Users' Manual For The CFHT Fourier Transform Spectrometer

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Abstract

This manual provides a brief introduction to the CFHT Fourier Transform Spectrometer (FTS); it discusses the general design of the instrument in a relatively nontechnical fashion as well as the basic procedures for its operation. Those interested in a more detailed technical discussion should consult “Active Control For a Fourier Transform Spectrometer” by J.-P. Maillard and G. Michel (Proceedings of IEEE Regional 6 Conference, 1981) and “An Astronomical Fourier Transform Spectrometer” by P. Connes and G. Michel (Applied Optics, Volume 14, pp. 2067, 1975). The latter article describes an instrument which is in many ways similar to the CFHT FTS. The CFHT FTS itself is discussed by Maillard and Michel in “A High Resolution Fourier Transform Spectrometer For The Cassegrain Focus At The CFH Telescope” (Instrumentation for Astronomy with Large Optical Telescopes, ed. C.M. Humphries, p. 213–222. An excellent review of interferometers in general can be found in “High Resolving Power Fourier Spectroscopy” by H. Sakai, which is Chapter 1 of the book “Spectrometric Techniques Volume” (Academic Press, 1981) and the text “Fourier Transform Infrared Spectrometry” by P.R. Griffiths and J.A. de Haseth provides a wealth of information. Finally, S. Johnston’s “Fourier Transform Infrared” (Ellis Horwood, 1991) provides a very interesting historical summary of Fourier transform spectroscopy.

This manual does **NOT** include a discussion of data reduction techniques and software for use with CFHT FTS data. Instead, the user should refer to the manual “The CFHT Fourier Transform Spectrometer Data Reduction Program Users’ Guide,” by Bohlender and Link for information on reducing CFHT FTS scans. This document is available in hardcopy form or can be accessed from Xmosaic.

It should be pointed out that this manual is a somewhat expanded version of an earlier draft written by Dr. Timothy Davidge during his tenure as a CFHT Resident Astronomer. However, the current author assumes full responsibility for any errors or omissions occurring in this final version of the manuscript. Any questions or comments should be referred to David Bohlender (david@cfht.hawaii.edu) or the Directors (directors@cfht.hawaii.edu).

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Chapter 1

An Introduction to Interferometers

1.1 Why Fourier Transform Spectrometry?

With the rapid improvement of the noise characteristics of infrared detectors the multiplex advantage of infrared spectroscopy with a classical Fourier transform spectrometer (FTS) is just as rapidly diminishing. However, the CFHT FTS has a number of instrumental characteristics that still make it very attractive for astronomical observations in the 0.9 to $5.5\mu m$ range.

The FTS has a very high throughput, or étendue which is largely independent of the wavelength of the incident radiation. It has a circular entrance aperture rather than a slit and an inherently high efficiency. With an appropriate choice of beam splitter the overall telescope plus FTS combination can transmit on the order of 25% of the incident flux.

High signal-to-noise observations can be made routinely and is a consequence of several factors. In the case of the dual aperture, dual detector CFHT FTS, rapid modulation of the path difference places the data frequencies in the range of a few hundred Hz, lower than the frequencies associated with atmospheric scintillation, or telescope or building vibrations and hence reduces noise substantially. Since the two detectors always detect all of the flux in the passband of the filter, internal normalization of the data can be applied to further reduce sensitivity to source variations of any kind, including guiding errors. The dual input apertures provide continuous internal sky subtraction prior to the detection of any signal and can typically reduce the sky contamination (such as OH emission) by a factor of 50. At longer wavelengths beam switching can be applied to compensate for any residual sky contamination and can result in a total cancellation factor of 10^3 to 10^4.

The quality of spectra obtained with the FTS can be superb. The instrumental profile is controlled by characteristics of the instrument and the observations, is very clean, and can easily be measured. Scattered light simply does not exist in an FTS, and wavelength precision of $100 ms^{-1}$ can be readily obtained throughout the passband. The flexibility of the instrument is remarkable — the resolving power can be tailored to the scientific program and the Doppler velocity resolution can approach $500 ms^{-1}$.

It is also possible to perform low-resolution, 2–dimensional spectroscopy on extended objects by replacing the normal InSb detectors with one of the CFHT Redeye cameras — an instrumental configuration referred to as "Bear". In this mode interferograms are recorded for each pixel of the image on the 256×256 NICMOS3 array. Spectra for each pixel or monochromatic images of the target can then be obtained by analysing the recorded data cube. This manual will not discuss this mode of operation and interested investigators should contact CFHT staff for more detailed information, or see the article by Maillard and Simons, "First Results of an Imaging FTS with a NICMOS Camera" (Proceedings of an ESA Workshop on Solar Physics and Astrophysics at Interferometric Resolution), p. 205–210.

The above characteristics and others lead some to refer to the CFHT FTS as the "last word" in astronomical Fourier transform spectrometers (Johnson, "Fourier Transform Infrared: A Constantly Evolving Technology," [Ellis Horwood, 1991] p. 249.).

