# THE CANADA-FRANCE-HAWAII TELESCOPE

Pierre Y. Bely and Gérard Lelièvre
C.F.H.T. Corporation, Kamuela,
Hawaii U.S.A.

ABSTRACT: Visiting astronomers have now used the CFH telescope for 18 months in the prime focus and coudé configurations. Many observers have reported very good image quality and high resolution plates have already been obtained. The general concepts and technical details of the telescope and observatory are discussed. The focal plane instrumentation includes more than 25 instruments and detectors, and these are also discussed.

## GENERAL CONCEPTS

Being part of the large optical telescope club means having access to a telescope with a direct prime focus. Allowing for minimal space for observer and instrument and a reasonable light loss, the primary mirror must be at least 3.5m in diameter. This is the maximum aperture that we could afford. Canada, France and Hawaii have relatively small research budgets, but big ambitions. In order to compete with the larger American telescopes and the Goliath Soviet 6 meter, we had to employ the ruse of David; what we could not obtain with large apertures, we would compensate by better images and more efficient use of telescope time.

We therefore concentrated our efforts along the following lines:

1. The optics should be of the best technically obtainable quality and efficiency.
2. The mount and drive should be very stiff to minimize vibration and allow rapid correction of image motion.
3. The control system should use the latest technology to minimize telescope setting time and facilitate observational data acquisition.
4. The observatory should be located at one of the best sites available on earth.
5. The immediate environment of the telescope, i.e., the dome and building, should be designed in such a way as not to degrade the intrinsic quality of the site.

*C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 21–32.*

6. The instruments to be attached to the telescope should be of the highest quality and performance.

## OPTICS

An f/3.8 parabolic primary was chosen to satisfy the requirement for a reasonably short focal length (giving reduced dome and building costs) whilst ensuring that the optical quality would not be compromised. However, a fast Cassegrain beam was also desired (around f/8) and for this, a 1.5m diameter Cassegrain secondary mirror was required. The primary mirror, polished by R. Dancey in Victoria(B.C.), does indeed fulfil all our expectations. Except for a very small band at the edge, which has been blocked off, the optical surface is extremely good and 90% of the light falls within 0.3 second of arc.

The main drawback of the classical parabolic/hyperbolic combination is, of course, the small field attainable at both prime and Cassegrain foci. This difficulty was circumvented thanks to elegant optical solutions found by Wynne (1974) of Imperial College, London. By mastering third order aberrations, Wynne was able to obtain a field of 40' at the prime focus with only 3 lenses. Image quality is better than 0.7" at the edge of the field. For the Cassegrain focus, Wynne was able to design a corrector with only two lenses for a field of 25'. The residual spherical aberration of the two lens combination is compensated by defocusing the Cassegrain mirror. Thanks to these innovations, our "traditional optics" compare favourably with the Ritchey-Chrétien combination from the point of view of field, and 25cm x 25cm plates can be covered at both the prime focus and Cassegrain.

On-axis mounts normally require no less than 5 mirrors for the coudé combination. Since variable incidence mirrors were ruled out because of polarization effects and enhanced coating problems, and since we wanted a horizontal coudé room, our coudé train ended up with 7 mirrors: primary, secondary and 5 flats (Figure 1). However, to reduce losses, the entire train is coated in the manner first introduced by Richardson (1972). The secondary mirror and the flat mirrors are each a 3-mirror combination coated for blue, red and UV. As a result, light losses after 6 reflections can be kept under 25% in the blue and UV and under 15% in the red/IR as compared about 70% if standard aluminum coatings had been used. The f/108 coudé focus is transformed into a more manageable f/20 thanks to a doublet objective, which itself is composed of 3 units, one for each colour.

## THE MOUNTING

The mount is an equatorial, a choice dictated by our generally conservative approach but also because it was felt that the 3.6m size did not justify going to new designs such as the altazimuth.

