a microcontroller, connected by Ethernet.

5.3 Typical specification of any component:

Any component of the whole embedded set has multiple specifications. The ideal component in this context has to be small in size, it should not make any heat or electrical parasite and has to be particularly reliable. Moreover in case of failure, an embedded component should not destroy or perturb the other ones. In the framework of the development of the cameras, the components are rather cheap and require little work. The criterion grid has been established:

Smallest	Power	Parasite interference	reliable	Fault propagation	Cost	Work

6. SUBSETS:

6.1 The camera, the cooling of the detector:

Figure 5:camera inside is box

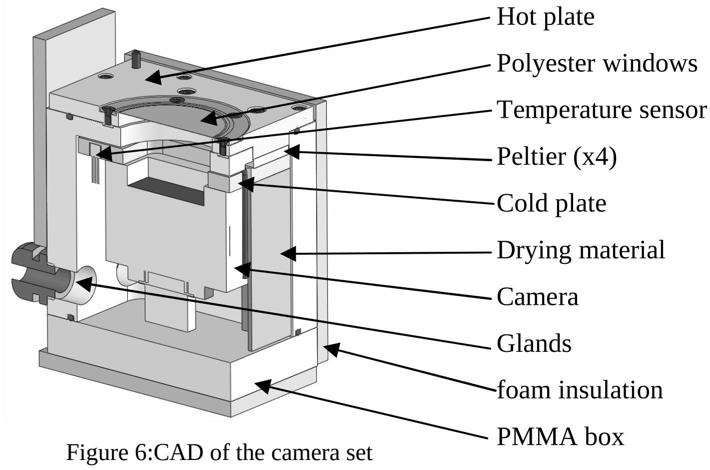


Figure 6:CAD of the camera set

Thermal performances:

The camera generates 4 W. The four thermoelectric modules (Peltier) generates 57 W. The thermal power assessment is: $P_{cooling} = P_{camera} + P_{isolation}$. Where $P_{cooling}$ is the thermal power, P_{camera} is the camera power and $P_{isolation}$ is the power transmit through the isolating box. Radiative exchanges are neglected.

The temperature inside the box is established by: $(T_{ambient} - T_{cold\ plate}) = P_{isolation} / R_{thermal\ box.}$ Where $R_{thermal\ box}$ is the box thermal resistance (in W/K), $T_{ambient}$ is the ambient temperature, and $T_{cold\ plate}$ is the overture of the cool plate on which the camera is mounted.

Thermally conducting materials are employed in each interface. Thermal grease is inserted between the hot plate and the dissipating box and on each plate of the thermal and electrical module. An Indium wire increases the heat transfer between the cooled plate and the camera. The difference of temperature between the outside box and the cool plate is 21°C (measured values).

6.2 The sunlight protection shutter, mechanics and captors:

The sunlight could burn the detector. The whole shutter masks the daylights. This component is rigorously tested. The software connected to a sensor verifies if it is well shut. An e-mail is sent if the shutter doesn't close.

