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Fifty years ago, the foundation of “Saint Véran – Paul Felenbok” astronomical observatory (1974)

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13 September 2024

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ABSTRACT

This paper is dedicated to the memory of Dr Paul Felenbok (1936-2020) who was astronomer at Paris-Meudon observatory, and founded in 1974 a high altitude station (2930 m), above Saint Véran village in the southern Alps (Queyras region). It was initially devoted to the study of the solar corona. After previous eclipses (1970, 1973) observed with the Lallemand electronic camera, the main goal was to detect with this high quantum efficiency detector the structures of the far and hot corona in forbidden lines, using either narrow bandpass filters or spectroscopy. But everything had to be built prior to observations: a track, a living house, a dome and a complex instrument. We summarize here this fantastic adventure, which was partly successful in terms of scientific results and had to stop in 1982; however, the activity of the station resumed after 1989 under the auspices of the “AstroQueyras” association, which replaced the coronagraph by a 62 cm night telescope on loan from Haute Provence observatory (OHP); the station extended later with two 50 cm telescopes, was rebuilt in 2015 and received the visit of thousands of amateurs.

KEYWORDS

Sun, corona, prominences, instrumentation, coronagraph, coronameter, forbidden lines, electronic camera

INTRODUCTION

After the total solar eclipse of Mauritania (Rösch, 1973, the famous eclipse chased during 74 minutes by the Concorde 001 prototype flying at 2200 km/h), the "Electronic Camera" group of Paul Felenbok (1936-2020, figure 1) of the Paris-Meudon Observatory, planned to resume the observations of the solar corona with a Lallemand-type electronic (or electronographic) camera mounted on a coronagraph. This layer is made of a hot (10^6 K – 10^7 K) and tenuous plasma, more than 10^6 times darker than the solar disk. For that reason, it is difficult to observe outside eclipses, so that Lyot (1932) developed a special instrument in order to eliminate as best as possible the parasitic light scattered by the lenses, which is brighter than the corona. In addition, high altitude stations are required to reduce the atmospheric diffusion, which is also brighter than the corona at sea level (for that reason Lyot observed at Pic du Midi). Hence, Felenbok's team had to find a suitable place and conceive an original instrument.



Figure 1: Paul Felenbok (1936-2020). Left: walking to the observatory (2930 m) in the late seventies (courtesy Remy Bellenger). Right: at the Sun's house of Saint Véran village in 2016 (courtesy Dominique Menel)

At that time, the Pic du Midi in French Pyrénées (2870 m) was considered as saturated (no free coronagraph, no possibility of adding a heavy instrument to an existing mount). The construction of a dedicated dome and mount would probably have been possible, but the group preferred to look elsewhere. Indeed, the preparation of the 1973 total eclipse took place in Auron, a ski resort in southern Alps, at the top of the cable car, an easily accessible location. However, the National Institute of Astronomy and Geophysics (INAG) of the CNRS (now INSU), organized a campaign of sites in 1970 and 1971, and identified the "Pic de Château Renard" (above Saint Véran) as the best night site in France (but for solar observations, it is never so good because of the heating of the ground). INAG was looking for an excellent site for a large night telescope of the 4-metre class, which finally became operational in 1979 in Hawaii in collaboration with Canada and Hawaii University, at an altitude of 4200 m (top of the Mauna Kea). This is the CFHT ([Racine, 1981](#)), whose dome is so large that it could host today a 10-metre class multi-mirror telescope. But in 1974, INAG recommended the coronagraph for Saint Véran, in order to start the development of a new station for future small or medium size instruments, and to characterize the seeing for long term observations.

THE 7-METRE DOME OF PARIS OBSERVATORY BEFORE TRANSFER TO SAINT VÉRAN

The budget for Saint Véran was rather limited, because it was not a national project, as it was only supported by Paris observatory which accepted to dismount the unused 7 m dome located on the roof of the old "Perrault" building (1667). This dome has a long story ([Véron, 2016](#)), which began in 1858 when Urbain Le Verrier (1811-1877) decided to put an instrument on the west tower. A 7 m diameter wooden dome was ordered in 1857 to Joseph Jean, a carpentry manufacturer and delivered in 1858. Le Verrier equipped it with an equatorial supporting a 30 cm refractor (5.25 m focal length). This instrument was built by Eichens, who owned the Secrétan workshops, under the supervision of astronomer Villarceau (1813-1883). It was ready in March 1858, and the first observation took place in October 1858. Villarceau considered that the objective was not of sufficient quality; it was then corrected and commissioned in November 1860. The mechanics was excellent, but the optics was not so good. A contract was signed with the optician Martin (1824-1896) for the supply of a new lens, delivered in 1878. But it was not installed until 1884 when Bigourdan (1851-1932) noticed systematic errors induced by the original lens. During maintenance work, a fire started in July 1904, but it was quickly brought under control by the firefighters and a repair was undertaken. From 1933 to 1949, the medical doctor Paul Baize (1901-1995), a volunteer collaborator, carried out measurements of double stars. He wrote: "After the war, the dome, pierced in many places by flak, began to let the rain through. It was necessary to interrupt the observations, and, in January 1949, to dismantle the refractor. André Danjon (the director of Paris observatory) then offered me to go to the east tower, and to use the 38 cm equatorial."

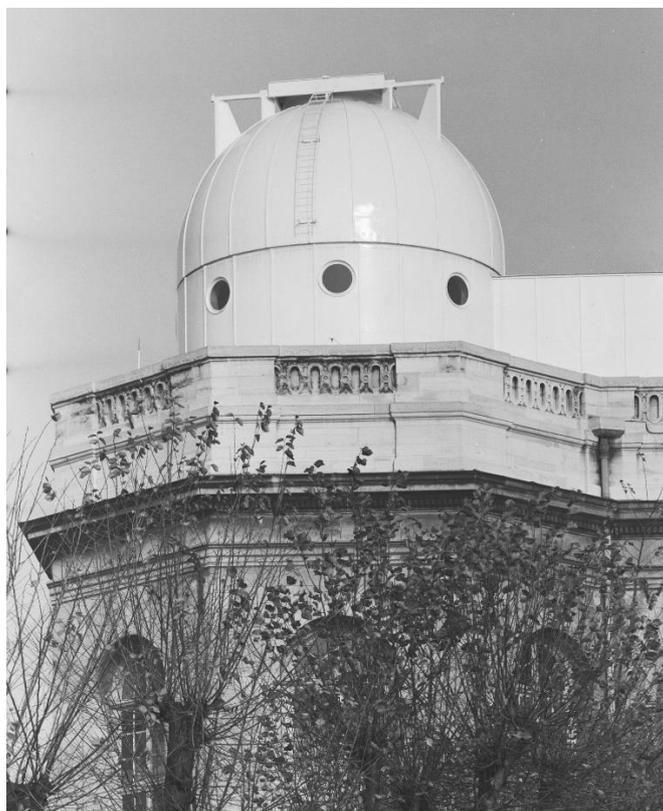


Figure 2: the new metal 7 m dome of the west tower in the fifties (courtesy Paris observatory)

The wooden dome of 1858 was abandoned and replaced by a new metal dome (figures 2 & 3) in the course of the fifties; this is the one transferred to Saint Véran in 1974. We have not been able to identify its manufacturer in the archives; it cannot be Eiffel, as has sometimes been read, but the hypothesis of one of the companies that succeeded the Eiffel workshops cannot be ruled out. An equatorial table was placed there, as shown in figure 4.

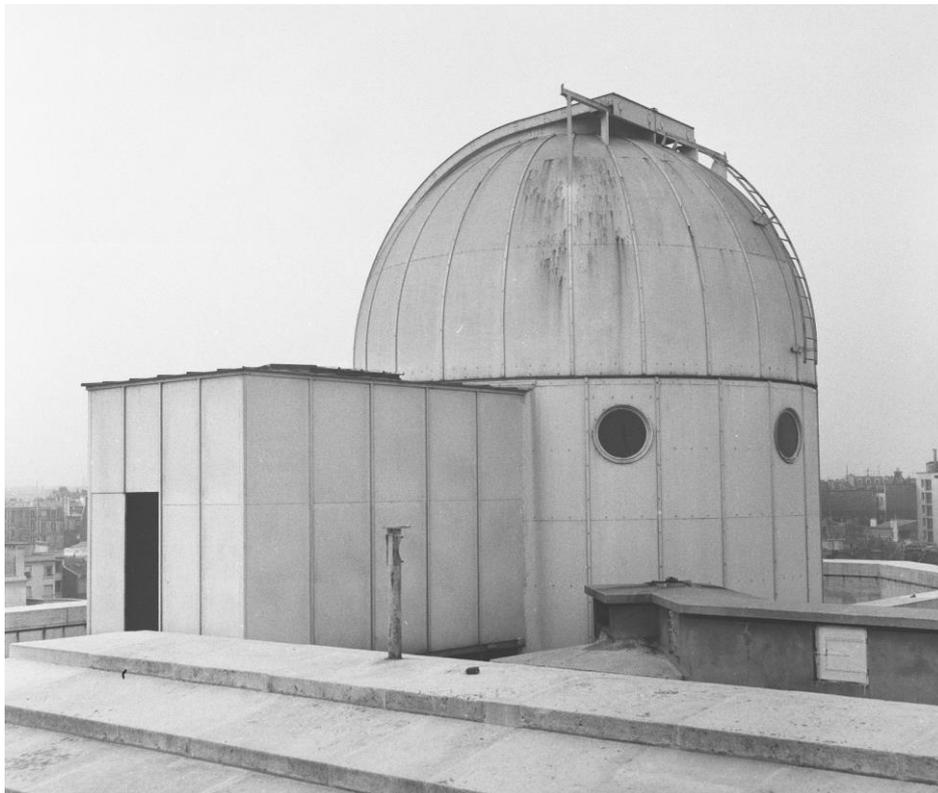


Figure 3: the new 7 m diameter metal dome of the west tower in September 1961 (courtesy Paris observatory)



Figure 4: the equatorial table of the west tower in May 1974 (courtesy Paris observatory)