**OPTICAL DESIGN PARAMETERS OF THE CANADA-FRANCE-HAWAII TELESCOPE**

| | |
|---|---|
| **Primary Mirror—** | |
| **Material** | **CER-VIT** |
| **Outside diameter** | **3.66 m** |
| **Usable diameter** | **3.60 m** |
| **Figure** | **paraboloidal** |
| **Focal length** | **13.53 m** |
| **Prime focus—** | |
| **Focal Ratio** | **f/3.8** |
| **Usable Field** | **2.5′ without corrector** |
| | **1° with 3-lens corrector** |
| **Cassegrain Focus (visible and ultraviolet)—** | |
| **Focal Ratio** | **f/8** |
| **Usable Field** | **10′ without corrector** |
| | **25′ with 2-lens corrector** |
| **Cassegrain Focus (infrared)—** | |
| **Focal Ratio** | **f/36.5** |
| **Oscillating Mirror** | **1′ amplitude (max.)** |
| **Coudé Focus—** | |
| **Focal Ratios** | **f/108 (intermediate focus)** |
| | **f/20 (actual focus)** |
| **Usable Field** | **20″ without field lens** |
| | **2′ with field lens** |

Table 1

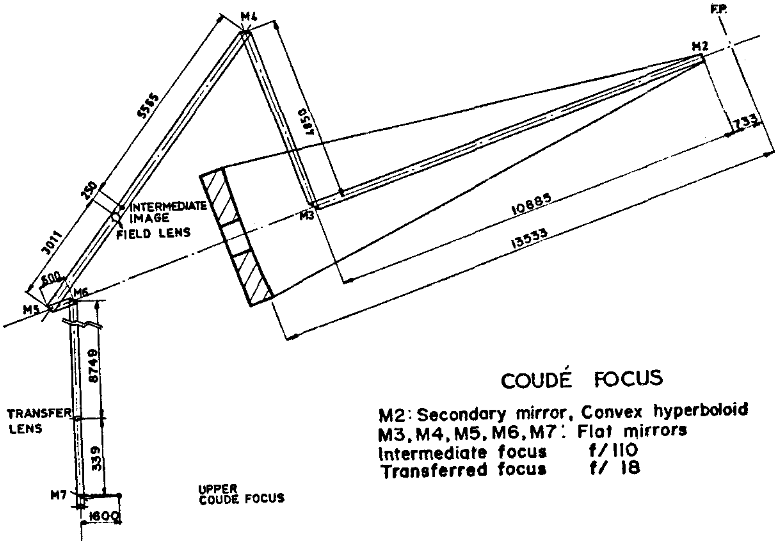


Figure 1

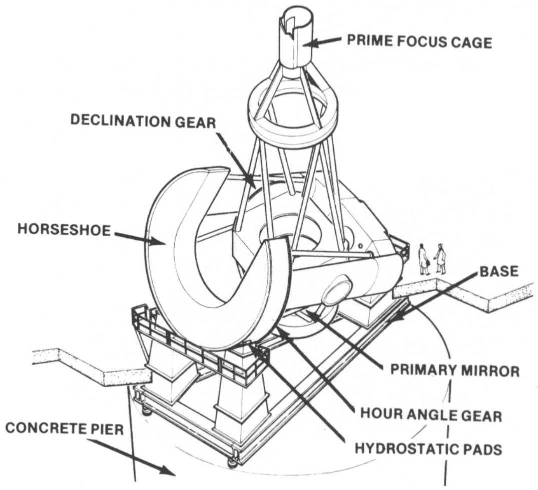
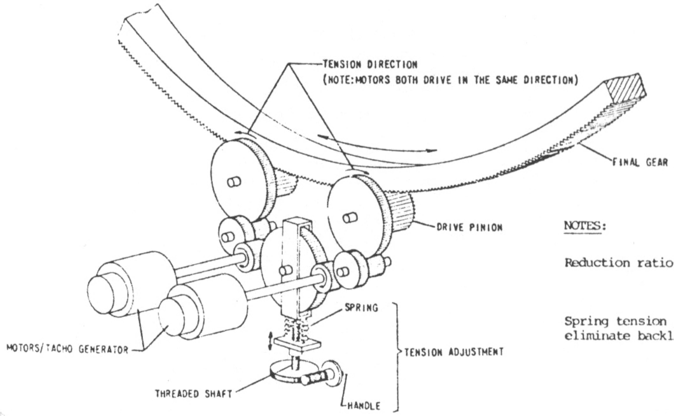


Figure 2. Artist's view of the telescope in the prime focus mode



NOTES:

Reduction ratios: 1/248 for alpha
1/251 for delta

Spring tension is adjusted to eliminate backlash under tracking.