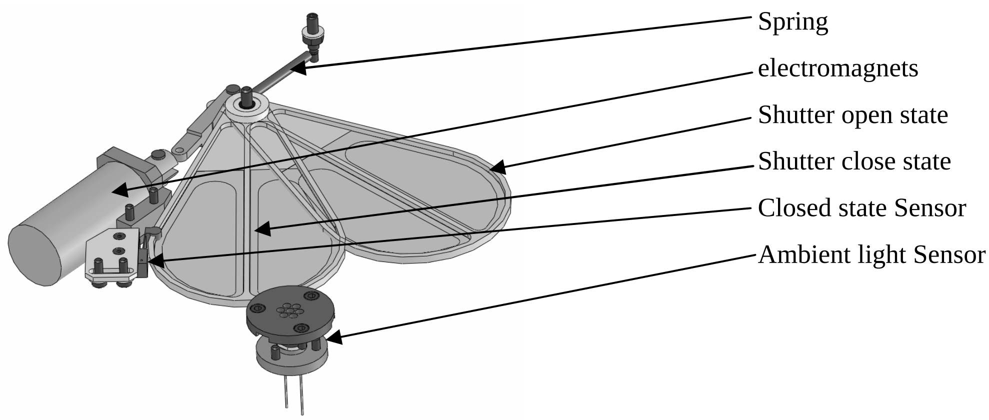


Figure 7: CAD see of Shutter

The shutter works in any orientation of the whole box. In order to limit the electromagnet power (3 Newtons in open position) the screen is highly enlightened and the electric circuits (described further down) boost the starting force to 12 Newton's a few milliseconds. The electromagnet dissipates 10 W in continuous regime.

The light sensors make hardware close of the shutter in case of software failure. (Mistake of set up the time of the software, bog). This security redundancy guarantees a tolerance to failure.

6.3 The window protection screen:

The window screen limits the frequency of cleaning the window. It protects from insects and bird dirt during the day. Because it is outside the box located, it can be temporally locked by the ice during low temperature time.

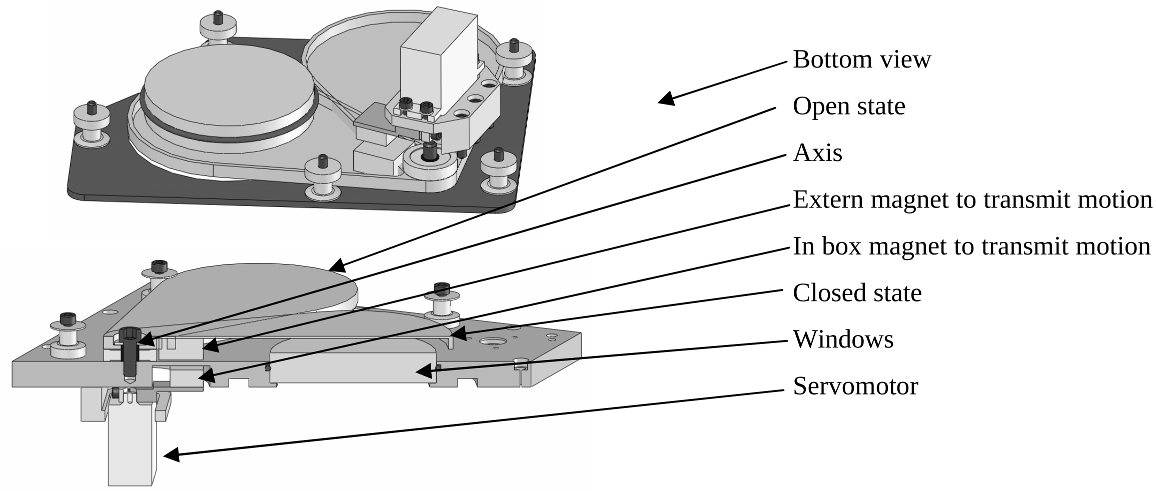
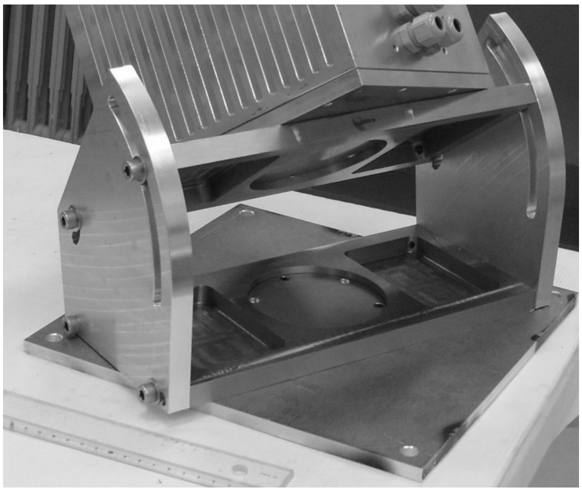


Figure 8: CAD sees of windows protection screen.

The motion of the servomotor is transmitted by magnets through the lid. A motion joint going through the lead could cause sealing failure.