THE TRANSFER OF THE DOME FROM THE WEST TOWER TO SAINT VÉРАН IN 1974

The selected place was “Pic de Château Renard” (2930 m) above Saint Véran village (2040 m), near Briançon. The “Hautes Alpes” administrative department took charge of the construction of the access track in June 1974 (only usable in summer by 4-wheel drive). The Paris Observatory provided the dome of the west tower, and the INAG paid the sheet metal house and the generators (because the connection to the public electric network was impossible at this altitude). The Nice Observatory lent an equatorial table for the dome. The solar instrument (a coronagraph of 25 cm and 3 m focal length, described below) was installed in October 1975. The 7 m diameter and 9 m high dome of Paris observatory required the construction of a strong masonry foundation. Under the observation floor, there was a basement used as a workshop. A 5 m high metal annex, also with two levels, was attached to the dome, as in Paris (figure 3). The opening of the cupola was 2.30 m wide and it rotated over 360°; both motions were manual. The dismantling, transport, and reassembly took almost two years: this operation started in summer 1974 and ended in autumn 1975. Gabriel Rousset (from Meudon) wrote in 1981: “We were in the presence of a rusty dome, having suffered from the dismantling and reassembly, with a rotating hard spot and a slight misalignment of the closing of the trapdoors; and zero impermeability to snow and condensation. To eliminate these defects, it was necessary to do many tasks, such as redo the painting, realign the rotation rollers to reduce the hard spot, eliminate snow infiltration with a system of skirts, deposit a waterproof coating on all joints and spray polyurethane on the inner wall of the dome to prevent water condensation. This work was spread over two summer campaigns, by which we had a more or less suitable dome, always having a defect in rotation and in closing the trapdoors”. The successive stages of the construction are illustrated by figures 5 to 16. After 1977, the station included:

- The dome and its annex, plus the coronagraph (detailed below).
- A metal sheet house of 40 m² used as a living base, including kitchen, living room, bedroom, bathroom, which could accommodate 4 people. It was heated by gas (12 bottles of 37 kg); water (non-drinkable) was delivered by tanks (14000 litres), and electricity was produced by fuel generators.
- A second metal hut of 15 m² for the liquid nitrogen liquefier (which in fact was never used).
- A technical hut containing 3 generators of 4, 6 and 10 KVA, as well as a small group of 1 KVA for domestic use; the fuel tank (3000 litres) was installed underneath.
- An iron tunnel connecting the dome to the living base and a second one to the nitrogen liquefier hut.
- A radio-telephone line lent by the administration of the “Hautes Alpes” department.



Figure 5: the reassembly of the 7 m dome in autumn 1974 was a complicated task. Two floors were available. The masonry is waiting for the annex installation at right (courtesy Paris observatory)

The construction of the station and assembly of the dome and coronagraph required the active participation of many people, such as Remy Bellenger (optics, electronics), Yves Zéau (logistics), Jean-Pierre Dupin (electronics), Gabriel Rousset and Isidore Raulet (mechanics), Annick Fayet, Jean Guérin, Mireille Dantel and Jacques Baudrand (instrumentation), Christiane Jouan (administration). Many inhabitants of Saint Véran village (such as Joseph Brunet, Jacques Jouve, Pierre Prieur-Blanc) helped a lot, together with Jean-Eugène Chabaudie from Nice observatory. Guérin was responsible of the instrument from 1975 to 1977 and Bellenger from 1978 to 1982.



Figure 6: the station under construction in autumn 1974. One sees the unfinished 7 m dome (1) without its technical annex, the house (2), a hut for temporary accommodation during the yard (3) and the caravan of INAG for site campaigns (4) (courtesy Paris observatory)



Figure 7: the living house (left) and dome (right) under construction in autumn 1974 (courtesy Paris observatory)



Figure 8: the observatory (2930 m) under construction in autumn 1974. One sees the unfinished 7 m dome (1), the metal sheet house (2), a hut for temporary accommodation (3) and the yellow caravan that was used by INAG for site prospection (4) (courtesy Remy Bellenger)



Figure 9: preparing the tunnel between the house (at left) and the dome in summer 1975. The UNIC Marmon (a 4 x 4 truck lent by UNIC) was the one used for the eclipse mission of 1973 in Mauritania (courtesy Paris observatory)



Figure 10: building the station in summer 1975; the heating of the house (left) was provided by gas, and electricity by fuel generators. The Mercedes Unimog U406 at left (4 x 4 truck) was owned by Joseph Brunet, an inhabitant of Saint Véran who helped a lot. The shelter (at right) was temporary (courtesy Paris observatory)



Figure 11: the station achieved in 1977; one sees the two-floor 7 m dome and annex (1), the house (2), the double tunnel (3), the electric plant (4), the liquid nitrogen liquefier hut (5), the gas storage area (6), and the yellow caravan that was used by INAG for site testing (7) (courtesy Paris observatory)

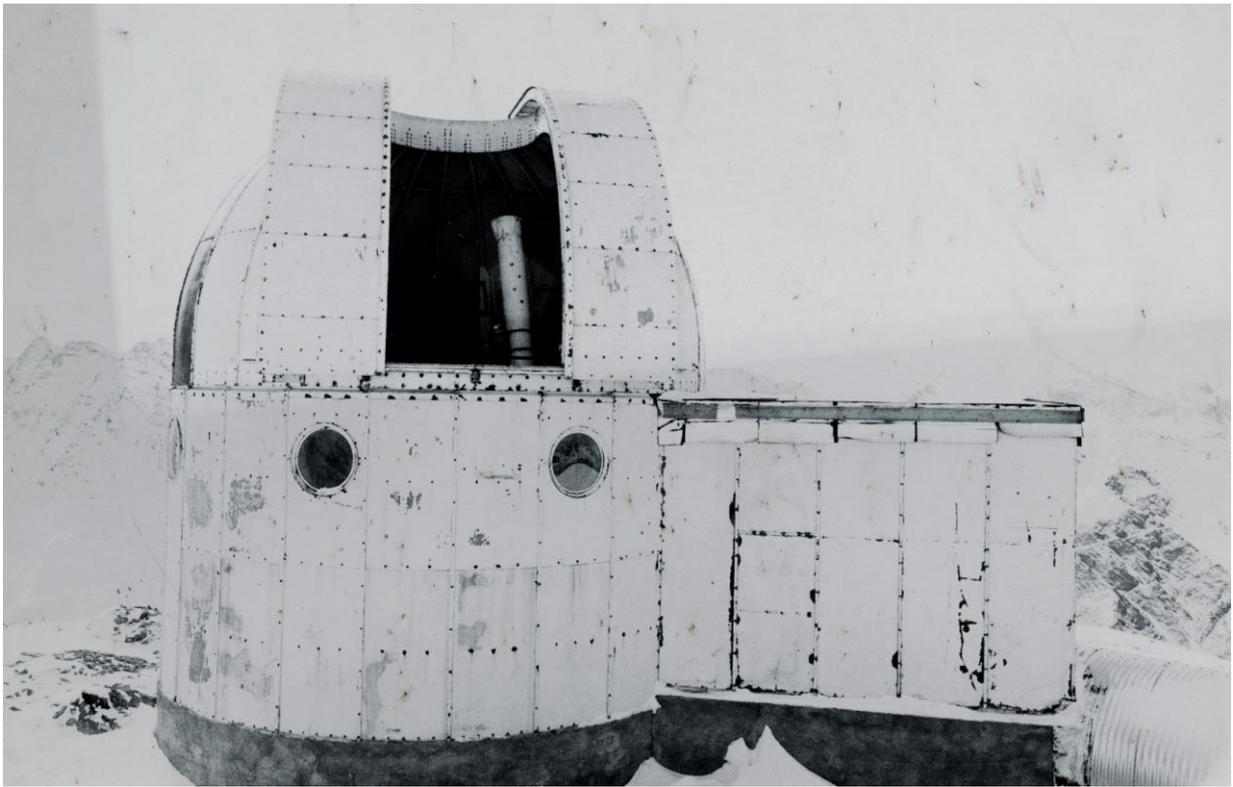


Figure 12: the two-floor dome and technical annex, at the end of 1975, with the coronagraph inside, before being repainted (courtesy Paris observatory)

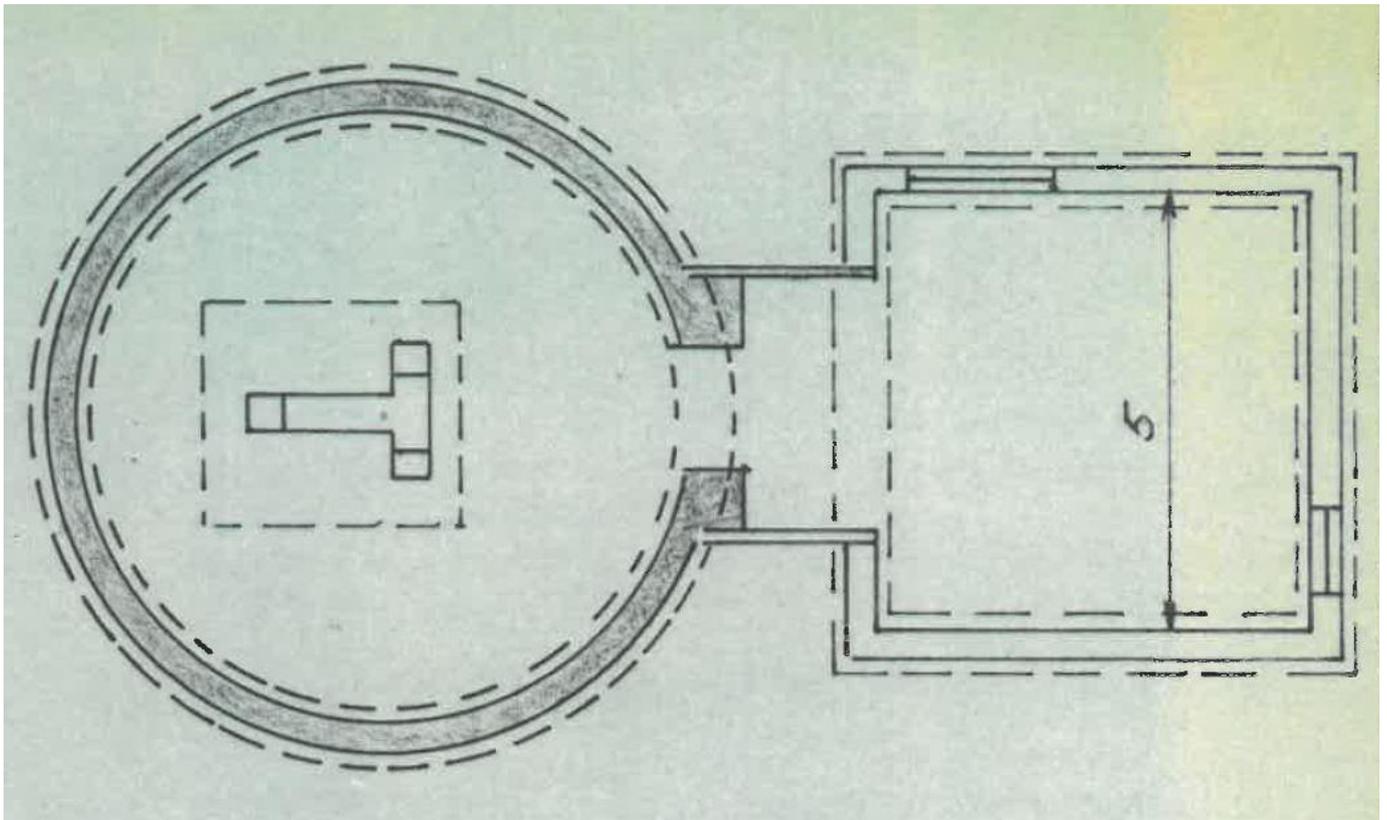


Figure 13: plan of the 7 m dome and its annex from above (courtesy Paris observatory)