Figure 3. Schematic of drive gear reducer

A polar type mount was preferred to the fork because of better access to the Cassegrain focus and also because of the low latitude (20° N). The general structure is therefore very similar to that of the 5 meter on Mt. Palomar except that the polar axis is driven from the "heavy end", i.e., from the horseshoe (Figure 2). We were thus able to reach a natural frequency around the polar axis of more than 6 Hz instead of 1 Hz had it been driven from the south "small end". Vibrations are minimized and automatic guidance systems are able to follow image wandering much more closely. The mount is driven through a 10 meter diameter gear attached to the horseshoe and encoded for the servo-system with a friction type encoder rolling on the horseshoe. The position encoder is connected to the driving pinion. The use of such a large radius for both driving and encoding allows for higher pointing and tracking accuracy (Bertin, 1971).

The drive on each axis is composed of a double train of gears and motors (Figure 3). Both motors are used for pointing, but only one for tracking. Antibacklash is not obtained through electrical controls as in most systems, but is purely mechanical for a better rigidity factor. Foci changes are accomplished by exchanging the upper end of the telescope. We have three upper ends: (1) Prime focus and coudé; (2) Cassegrain f/8; (3) Cassegrain f/35 for IR observations.

## THE CONTROL SYSTEM

The telescope controls are fully computerized. Pointing accuracy is typically less than 20" and it is hoped that we shall attain 5" or less when flexure parameters are introduced. The computer is also used to control auxiliary functions such as balancing, dome positioning, etc. The telescope control system is fully linked to the instrument acquisition system, thus allowing the telescope to follow the observer's program automatically (sequential pointing, trailing, etc).

## THE SITE

Located at an elevation of 4200m in the middle of the Pacific, Mauna Kea on the island of Hawaii is one of the best sites in the world. About 75% of the nights can be used for observing with close to 60% being of photometric quality (Morrison et al., 1973). Seeing is often better than 1 arcsecond and seeing as good as 0.3 arcsecond is not unusual. Values greater than 2 arcsecond are rare. This is confirmed by trailed plates obtained with the telescope locked at zenith position. These plates show images around 0.3-0.4 arcsecond (Figure 4). Because of the isolation of the mountain from light pollution, the sky is extremely dark. Sky brightness approximates 22.5 magnitude arcsec$^{-2}$ in B. Mauna Kea is also an excellent site for infra-red and submillimetre observations due to low water vapor concentrations. Water vapor is usually well under 1mm precipitable and sky noise less than $10^{-7}$ W cm$^{-2}$ steradian$^{-1}$.

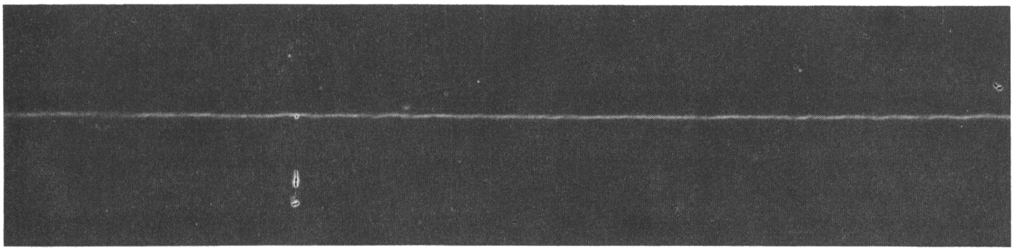


Figure 4: Typical trail plate at the prime focus.

## THERMAL ENVIRONMENT OF THE TELESCOPE

An additional feature of the site is that the night temperature is extremely stable from the beginning of the night to the end, and from one night to the next (Figure 5). This helps to keep the telescope and its immediate environment at a temperature close to the ambient, thus minimizing local seeing deterioration.