6.4 The pointing device:

The pointing device orients the camera along three axes. It is rigid enough to enable observations even by high-speed winds.



Picture of the pointing device.

6.5 The cooling set:

The power dissipated by the inside component is 90 W. The outermost box is made of aluminum massif and dissipates the calories. Moreover, in order to ensure that the detector temperature is as low as possible (see section 6.1), the box has to be as cool as possible.

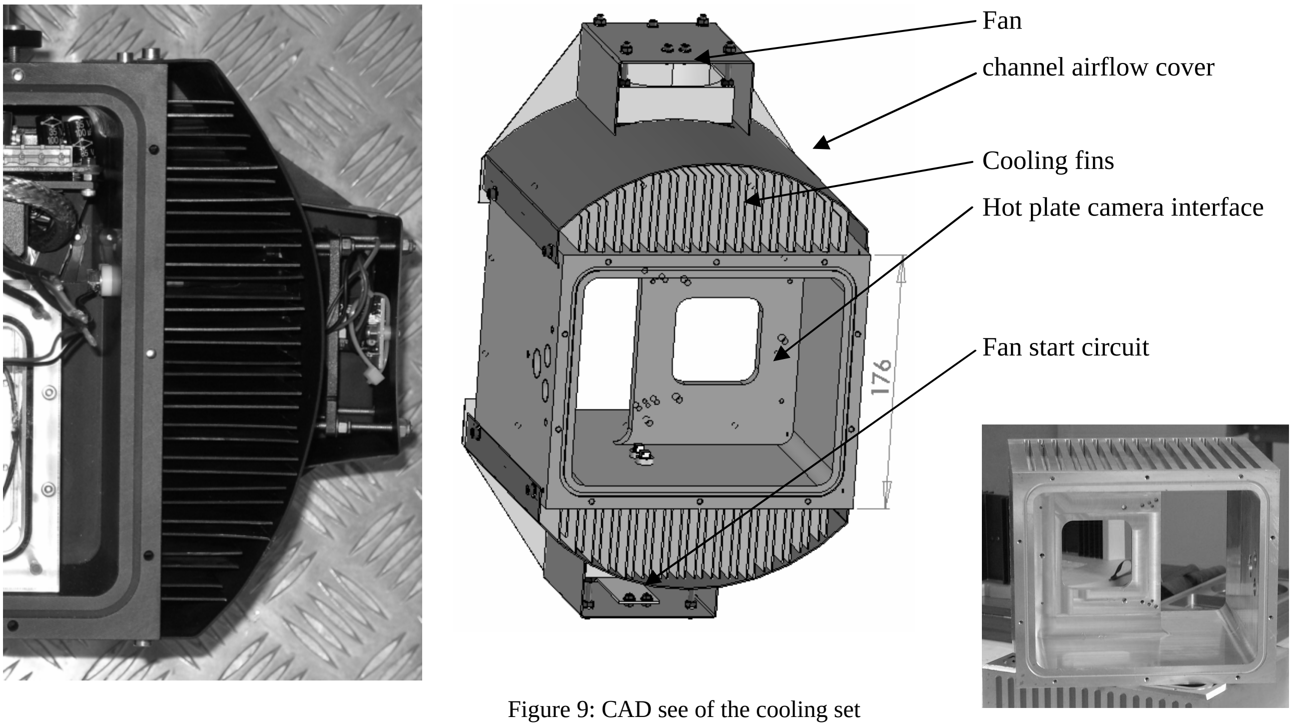


Figure 9: CAD see of the cooling set
(unit : mm)

The 64 cooling fins have a total surface of 2m². The fans airflow outputs are 2 x 40 ft.³ per minutes. Preliminary tests show that the inside and outside temperature differs by 5°C. The fan start circuit turns on if the ambient temperature is higher than 4°C.

The command card:

The command card turns on / off or regulates each electrical component, acquires binary or analogical sensor signal and survey fuses, thanks to its embarked software. Except for the microcontroller (MBED, NXP 1768), the employed technology are simple and robust, due to a careful choice of actuators and sensors.