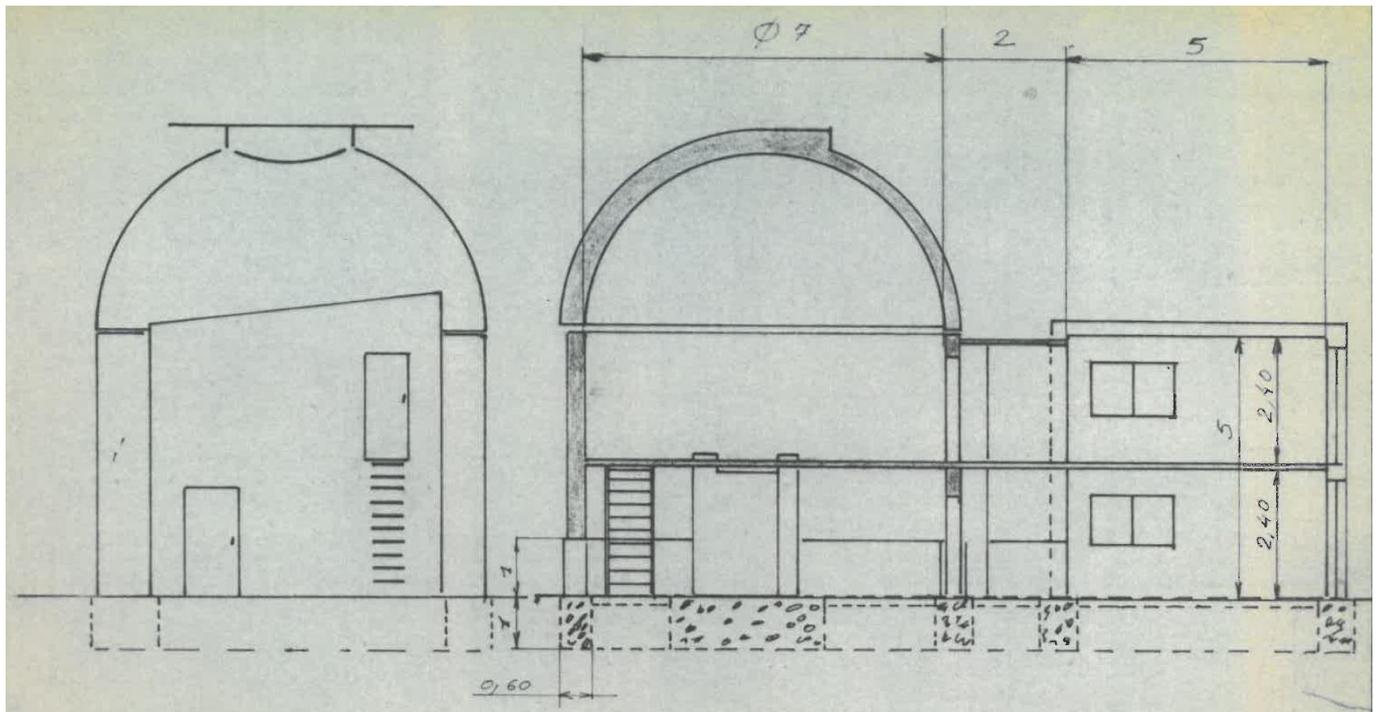


Figure 14: side view (left) and cross section (right) of the dome and annex, both with two floors, including a workshop below the observing level. The height of the dome was 9 m, and its diameter 7 m. The technical annex was a square of 2 x 25 m² and 5 m high (courtesy Paris observatory)



Figure 15: the dome before being repainted, the technical annex, and the tunnel towards the living base in 1976 (with Annick Fayet and Jean-Eugène Chabaudie, courtesy Paris observatory)



Figure 16: Remy Bellenger, responsible of Saint Véran observatory in 1980 (courtesy Mireille Dantel)

THE LALLEMAND ELECTRONIC CAMERA AND SOLAR OBSERVATIONS

Despite of the astronomical quality of the Pic de Château Renard at Saint Véran, identified as the best nocturnal site of France by INAG in 1970-1971, the place of Hawaii (Mauna Kea at 4200 m) was selected in 1972 for the construction of the Franco-Canadian-Hawaiian telescope of 3.60 m diameter (the CFHT). At the same time, when CCD targets did not exist, coronagraphy projects, based on the André Lallemand electronographic camera, were in progress: its principle (Lallemand, 1937; Lallemand *et al*, 1960) is based on photo-electricity (photon/electron conversion by a photocathode). Photo-electrons are then accelerated and focused by high voltage electronic lenses on a nuclear photographic plate (figure 17), which made the Lallemand camera 100 times more sensitive than conventional photography (the quantum efficiency was close to modern CCD, which became available only in the early eighties). Fifty years of developments were summarized by Wlérick (1987). The Lallemand camera was therefore well suited to the observation of faint objects (such as galaxies with the CFHT). At Pic du Midi, imaging coronagraphs mainly worked with argentic films, but the coronameters (dedicated to high precision photometry and polarimetry of coronal emission lines) used either photomultipliers or photodiodes (Charvin, 1965; Ratier, 1975; Arnaud, 1982; Noens *et al*, 1984) providing a single point measurement (one pixel of many arcsec). Surface sampling was necessary with coronameters and was slow; this is why the Lallemand camera (native 2D field of view, CCD like sensitivity) was a major step to improve the process and temporal resolution. The first use of an electronic camera on a coronagraph associated with a spectrograph (Figure 18) was successfully experimented by Rozelot & Despiau (1972) at the Turret dome, Pic du Midi observatory, which hosted a camera since 1960 for the 1 m telescope (Raymond Despiau was also a famous Pyrenean climber, who took part to the French expedition at Everest, headed by Pierre Mazeaud in 1978). The first observations of a total eclipse with an electronic camera were performed by Fort *et al* (1972) in Mexico (1970). Two years later, the Meudon camera group lined up two electronic cameras with electrostatic focusing at the 1973 eclipse in Mauritania (Fort & Picat, 1975, Picat *et al*, 1979), after having carried out tests at the top of the Auron cable car station (Southern Alps, figure 19); one camera was prepared for images and polarimetry in forbidden coronal lines, and the other one for spectroscopic studies, conducted by Bernard Fort and Jean-Pierre Picat (Figure 19). It appeared natural to the group led by Paul Felenbok, to continue this strong technical

and scientific investment with a high altitude coronagraph at Saint V eran, a good site in perspective, but where the station had to be created from nothing.

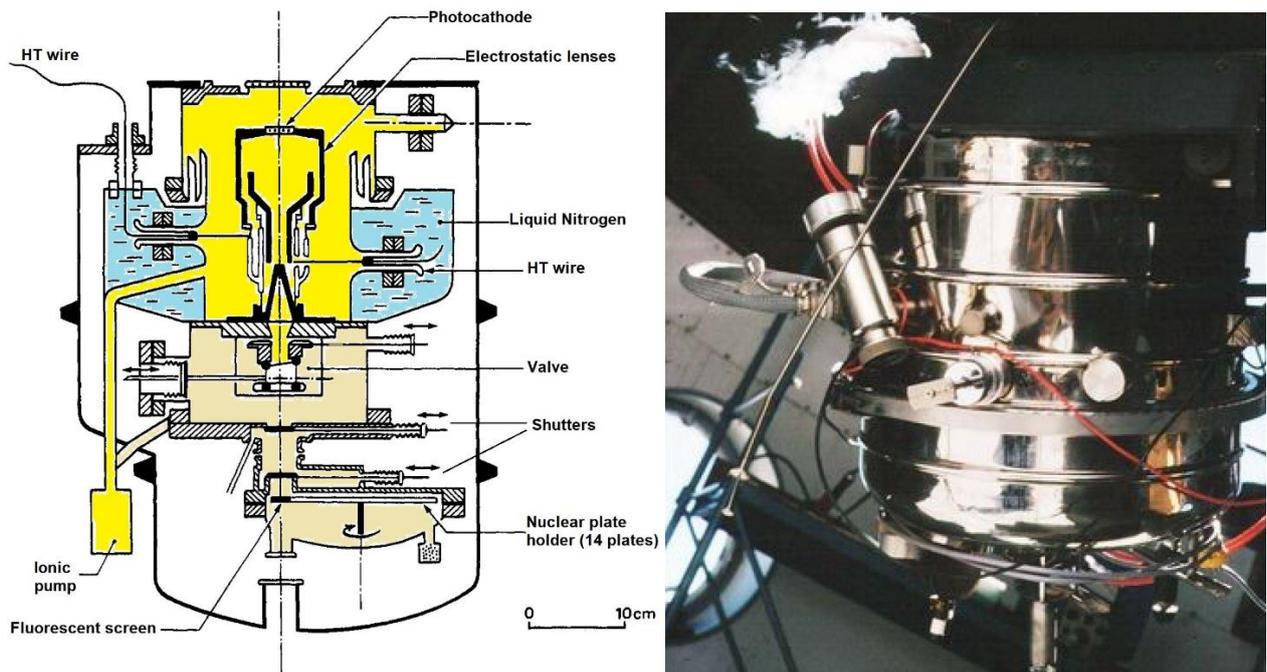


Figure 17: the principle of the electronic valve camera (modified figure of [Baudrand et al, 1982](#)): it is a high quantum efficiency image converter (photons/electrons) with two cooled compartments, one permanently evacuated (the photocathode and electrodes) and the other one (only evacuated during observations) for the nuclear plates.