Additional care was also taken in the design to minimize degradation of the seeing by the local environment of the telescope. The exact location and shape of the observatory were selected after extensive studies had been made both with wind tunnels and on site. A 40 meter mast was installed at the proposed site to ascertain the minimum height needed to alleviate ground effects. This height was found to be about 20 meters (Laboratoire d'Aerodynamique Report, 1974). To avoid optical disturbances arising from heat which is generated within the building, the latter is well insulated and cooling of the observing floor acts as a further barrier (Figure 6). Building air is exhausted away from the building and a slightly negative inside pressure is maintained to avoid leaks towards the telescope area.

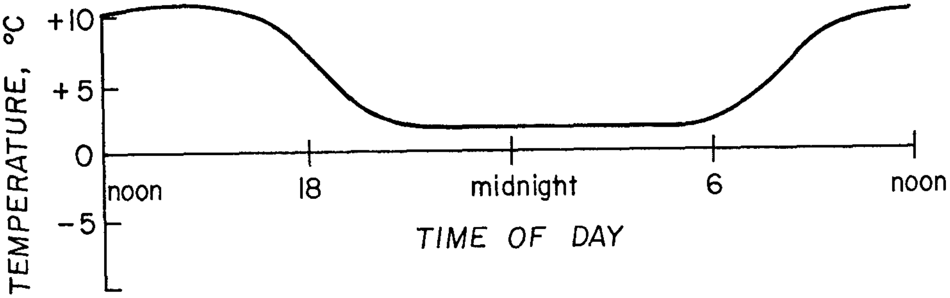


Figure 5: Typical temperature profile at Mauna Kea.

## INSTRUMENTATION

To ensure the most efficient use of telescope time, the quality of the instrumentation has to be matched with the natural quality of the site and the technical performance of the telescope. Six years ago, a program was initiated for the construction of instruments and detectors. These instruments are being, for the most part, developed by the astronomical institutes within the CFH community (Table 2). They cover the 300nm to 2.5mm radiation wavelength domain.

### Data Acquisition and Instrument Control System

Many instruments are remote controlled. The standard communication system used is CAMAC. Figure 7 shows the general arrangement of Hewlett Packard computers and CAMAC crates available for instrumentation.