<u>Power circuits:</u>

Power circuits empower or pilot the component at low frequency (0.5 Hz max). In order to limit parasites, On/off commands are soft starts and soft stop to limit current variation.

For no polarized or without mass connected components (such as Thermo electrical modules, heat resistance, shutter electromagnet) the gate command of the Mosfet is transmit through a high resistance (RC filter).

The components polarized and mass connected to the power mass by the shield (such as the camera and the camera Link network interface) are controlled by the positive power plug.

In those two circuits, the Mosfet gate capacity associated to the resistance (1 M.Ohms) constitute a low pass filter. It is not accurate but this is enough to make progressive transitions (5 ms) of current. The resistance is located as close to the transistor in order to limit the antenna effect of the track.

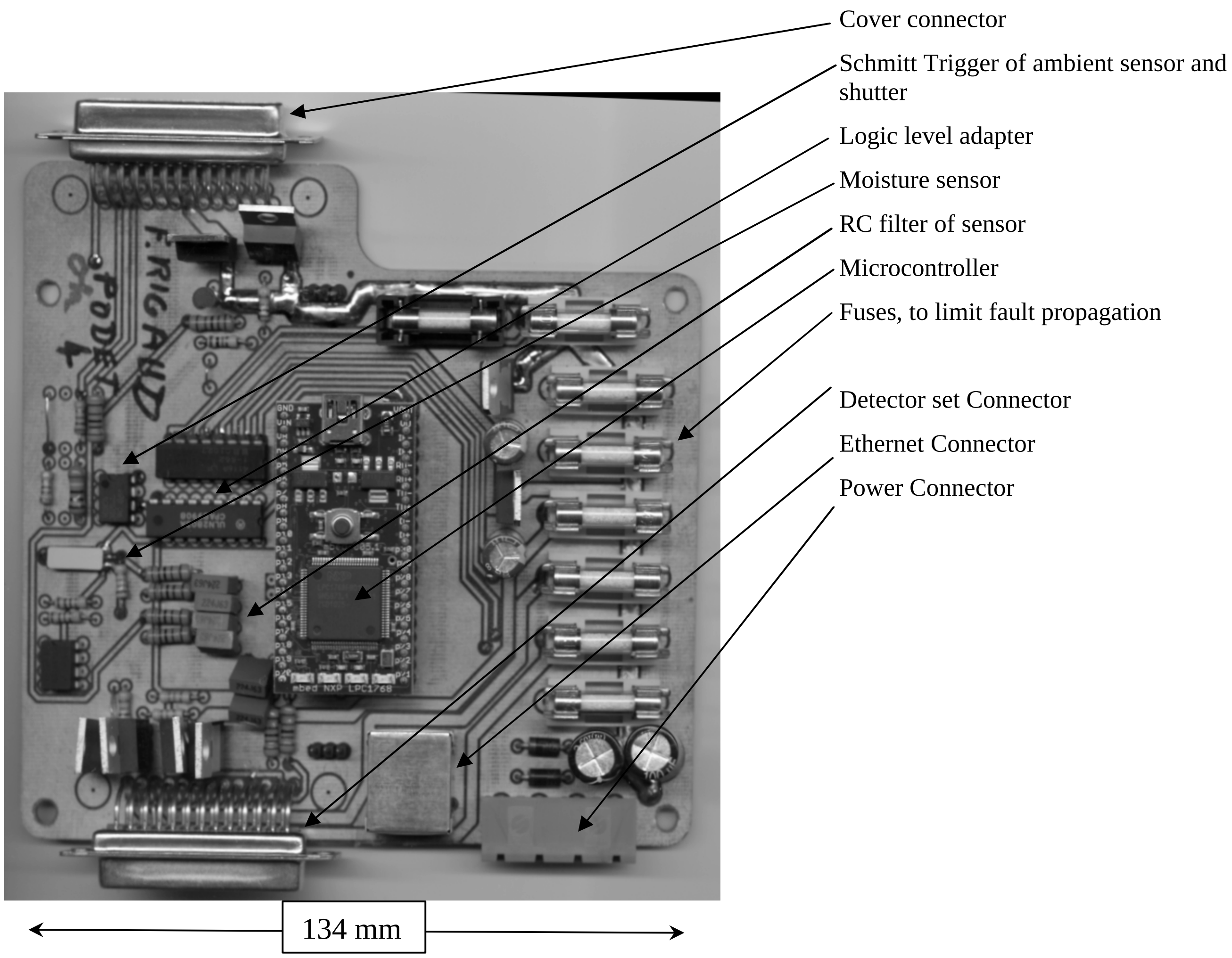


Figure 10:Picture of electronic card

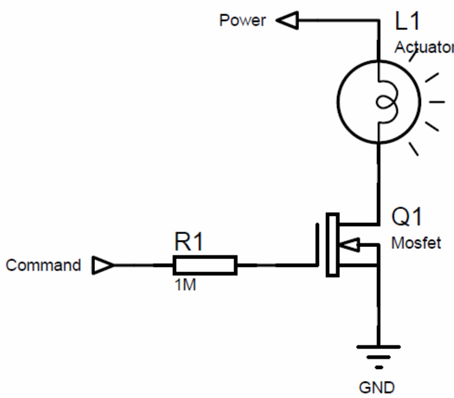


Figure 11: Power Command, no polarized actuator

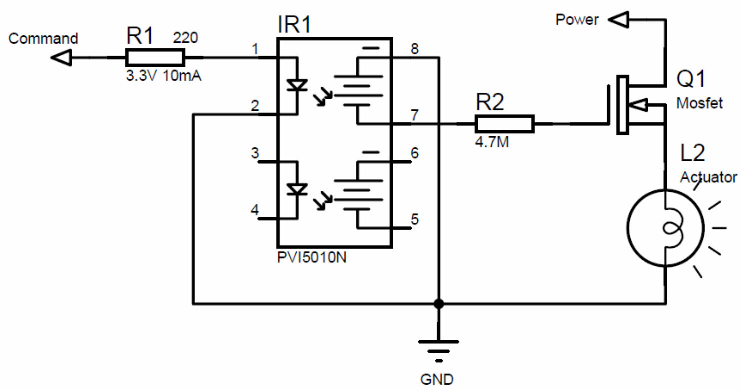


Figure 12: Power command , polarized components

The shutter power and command are peculiar. A charge pump stores three time the nominal voltages in a capacitor. At the opening, this tension boosts temporarily the electromagnet force.

The opening command is piloted by the software. Software or Schmitt trigger controlled by an excessive ambient light can independently close the Shutter.