It should be noticed that Felenbok’s team developed a version of the Lallemand system, the electronic valve camera ([Baudrand et al, 1972](#)), which avoided breaking the vacuum around the photocathode and electronic lenses during the change of nuclear plates, and consequently prevented to discard the photocathode which had to be replaced, in the Lallemand initial design, each time the vacuum was broken. Indeed, the issues of vacuum and cooling by cryostats at low temperature (liquid Nitrogen, 77 K) were the major obstacles to the use of these delicate devices, especially in environments with reduced logistics (such as Saint V eran or eclipse missions). As solar structures may evolve rapidly (the minute for coronal mass ejections), it was also essential to have many plates on the same holder. Unfortunately, the Saint V eran prototype did not work properly due to unsolved problems of vacuum, and the first successful valve camera of the group was the next one, built for the CFHT (more than one thousand images of galaxies were got at the CFHT prime focus with the valve camera, see [Wl erick, 1987](#)).

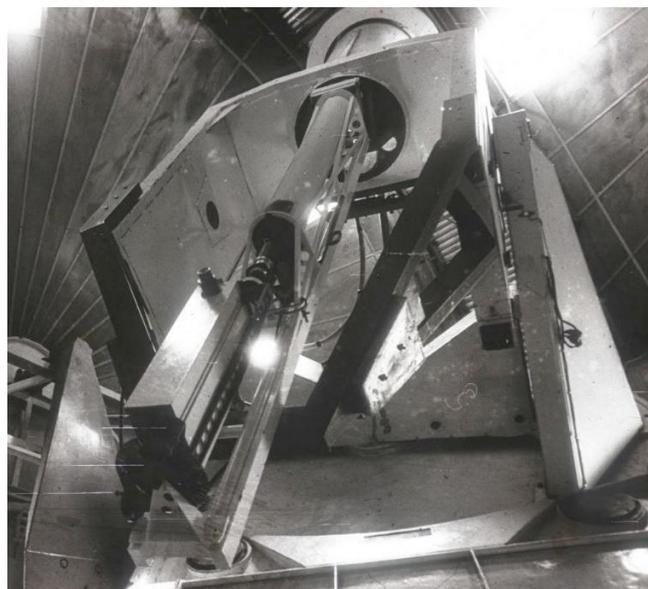


Figure 18: the 15 cm spectro-coronagraph of [Rozelot & Despi au \(1972\)](#) was the first to work (occasionally) with a Lallemand electronic camera, at the Pic du Midi (camera not mounted on the photo, courtesy Rozelot)

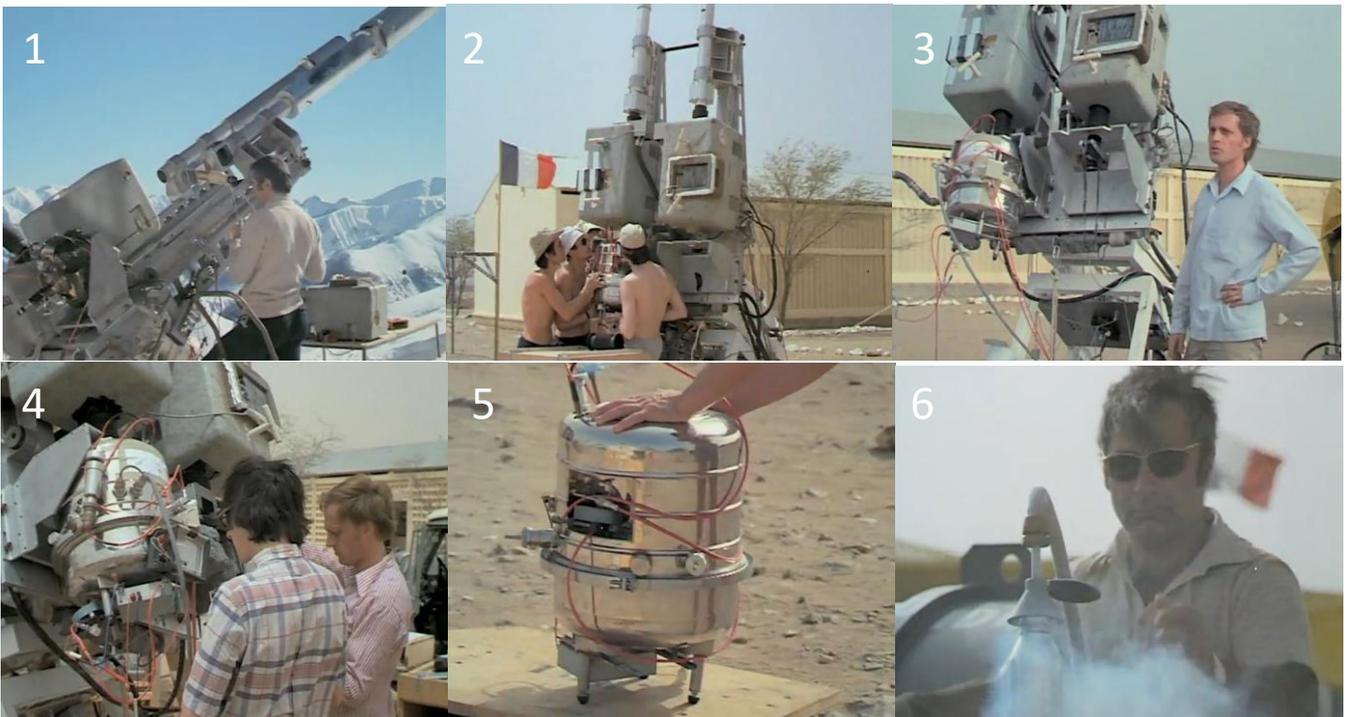


Figure 19: the electronic cameras of Felenbok's group tested in Auron (1) in French Alps and then used in Mauritania (2-6) for the 30 June 1973 eclipse in Atar airport (3: Bernard Fort; 6: Paul Felenbok; courtesy CNRS, images extracted from the movie available at <https://www.youtube.com/watch?v=BNxz-2NRsBs>)

THE PRINCIPLE OF THE CORONAGRAPH

It was invented by [Lyot \(1932\)](#). The principle was described for non-specialists by [Crifo \(1981\)](#) and [Detwiler & Noëns \(2008\)](#). It is a much more subtle instrument than a classical refractor with a simple occulting mask in the image plane. Indeed, the corona is 10^6 times less luminous than the solar disk, whose light penetrates the coronagraph (this is not the case during an eclipse) and produces parasitic light. First of all, there is the diffusion by the dust of the sky (attenuated in the high mountains) and the molecules, as bright as the corona; it will therefore be better to observe with filters towards the red, because Rayleigh scattering (in $1/\lambda^4$, where λ is the wavelength) dominates in the blue. Then we are confronted with the reflection of light on the inner faces of the entrance lens ([Figure 20](#)), which is also brighter than the corona. At the primary focus, in the image plane, a reflecting cone obscures the solar disk; but there is a secondary focus, resulting from two internal reflections (attenuation $R = 0.04^2 = 0.0016$). The secondary focus has a very short focal length, equal to $[(n-1)/(3n-1)] F = F/7$ for a refractive index $n = 1.5$, if F is the focal length of the primary focus ([Detwiler & Noëns, 2008](#)). At last, the diffraction of light by the contours of the objective, which is also brighter than the corona, must be eliminated in the pupil plane.

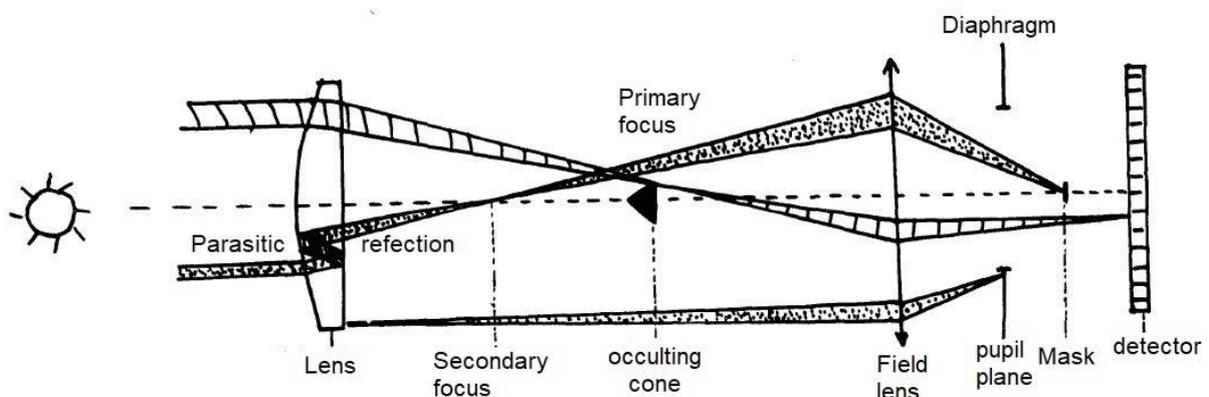


Figure 20: diagram of the coronagraph (after [Crifo, 1981](#)). The occulting cone is at the primary focus. The secondary focus forms by two internal reflections. The field lens gives a pupil image which is cut by a diaphragm to eliminate edge diffraction. There is a small circular mask (the Lyot stop) to cut the secondary image.

How to eliminate the parasitic sources ? Near the occulting cone, in the vicinity of the primary focus, a field lens is placed, which forms an image of the entrance objective in the pupil plane. At this location, a diaphragm cuts the diffractive edges of the pupil (figure 21). Just behind this diaphragm, there is the image of the secondary focus by the field lens, it is a small central bright spot of a few millimetres (figure 21), which can be masked by the Lyot stop. After eliminating these major defects, an image of the corona forms on the detector; a photographic plate for the low corona is sufficient, but an electronic camera (or a CCD today) is necessary for the far corona.