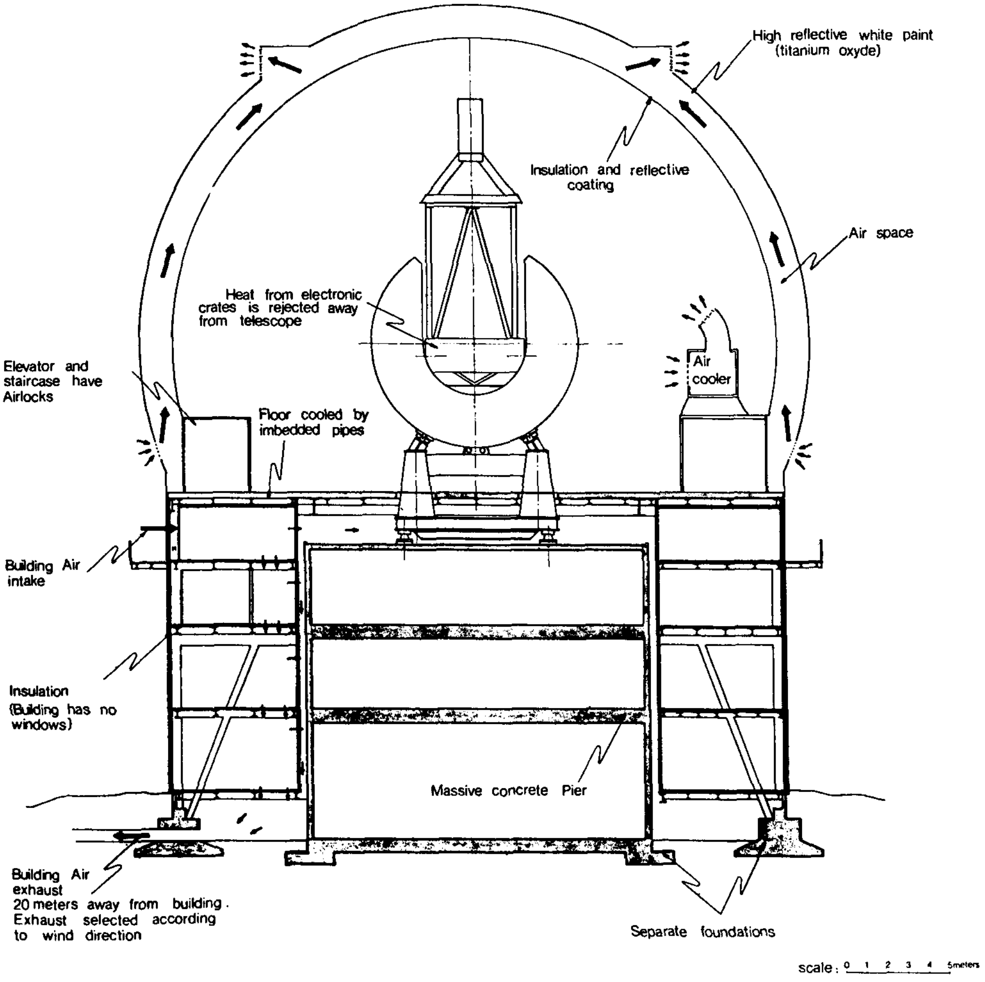


Figure 6: Section of dome showing thermal design features.

Computers, modules and cables are easily exchangeable. Computer no. 1 is currently used for data acquisition, while computer no. 2 is dedicated to test new equipment and is also available as a back-up. A permanent dialogue is established between the data acquisition computers and the computers for the Telescope Control System so that the telescope can be driven according to the constraints of the experiment. In Figure 8, we give a typical example where four complex instruments have to work together on the telescope: Cassegrain adapter, Focal reducer, scanning Perot-Fabry, and Photon Counting TV. A general TV system is located at the various foci and in the guiding heads for focusing, centering and guiding.