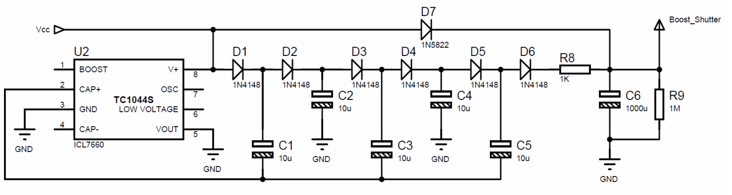


Figure 13: Charge Pomp, 12 to 41Volts, boost power shutter to short time

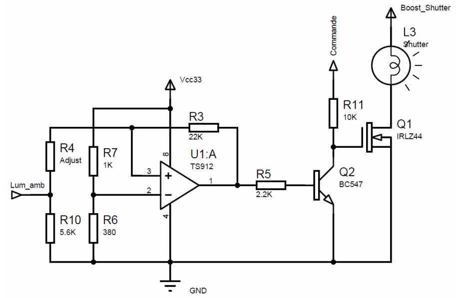
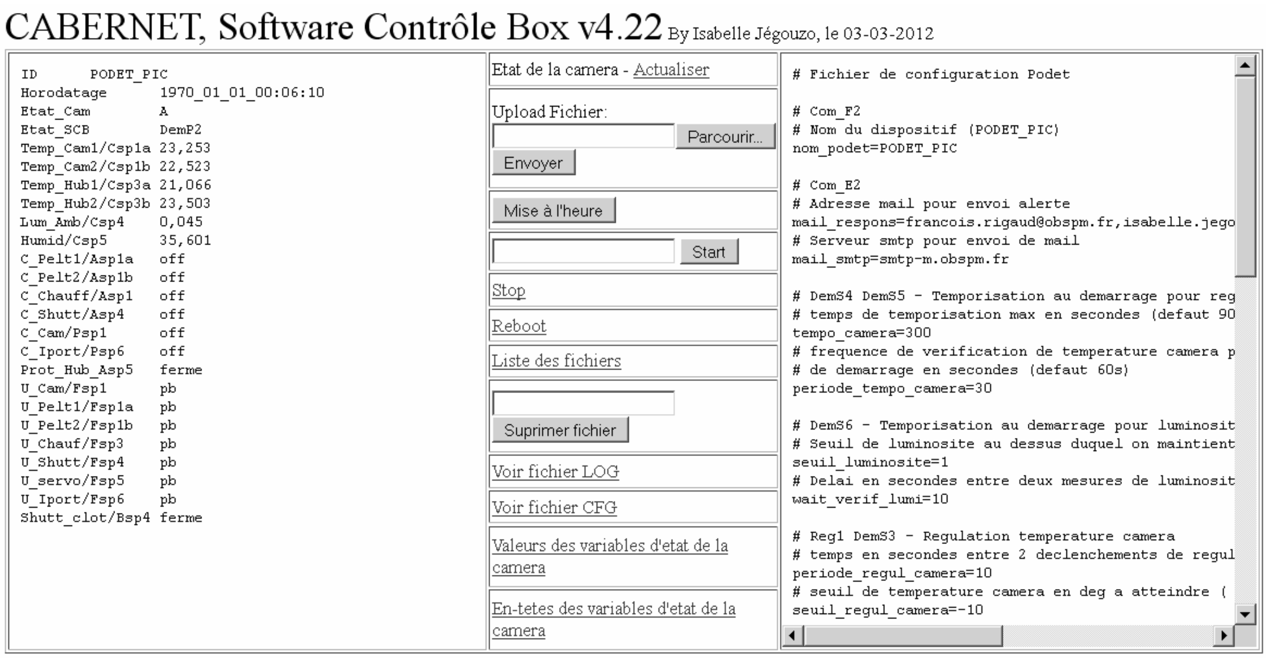


Figure 14: Schmitt Trigger connected to ambient light sensor.

6.6 The Software Control Box (SCB):

The software control box does the following: it regulates the camera temperature, it heats the window if its temperature is lower than 2°C, and it surveys the temperature sensors, the shutter position sensor and the humidity sensor, the power state in stands e-mail alerts in case of malfunction or failure. The communication interface is Ethernet-based and the embedded web server responds to requests with the HTTP protocol.



Manual control of the camera by standard sofwtware (firefox).

An autonomous script gets the camera state and transmits it to the acquisition and data storage software. All their parameters, time and states are included in the fits image file.

The software platform is an MBED circuit with an ARM7 Cortex (32-bits, 96 MHz) microcontroller, chosen for its simplicity of implementation and programming (C++) as well as the available software libraries.

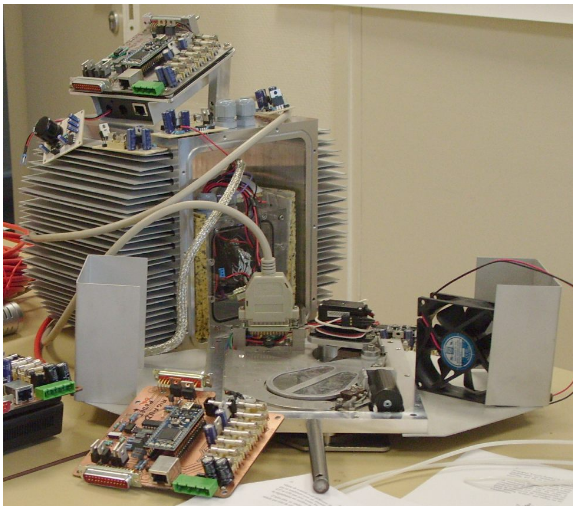
Moreover, its memory and execution speed are oversized compare to the need of a camera accessory control functions. We ensure that we would keep up this platform to the end of the project.