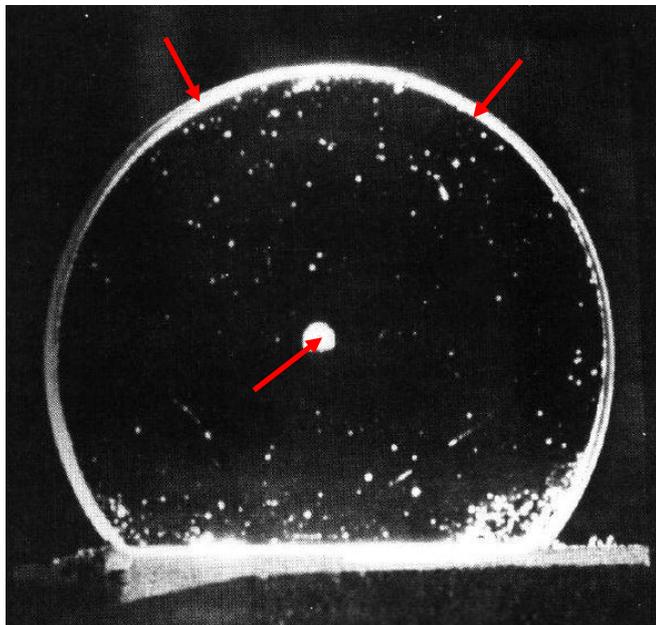


Figure 21: Image of a good quality coronagraph objective (After Dollfus, 1983). We can distinguish the diffractive edge and the central reflection (both are 1000 times brighter than the corona, they are eliminated by placing a diaphragm in the image of the pupil, and by obscuring the image of the secondary focus by the Lyot stop). There are also dusts, heterogeneities, scratches and bubbles, which scatter light in the lens glass. In order to minimize these defaults, a single lens of exceptional quality and precise polishing is necessary. This implies observations with narrowband filters because of the chromatism of the glass, which cannot be corrected. But a mirror telescope would be much more diffusing than a single lens refractor.

THE CORONAGRAPH OF SAINT VERAN

Paul Felenbok left us an optical diagram (Figure 22). The objective is a single lens with a diameter of 25 cm and a focal length of 300 cm (Figure 23). The solar image at the primary focus has a diameter of 2.8 cm and is intercepted by the reflecting cone. At this place (in the image plane), there is a field lens with a focal length of 85 cm. It forms an image of the entrance pupil about 120 cm away, where the diaphragm and the Lyot stop are located. The diaphragm reduces the effective coronagraph diameter from 25 cm to 16 cm by eliminating the diffractive edge. The secondary image focus, resulting from two internal reflections inside the entrance objective, is located at $300/7 = 43$ cm from the lens and gives a small (but bright) parasitic solar image of 0.4 cm diameter; it is reported by the field lens just behind the diaphragm, where it is obscured by the Lyot stop.

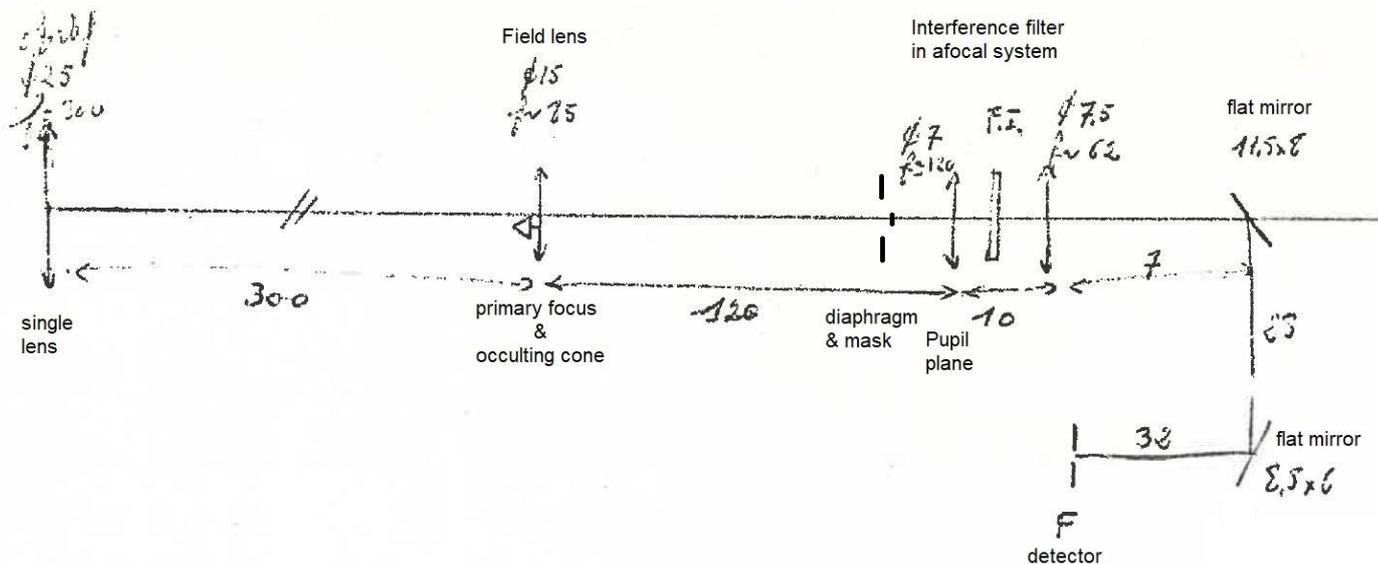


Figure 22: diagram of the coronagraph of Saint V6ran (after Paul Felenbok's original drawing).

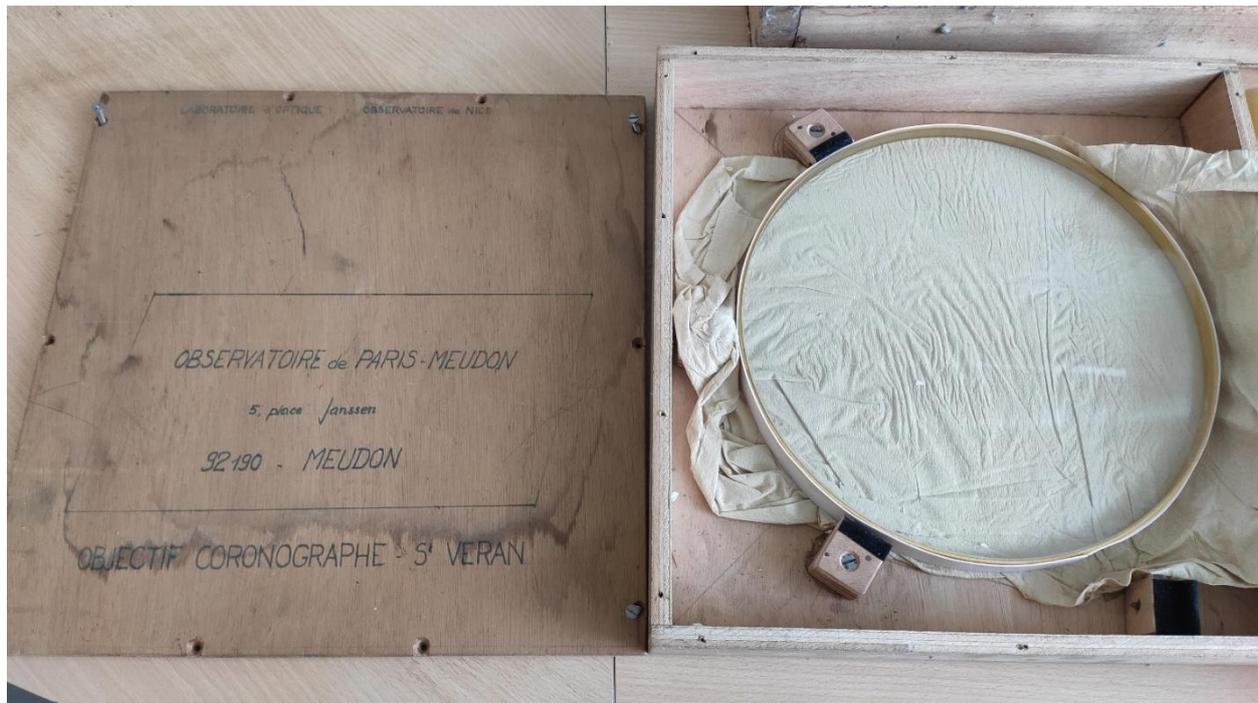


Figure 23: the coronagraph lens with a diameter of 25 cm and a focal length of 300 cm, polished by Demarcq (former optics laboratory of Nice Observatory). It is a convex ($R = 1.5$ m) planar single lens (courtesy Paris observatory).

A train of two lenses follows: it contains a narrowband interference filter (a few Angström wide) isolating a coronal emission line. This afocal system (0.5 magnification) consists of two converging lenses, with focal lengths of 120 cm and 62 cm respectively. The filter is crossed by a beam of parallel rays; the second lens forms an image of the corona at the image focus denoted F in figure 22. As the focal length ratio of the two lenses is 0.5, the equivalent focal length of the coronagraph becomes $300 \times 0.5 = 150$ cm, which means that the masked solar disk has a diameter of 1.4 cm at the exit. All lenses are made of borosilicate glass BSC 16-64. The elements of the coronagraph are located, along the z-optical axis, at the following positions:

- z = 0 cm, entrance objective L1, single lens \varnothing 25 cm, $f = 300$ cm (plano-convex, $R = 1558$ mm)
- 43 cm, secondary focus (from two internal reflections), image \varnothing 0.4 cm
- 300 cm, primary focus, image \varnothing 2.8 cm, occulting cone, and field lens L2 ($f = 85$ cm, bi-convex, $R_1 = R_2 = 878$ mm, \varnothing 15 cm)
- 300 + 118 cm, pupil plane \varnothing 10 cm, Lyot diaphragm \varnothing 6.4 cm, Lyot spot \varnothing 0.2 cm
- 300 + 120 cm, L3, 1st lens of the afocal system, $f = 120$ cm (plano-convex, $R = 612$ mm, \varnothing 7 cm)
- 300 + 125 cm, narrow band interference filter (a few Angström) and oven (temperature control)
- 300 + 130 cm, L4, 2nd lens of the afocal system, $f = 62$ cm (plano-convex, $R = 321.5$ mm, \varnothing 7.5 cm)
- 300 + 130 + 62 cm, exit image, equivalent focal length = 150 cm, solar diameter \varnothing 1.4 cm

At the exit focus F of figure 22, an electronic camera of Lallemand-type could be installed, or a conventional 35 mm photographic plate. A small spectrograph could also be inserted. It was first designed for the 1973 eclipse in Mauritania and was re-used. It had a magnification of 0.67, a grating of 10×10 cm², 600 grooves/mm, providing the dispersion of 12 Å/mm in the second order, and a spectral resolution of 0.3 Å. The useful spectral domain was the 3000 Å to 11000 Å range. The detector was in all cases either a standard or nuclear (for the electronic camera) plate. The development of the plates was locally done; but the digitization was performed after the missions, with a micro densitometer (such as the Joyce at Meudon or the PDS-Perkin Elmer of Institut d'Optique at Orsay), allowing to measure the photographic densities and convert them into numerical values that could be processed by a computer (at that time, the IBM 360/65 of INAG was available in Meudon, together with a PDP 11/34 running the software of the "Centre de Dépouillement des Clichés Astronomiques", the CDCA system developed at Nice by Albert Bijaoui ; all were replaced by a VAX 11/780 in 1981). Figure 24 shows the coronagraph being assembled in Meudon; optical details are reported in Figure 25.