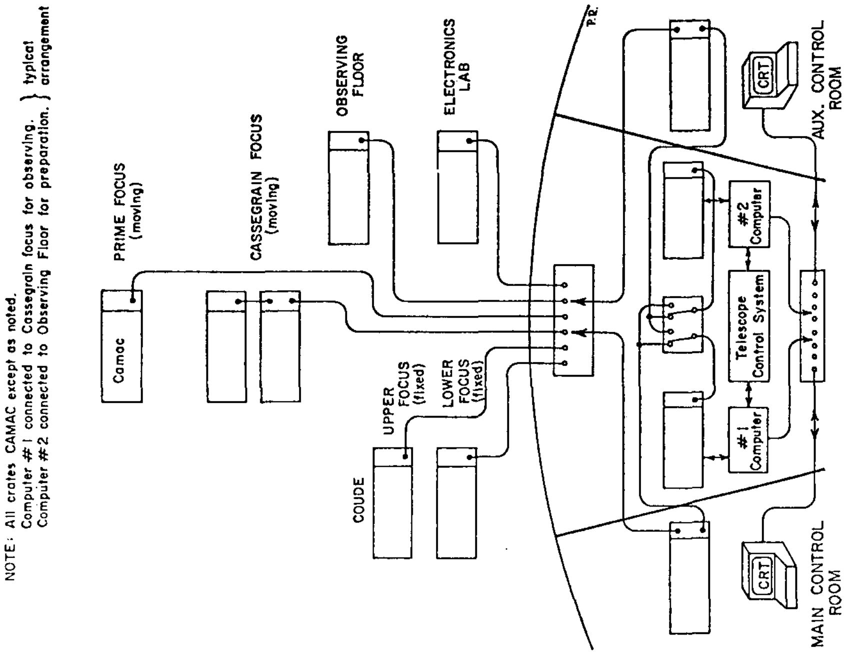


Figure 7. Computers and CAMAC system

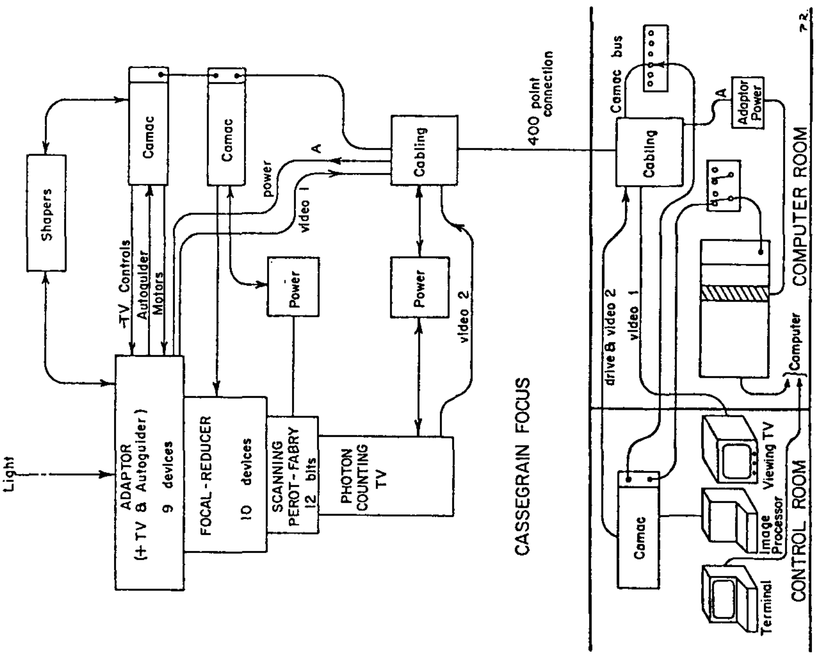


Figure 8. Perot-Fabry scanner

## General Purpose Detectors

A wide range of detectors will be available at C.F.H.T. These are summarised in Table 2. A set of electronographic cameras is being made at Paris Observatory for direct imagery or spectrophotometry with a long slit spectrograph at the Cassegrain or a coudé F/3.7 spectrograph. A 9cm photocathode ITT image tube is available and an EMI tube will be associated with the faint object spectrograph. A Photon Counting Camera (256 x 256 pixels) has been completed by the Laboratoire d'Astronomie Spatiale, Marseille, and the Observatoire de Haute Provence. The University of British Columbia is developing Reticon and CCD detectors. The Reticon device, already in operation with the F/7.4 coudé spectrograph, provides excellent data. The CCD will have 388 x 480 pixels.

## Prime Focus Instruments

The prime focus has now been in use since March, 1980, for both direct images and spectroscopic work. Wide field work is very popular. The properties of the wide field corrector are described elsewhere (Fouéré et al., 1982). The particular property of this corrector is that the third lens can be replaced by a special lens on which a grating has been replicated to obtain wide field slitless spectroscopy. A small UV corrector, with a field of 25 arcmin, has been specially designed for UV and blue (300 - 500nm). Its optical quality is also excellent and image quality of less than 0.7 arcsec (FWHM) has been obtained.

| | |
|---|---|
| Prime Focus<br>Guiding head and adapter<br>Wide field corrector<br>Grenses (blue/green); grism (red)<br>UV corrector<br>Racine wedges<br>Photographic assembly<br>Faint Object Spectrograph | Cassegrain f/8<br>Guiding head and adapter<br>Cassegrain corrector<br>Focal reducer<br>Fabry-Perot<br>Visible photometer<br>Photographic assembly<br>Polarimeter<br>Faint Object Spectrograph<br>Long slit Spectrograph |
| Coude Focus<br>f/7.4 Spectrograph<br>f/3.7 Spectrograph | Cassegrain f/35 (IR)<br>Guiding head and adapter<br>IR Photometer<br>Fourier transform Spectrometer |
| Detectors<br>Photographic plates, electronographic camera, photon counting camera, image tubes, Reticon, CCD | |

Table 2. Summary of CFHT Instrumentation

A variety of photographic and photometric instruments are available, including photographic cameras, Racine wedges (Racine, 1969), etc. A prime focus adapter and guiding head can be mounted behind the wide field corrector for adaptation of any instrument designed for the prime focus and remote control guiding and focusing.