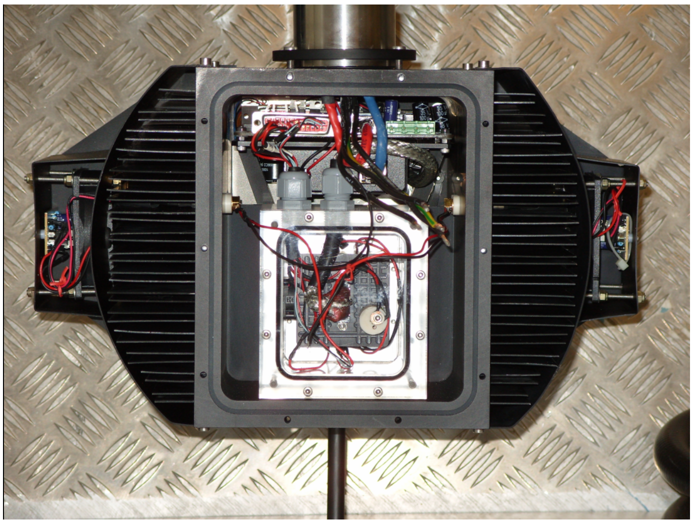
CABERNET CAMERA PICTURES:

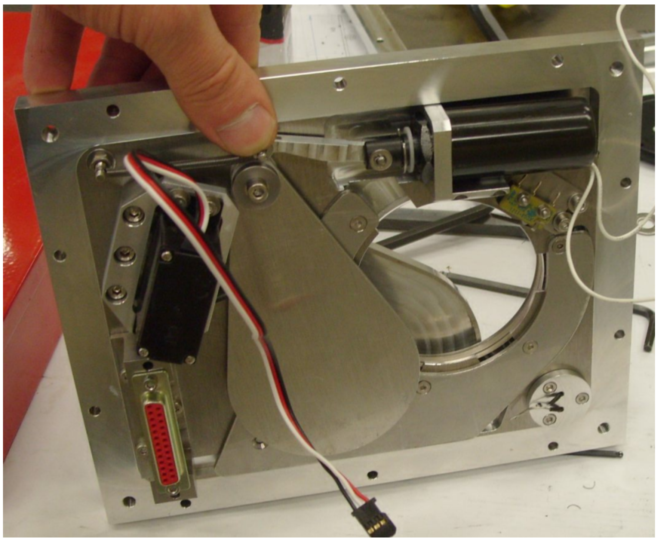
l'Observatoire de Paris | GEPI
Galaxies Étoiles Physique et Instrumentation

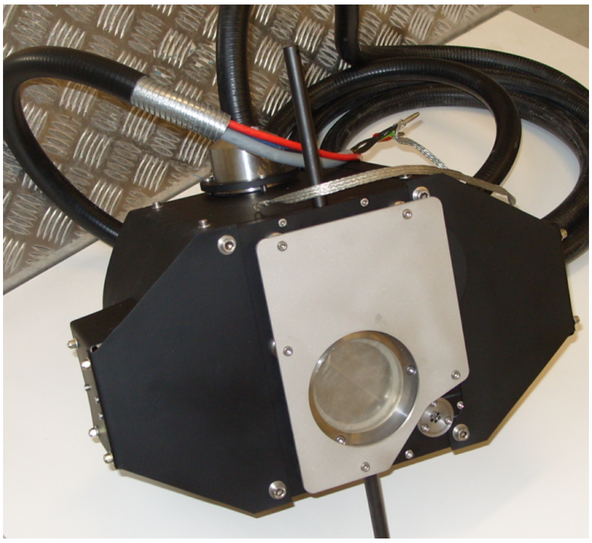
CNRS advancing the frontiers

l'Observatoire de Paris | IMCCE
Institut de Mécanique Céleste et de Calcul des Éphémérides