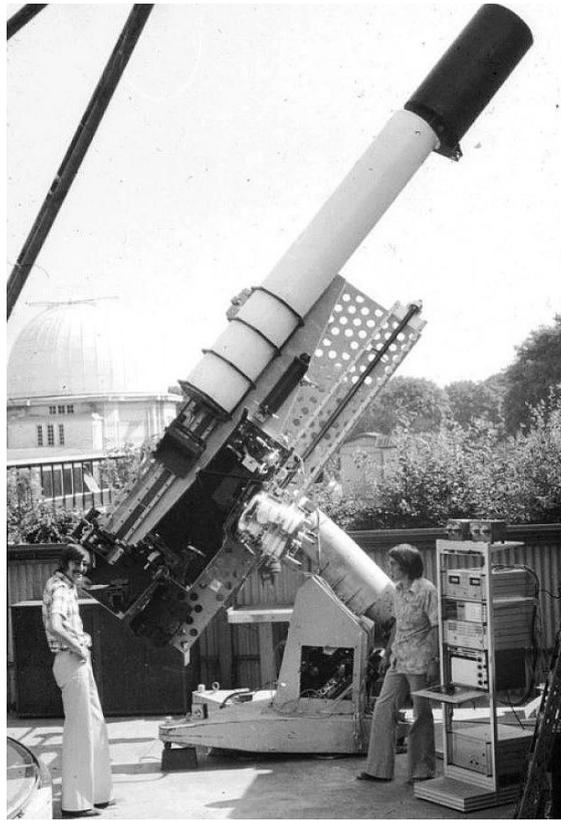


Figure 24: the coronagraph with the electronic camera at the spectroscopic exit, assembled in Meudon, with Laporte (left) and Jean-Pierre Dupin (right) (courtesy Paris observatory).

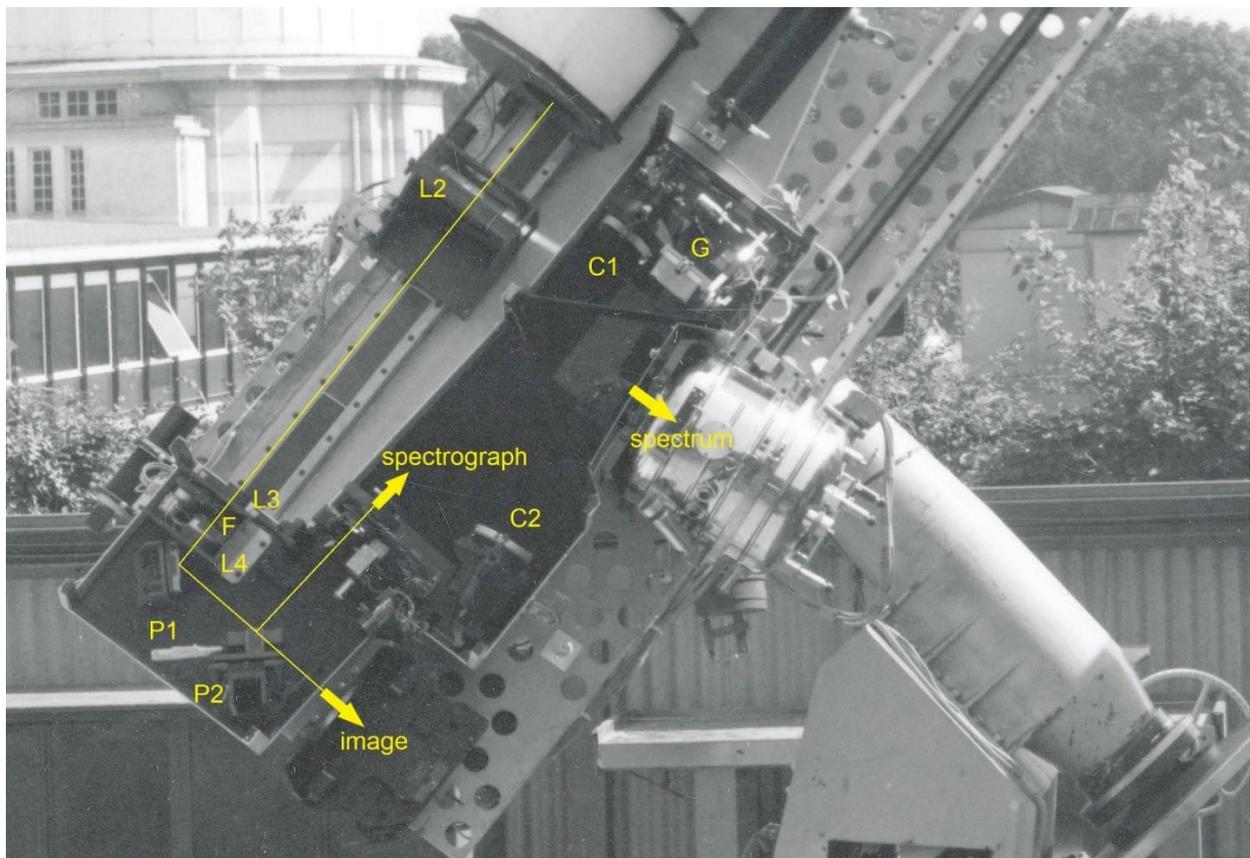


Figure 25: detail of figure 24. L2 = field lens ($f = 85$ cm); L3 ($f = 120$ cm), L4 ($f = 62$ cm) = afocal system with interference filter denoted F; P1, P2 = plane mirrors (P2 is shifted in imagery mode); C1, C2 = spectrograph collimator ($f = 90$ cm) and chamber ($f = 60$ cm); G = grating 600 grooves/mm. The electronic camera could be mounted either at the spectrum or image exit (courtesy Paris observatory).

The coronagraph after transport to Saint V eran in October 1975 is shown in [figures 26, 27 & 28](#), while [figure 29](#) displays an example of typical observations. The scientific program was based on the extreme sensitivity of the electronic valve camera, a modified version of the Lallemand system to facilitate nuclear plate exchange. Indeed, Felenbok wrote: "the preferred detectors are the electronic camera or the photomultiplier, whose photometric properties allow to increase the observation height in the corona and the spectral field compared to conventional photometry". Hence, the goal was to explore the hot corona at large distance to improve our knowledge of coronal loops (review by [Reale, 2014](#)) and material ejections (reviews by [Chen, 2011](#); [Webb & Howard, 2012](#)). For that purpose, it was necessary to acquire monochromatic images in the green and red lines (5303   of FeXIV, 6374   of FeX, respectively $1.8 \cdot 10^6$ K and $1.0 \cdot 10^6$ K) up to 0.4 solar radius from the limb, and even 0.8 radius in the IR lines of FeXIII (10747   and 10798  , $1.6 \cdot 10^6$ K). Such observations give access to the temperature (ratio of FeXIII to FeXIV intensities) and electron density (ratio of intensities of the FeXIII lines), and trace the direction of the coronal magnetic field (FeXIV with linear polarization analysis). More specifically, the experiments envisaged were the following:

- Determine the electron density and temperature using neighboring ions, such as FeXIII and FeXIV (i.e. density diagnostics described by [Pasachoff et al, 1976](#), temperature determination by [Srivastava et al, 2007](#)).
- Plot the direction of the magnetic field by measuring the linear polarization of the IR line of FeXIII at 10747   and the green line of FeXIV at 5303   ([Picat et al, 1979](#), results of the 1973 eclipse).
- Study the cold prominence/hot corona interface (condensation, plasma transfer) using the H α line (cold material at 10^4 K) and the red line of FeX at 6374   (hot plasma at 10^6 K, filtergrams of [Figure 29](#)).
- Explore the oscillations of the prominences, provided that sufficient temporal resolution was available.
- Measure the magnetic field of the prominences in the IR line of HeI 10830  , by measuring the Hanle linear depolarization and rotation (this topic was finally extensively studied, including theory applied to observations with the Pic du Midi polarimetric coronameter, by [Bommier et al, 1981](#); [Leroy et al, 1983, 1984](#)).

It should be emphasized that the interest of the electronic camera was the sensitivity, linearity and absence of threshold, allowing, in comparison to the conventional photographic plate, either to detect fainter coronal lines in spectroscopic mode (spectrum of [Figure 30](#)) or to see higher in the corona (provided that the sky permitted it). These advantages were offered ten years later by CCDs, without the disadvantages of vacuum and liquid N₂ cryogenics.



Figure 26: Mireille Dantel making adjustments at Saint V eran observatory in 1980 (courtesy Remy Bellenger)



Figure 27: Jean-Pierre Picat (left) and Mireille Dantel (right) at the observatory in 1980 (courtesy Remy Bellenger)

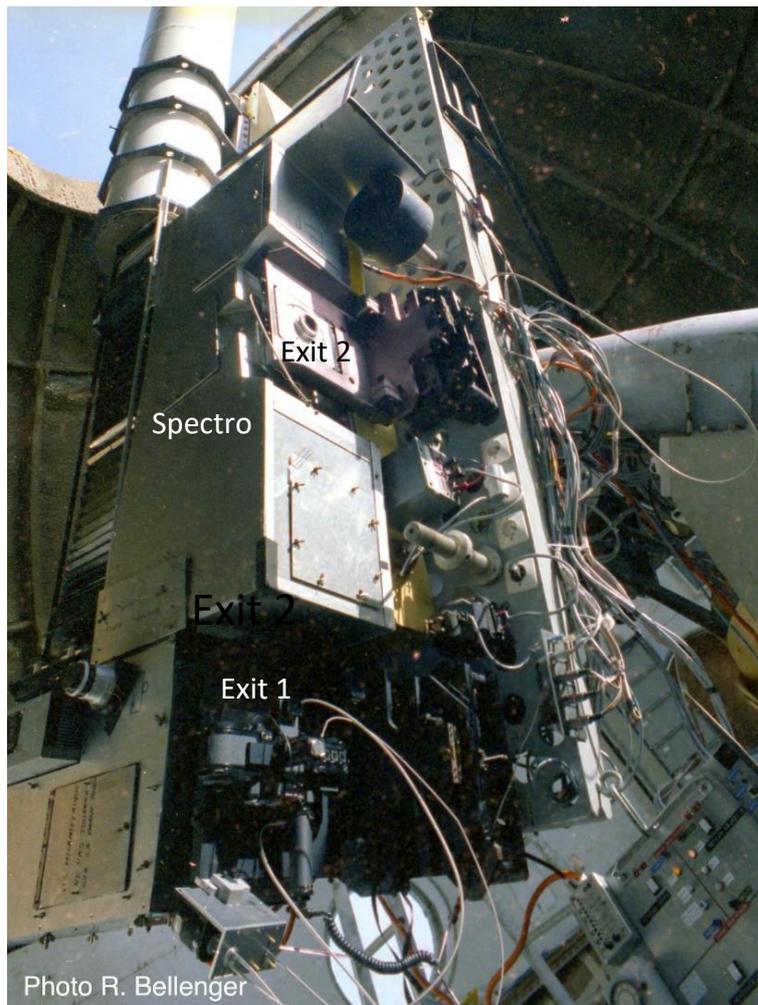


Figure 28: The coronagraph with the 35 mm Canon photographic camera at the imagery focus (exit 1, $f = 150$ cm); it could also operate at the spectrograph focus (exit 2, $f = 100$ cm) (courtesy Remy Bellenger)