## Coudé Focus Instruments

The coudé focus was put into operation in October 1980. The coudé spectrograph F/7.4 gives a dispersion of 2.8 Å/mm in the blue with a mosaic grating (308 x 412mm). With the Reticon, this spectrograph allows one to reach a star of magnitude R=5 in 6 minutes at 2.38 Å/mm with a signal to noise ratio of 100.

An echelle coudé spectrograph is being designed with an F/3.7 camera to give a dispersion of 1 Å/mm. Detectors will include photographic plates, Reticon, photon counting camera, electronographic camera and CCD.

## Cassegrain Focus Instruments

Two aperture ratios will be used: F/8 and F/35. The guiding head, already operational, will remain the same in both configurations. One big instrument and four small devices can be mounted at the same time on the adapter and changed by means of a rotating mirror.

The F/8 focus will be equipped with photographic equipment, a photoelectric photometer completely computer controlled, and a polarimeter built by the University of Toronto. A faint object spectrograph is being fabricated by the Dominion Astrophysical Observatory at Victoria, B.C. It will have small and intermediate dispersion (160 to 40 Å/mm) and good luminosity. A long slit spectrograph is also being made by the Institut National d'Astronomie et de Géophysique in Paris, with a total weight of 1.6 ton. The spectrograph will give an intermediate dispersion 20 to 60 Å/mm. With the help of the electronographic camera, spectra of 19th magnitude stars are expected. A scanning Perot-Fabry spectrometer will also be ready soon.

The f/35 focus is equipped with a special oscillating mirror for background subtraction and is dedicated to IR work. Main instruments for that focus will include an infra-red photometer working in two modes, 1 to 5μm and 5 to 30μm with a bolometer, and a Fourier Transform spectrometer which is described by Maillard (1982).

## Non-CFH Instruments

In addition to the CFHT basic instrumentation listed in Table 2, the agencies of Canada, France and Hawaii have their own program of instrumentation specially designed for the CFH Telescope. As an example, we give here the program conducted by the Institut d'Astronomie et de Géophysique:

(1) Electrostatic electronographic camera (30mm for prime focus); (2) Magnetic electronographic camera with a large field (90mm) and high resolution; (3) Phircom: a device for infra-red imagery using a coding with a Hadamard grid; (4) Speckle interferometry in the infra-red with a CID mosaic; (5) Si-As mosaic for infra-red imagery; (6) Two types of Michelson interferometer (Romeo II and Doronic) to study planets or interstellar matter; (7) A multi-slit spectrometer which will give a 15 arcmin field. It will be possible to suppress the sky background and bright stars; (8) A special UV spectrograph with an aspheric holographic reflection grating as described by Lemaître (1982); (9) A sub-millimeter photometer which will have 12 filters in the atmospheric windows in the spectral range 330μm to 2.5m.

## CONCLUSIONS

After only a year and a half of use by observers, the Canada-France-Hawaii Telescope is just starting its "scientific life". However, the first scientific results obtained already seem to justify the efforts put into its making and in the choice of Mauna Kea for optimum observing conditions. Excellent seeing conditions of less than one second of arc are frequently reported showing that by careful design of the dome and building, the natural quality of the site is not adversely affected.

The high resolution of the prime focus has already led to novel observations: new galaxy structures have been discovered; knowledge of the M87 jet and of the nucleus of NGC 2903 has been improved; all globular clusters around M33 presently known from 2.5 hour Kitt Peak plates can be identified at CFHT on a 15 minute exposure in B with a limiting magnitude approaching 22; structures around close quasars have been detected either with traditional photographic plates or with the electronographic camera; the Pluto-Charon system has been resolved using speckle interferometry. The 25th magnitude in B is easily, routinely reached with long exposures. At the coudé focus 10th magnitude sources can be reached with 2.4 Å/mm dispersion.

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