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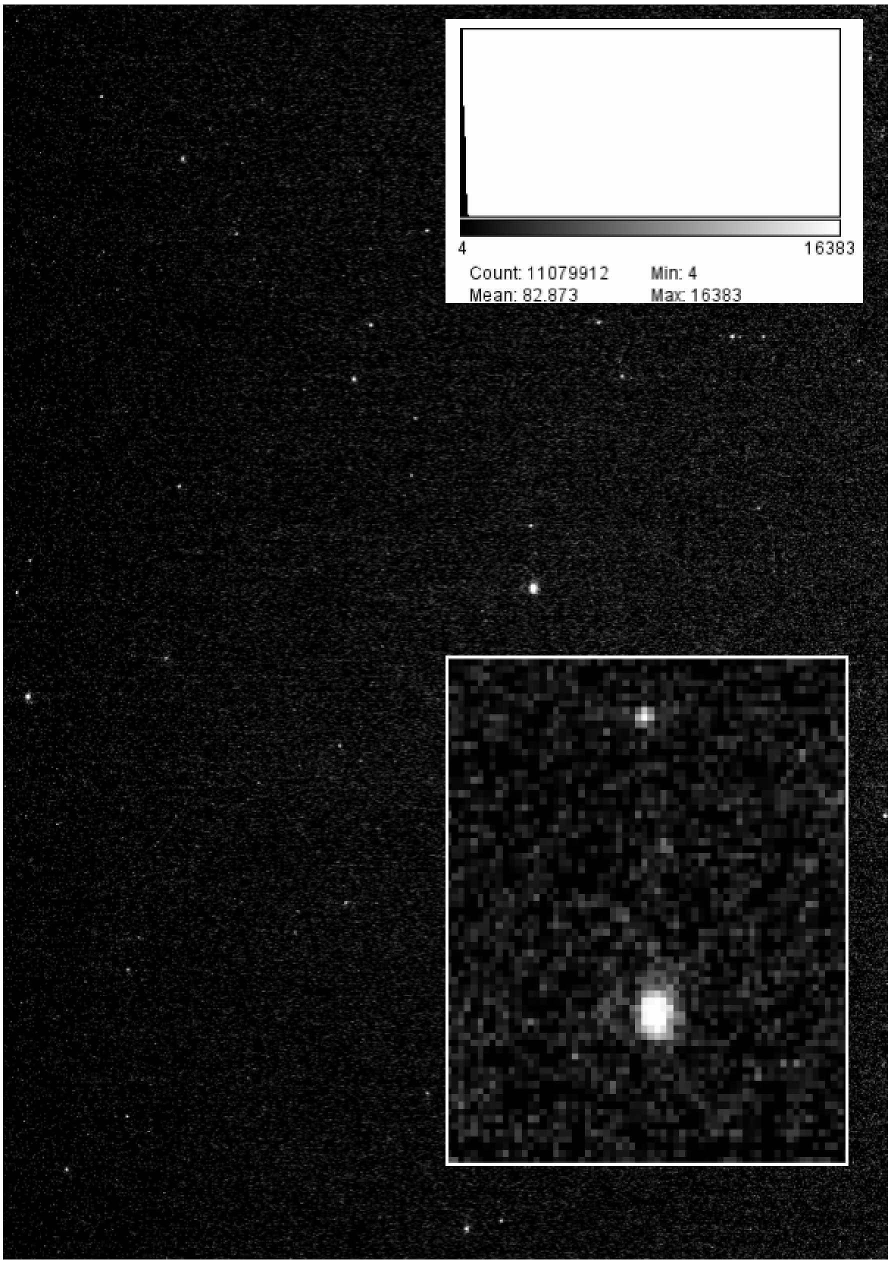
CONCLUSION:

In early June 2012, a CABERNET camera was installed at the Pic-du-midi observatory. The optical, mechanical, electronic and software system behaved as planned. Here is one of the 85,000 images taken within the two days following the installation:



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