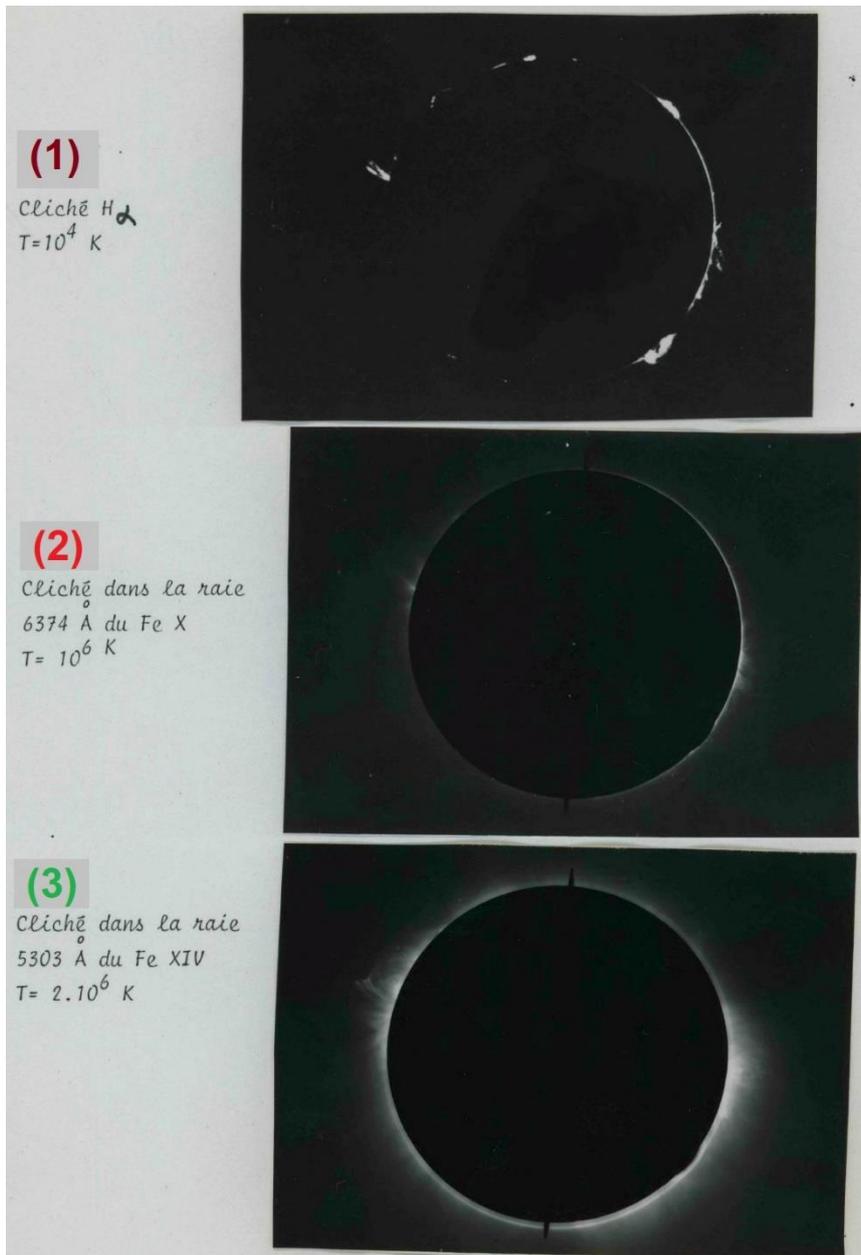


Figure 29: monochromatic images of the corona and prominences (30 October 1980, 9:00 UT) with narrow bandpass filters, obtained in usual photography with the coronagraph. (1) cold corona (prominences), H_{α} 6563 Å, 10^4 K; (2) hot corona, Fe X 6374 Å, 10^6 K (red line); (3) Fe XIV 5303 Å, $1.8 \cdot 10^6$ K (green line). (Courtesy Paris observatory).

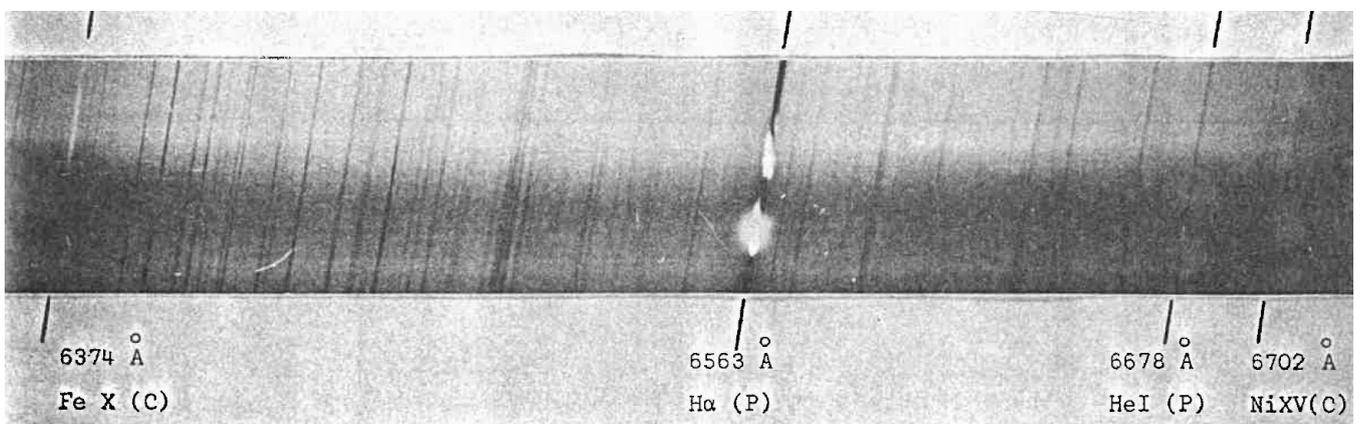


Figure 30: spectrum of the hot corona (C) and prominences (P) obtained in usual photography at Saint Véran, 4 October 1977. The red line of Fe X corresponds to $T=10^6$ K, that of Ni XV to $2.3 \cdot 10^6$ K. The prominences, visible in H_{α} or HeI, are 100 times cooler (10^4 K) and much brighter than the hot corona (courtesy Paris observatory).

WHY THE SAINT VÉRAN OPERATION WAS NOT A FULL SCIENTIFIC SUCCESS

Two young scientific researchers (retired today) of CNRS, from Meudon, worked with the coronagraph, namely Jean-Pierre Picat and Françoise Crifo, in collaboration with Paul Felenbok. It was certainly a very difficult task for them, because we did not find, unfortunately, any scientific publication done with Saint Véran observations. The electronic valve camera never worked properly (vacuum problems), and it was necessary to return to a classic 35 mm reflex camera (Canon) with a motorized magazine of 250 frames to produce spectra and coronal images such as those of [figures 29 and 30](#), showing that the coronagraph worked perfectly. But observations with such a detector, or with photo-electric coronameters, were common in other places (Pic du Midi), so that it was no more enthusiastic.

We saw that the coronagraph project at Saint Véran was in the continuity of the total eclipse missions (1970, 1973) with electronic cameras. During an eclipse, the sky is dark, and it is possible to observe the high corona at several solar radii. This was the purpose of the Lallemand camera, which was invented for night time observations of faint deep-sky objects. Trying to detect coronal structures far from the Sun, in the forbidden lines of iron, with this device 100 times more sensitive than photographic plates (close to modern CCDs), was a truly original and audacious goal. But we think that the choice of the electronic camera, a fantastic but complex tool with severe constraints of vacuum and cooling, was probably too ambitious for Saint Véran, because of the lack of logistics, human and financial resources. This was especially the case, when one has to ensure the start-up from nothing of a new high-altitude station with complicated access and no permanent local staff. Rozelot already mentioned difficulties in 1972, even at the Pic du Midi (where working conditions were much better). The classical photography, introduced later (1979), saved the project, but it was no longer as innovative compared to what was done elsewhere, so that it became compromised to produce new and original results of international level.

We can also notice the growing competition from space, at first instruments using 35 mm films, such as the white light coronagraph onboard SKYLAB/NASA (Apollo Telescope Mount platform) from 1973 to 1979 ([figure 31](#), see [MacQueen et al, 1974](#)), then those equipped with vidicon tubes, such as the SMM coronagraph, with real time digitization ([Figure 32](#), see [MacQueen et al, 1980](#)). NASA's Solar Maximum Mission satellite only operated for six months in 1980 (March-September) and unfortunately failed. It was later repaired in April 1984 by an extravehicular spacewalk from the American space shuttle, when the coronagraph of Saint Véran was already closed, so that there were only 6 months of intersection between them. The SMM coronagraph then operated until 1989 with filters and polarimetric optics. Later, LASCO's wide-field coronagraphs onboard SOHO used CCDs ([Figure 33](#), up to 30 solar radii, working since 1996) and attested the importance of coronal observation. LASCO is unique and still supported in 2024 by ESA and NASA; this is also the case of EIT, the EUV telescope onboard SOHO, which produces images of the low corona above the disk in the hot lines of highly ionized iron (but in this wavelength range, Solar Dynamics Observatory SDO/NASA does much better since 2010 with the AIA package).

The start-up of the CFHT in Hawaii (1979) undoubtedly precipitated the rapid end of the Saint Véran project, as the team published his first scientific results with the CFHT and the revised model of electronic valve camera as early as 1982 ([Baudrand et al, 1982](#); [Picat et al, 1982](#)).

The Saint Véran coronagraph lasted only a few years, due to the camera issues and local conditions to operate such a sophisticated instrument. The future of the 7 m dome was then questioned, and in the expert report (1981) of Gabriel Rousset, we read: "a new dismantling and reassembly of this dome, if not impossible, presents great difficulties. Indeed, such an operation cannot be conceived without: (a) completely review the rotational motion path and its driving system; (b) completely overhaul the trapdoors opening and closing system; (c) redo the polyurethane spray that would be fatally destroyed by the dismantling, and the painting. Because of these major problems, I think that such a project could not provide a serious, fast and economical means available to researchers". As a consequence, the coronagraph was removed, but the dome and the living base remained on the site, which stayed unoccupied for several years.

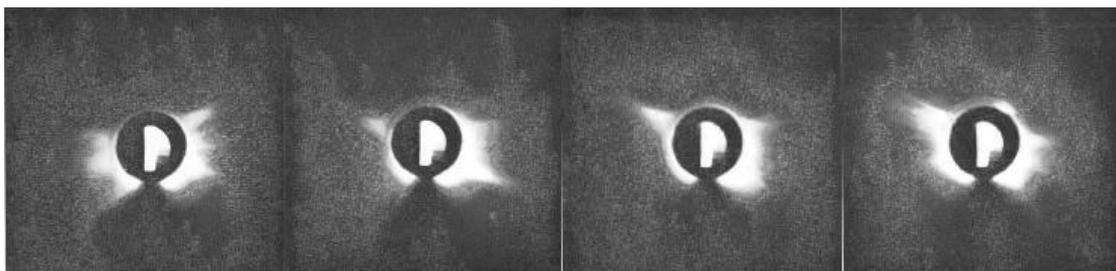


Figure 31: A space competitor, SKYLAB (1973-1979), here white light images of the corona on 28 May and 1, 5, 10 June 1973 (argentic film, Courtesy NASA, after [MacQueen et al, 1974](#))

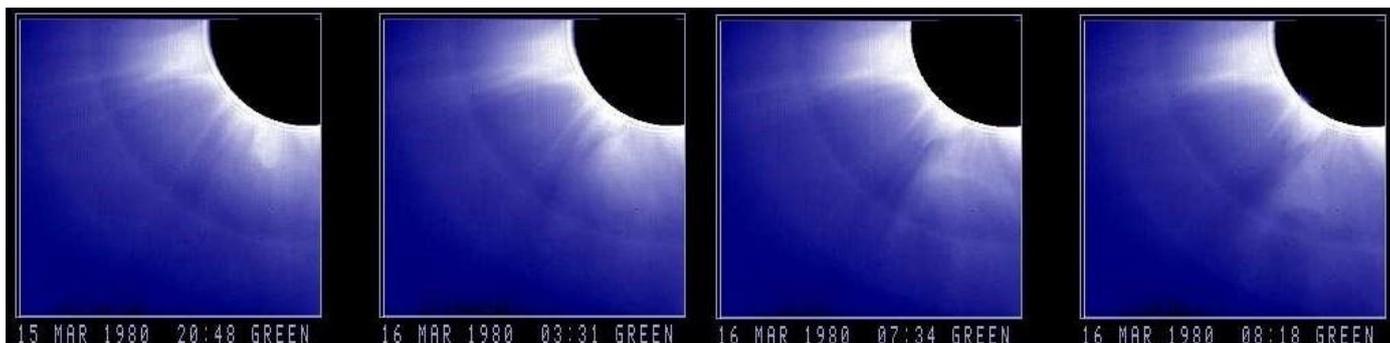


Figure 32: A space competitor just for 6 months in 1980, and 1984-1989, Solar Maximum Mission, here the coronal mass ejection of 15 March 1980 (vidicon tube, courtesy NASA and High Altitude Observatory)

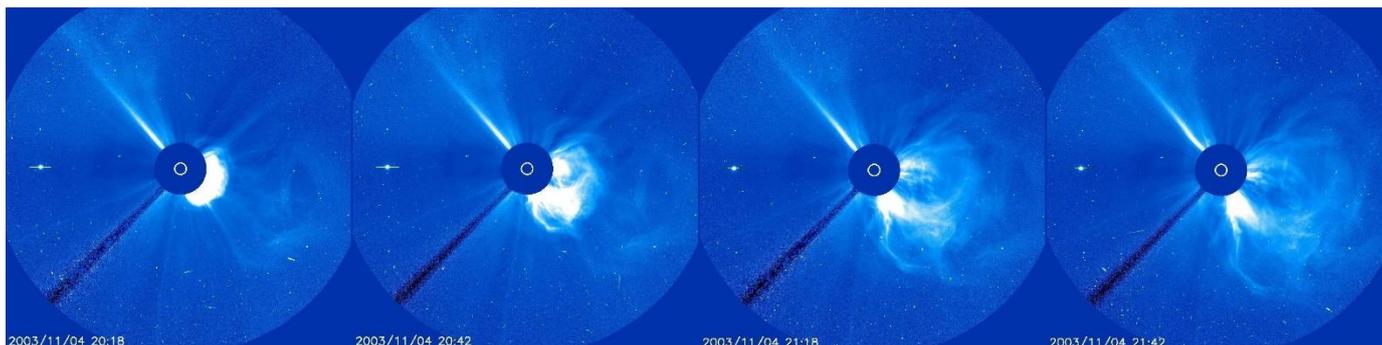


Figure 33: C3 SOHO/LASCO wide-field coronagraph running since 1996, here the coronal mass ejection of 4 November 2003 (1024² CCD, courtesy ESA/NASA)

THE HERITAGE: TOWARDS A SECOND LIFE FOR THE OBSERVATORY

The second life of the Saint V eran station began after a visit by Paul Felenbok and Jacques L orat in the summer of 1988: they were surprised to see the good conservation of the facilities after six years of closure; L orat then tried to interest amateur astronomers and promote the dissemination of scientific culture, with the agreement of Paris Observatory. The next step was in 1989, when the AstroQueyras association of amateur astronomers was created and took in charge the observatory. They installed in the 7 m dome a 62 cm Cassegrain telescope (Figure 34) on loan from Observatoire de Haute Provence (OHP), which was open to amateurs in 1990 (Menel, 2017).



Figure 34: the 62 cm night telescope replaced the coronagraph in the 7 m dome (courtesy Paris observatory)

The observatory developed progressively with the adjunction of two other domes, both with 50 cm aperture night telescopes. In 2015, the capacity of the station was extended from 6 to 18 visitors and the living areas were totally rebuilt (figure 35). Solar photovoltaic panels provide now electric energy. In parallel, “la Maison du Soleil” (the Sun’s house), in Saint Véran village, was open in 2016, in collaboration with Paris observatory. It is a modern interpretation space for the public devoted to the nature of the Sun. It includes professional instruments, operated by the local staff: a 40 cm coelostat, a 30 cm solar refractor to produce a large white light image, and a 7 m Czerny-Turner type spectrograph. It is the SHARMOR, a powerful tool formerly used for the analysis of laboratory studies in Meudon; this high resolution spectrograph (5 mm/Angström) is now fed by a 50 cm concave mirror (previously used at Pic du Midi by Raymond Michard), to demonstrate the Doppler effect in Sodium lines. Paul Felenbok was in charge of the scientific conception and setup of all these experiments provided by Paris observatory; he also defined the contents of the scenography concerning the Sun.

Other altitude stations were founded by French astronomers in other mountain sites, which operated for ten years within the framework of specific objectives, and then were made available to amateur astronomers who took advantage of the infrastructure thus created. This is the case, for example, of the Chiran station (1910 m, Haute Provence) where a temporary 1 m telescope was installed in 1976 by OHP. The Chiran is now managed by a local association. In the same area, Mount Mounier station (2800 m) was created by Nice observatory (a 38 cm refractor) at the end of the nineteenth century, but was dismantled at WW1. The only altitude site where professional and amateur astronomers seem to coexist today is the Pic du Midi. The situation is more or less similar for Swiss mountain sites; the Gornergrat (3100 m) hosted two optical telescopes and a radio antenna which were stopped and replaced by small instruments for academic or public outreach; the Jungfrauoch Sphinx (3570 m) had a 76 cm telescope which is no more active. Modern astronomy focuses now on space missions, or giant ground based telescopes for which available place, easy access, dry climate and good seeing are essential criterions.



Figure 35: Saint Véran observatory after reconstruction in 2015 (courtesy Dominique Menel)

CONCLUSION

The foundation of the high altitude (2930 m) astronomical station at Saint Véran was a fantastic and difficult adventure led by Paul Felenbok. Everything had to be constructed, such as a track, a living house, a dome, or brought, such as electricity and heating generators; the task was complicated by the altitude and the lack of human and financial resources. The coronagraph project was innovative and original, as it was based on the electronic valve camera in order to explore the far corona or faint emission lines. Unfortunately, the operating of the camera failed. At the same time, the pressure to use the new CFHT telescope with an improved model of electronic camera was increasing, so that the station stopped prematurely in 1982. It is clear, forty years later, that this beautiful undertaking was complicated by the lack of logistics and resources. Professional astronomers proposed later for Saint Véran projects of night telescopes, such as a large 3 m polar telescope (POST, 1990) or recently a 1 m robotic telescope, but they were either not selected or not built there, because of working conditions. An automated solar telescope (MeteoSpace) was also proposed in 2015 and finally achieved at Calern plateau (Côte d’Azur observatory). The main issue with telescopes which operate remotely or automatically, in environments similar to Saint Véran, is the access and the lack of permanent staff in case of failure. But amateur astronomers succeeded to develop the observatory

after 1989; they now own three night telescopes of the 50 cm class. The accommodation capacity increased in 2015, owing to local and European grants, allowing the public to come, visit and observe for one night; in 2016, the Sun's house was open in Saint Véran village in close collaboration with Paris observatory. The high altitude station is now officially called "Saint Véran – Paul Felenbok" observatory.

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Remy Bellenger (retired in 2014) was optician, and later electronician, of the Centre National de la Recherche Scientifique (CNRS). He was part of the technical staff of Paris-Meudon observatory and strongly implied in the construction and the development of Saint Véran station from 1974 to 1982, and was responsible of the site. He contributed later to major international projects, such as instruments of the ground based European Southern Observatory or the Canada France Hawai Telescope, and subsystems of space missions, such as EVRIS or COROT.