1.2 The Basic Mathematics of Interferometry

Consider a monochromatic light source with wavenumber k ($k = 1/\lambda$, where λ is the wavelength of the source) and intensity I_0, directed into the classical Michelson interferometer shown in Figure 1.1. In the ideal case, half of the incident signal is transmitted by the beam splitter towards the movable mirror along path A while half is reflected towards the stationary mirror along path B. If the difference in lengths, x, of the two light paths to the detector is zero or an integer multiple of λ, then the signals from both arms of the interferometer will combine constructively after the beam splitter, and the output measured by the detector will be

$$I_D = I_0. \tag{1.1}$$

If the path difference is nonzero and not an integer multiple of λ then interference will occur, and the detected signal will depend on the path difference such that

$$I_D(x) = \frac{I_0}{2} + \frac{I_0}{2}\cos(2\pi kx). \tag{1.2}$$

Clearly, to conserve energy a signal of strength

$$I_I(x) = \frac{I_0}{2} - \frac{I_0}{2}\cos(2\pi kx) \tag{1.3}$$

is directed out of the interferometer in the direction of the input. The phase difference of 180° between the two output beams arises from the different number of reflections and transmissions that the light experiences as it traverses the two paths.

The above expressions can be generalized to sources with continuous spectral distributions, which can be thought of as the sum of an infinite number of monochromatic sources. Therefore, for a source with a spectral intensity distribution $I_0(k)$, the interference signal detected at a given path difference will be

$$\begin{aligned} I_D(x) &= \int_{-\infty}^{+\infty} \left\{ \frac{I_0(k)}{2} + \frac{I_0(k)}{2}\cos(2\pi kx) \right\} dk \\ &= \frac{1}{2}\int_{-\infty}^{+\infty} I_0(k)dk + \frac{1}{2}\int_{-\infty}^{+\infty} I_0(k)\cos(2\pi kx)dk. \end{aligned} \tag{1.4}$$

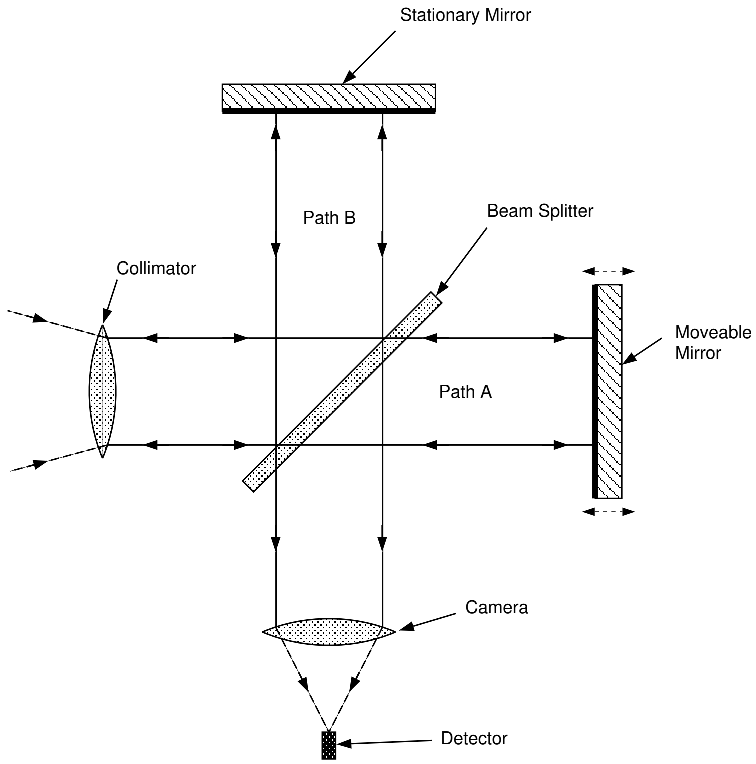

Figure 1.1: A Simple Interferometer

Note that at zero path difference (**ZPD**) $x = 0$ and

$$I_D(0) = \int_{-\infty}^{+\infty} I_0(k)dk \tag{1.5}$$

so that

$$I_D(x) = \frac{1}{2}I_D(0) + \frac{1}{2}\int_{-\infty}^{+\infty} I_0(k)\cos(2\pi kx)dk, \tag{1.6}$$

while for $x \gg 0$

$$I_D(x) \simeq \frac{1}{2}I_D(0). \tag{1.7}$$

In other words, the strength of the DC component of the signal is about one half that of the burst signal at ZPD.

By employing a different design than that shown in Figure 1.1, the CFHT FTS makes use of both outputs of the interferometer. The signals from the two detectors, $I_D(x)$ and $I_I(x)$ (Equations 1.2 and 1.3), are subtracted, after the appropriate gains have been applied to each to balance the DC component, and as a result the DC component is not recorded. This has the advantage of partially compensating for source fluctuations. The remaining AC component is the interferogram and is given by

$$I_S(x) \approx \int_{-\infty}^{+\infty} I_0(k)\cos(2\pi kx)dk \tag{1.8}$$

so that the recorded signal is essentially the Fourier transform of the source's spectrum. Consequently, the source's spectral distribution can be recovered by applying an inverse Fourier transform to the recorded interferogram:

$$I_0(k) \approx \int_{-\infty}^{+\infty} I_S(x)\cos(2\pi kx)dx. \tag{1.9}$$

In practice, the exact spectral distribution of the source can not be recovered since an interferometer is restricted to finite path differences. Because of this restriction, a truncated version of the interferogram is actually recorded:

$$I'(x) = I_S(x) \times \Pi\left(\frac{x}{2a}\right) \tag{1.10}$$

where $\Pi(x)$ is the so-called 'boxcar' function:

$$\Pi(x) = \begin{cases} 1, |x| < \frac{1}{2} \\ 0, |x| > \frac{1}{2} \end{cases} \tag{1.11}$$

and a is the maximum path difference. Therefore, the spectral distribution which is recovered from a measured interferogram is:

$$I'_o(k) = \int_{-\infty}^{+\infty} \left\{ I_S(x) \times \Pi\left(\frac{x}{2a}\right)\right\} \cos(2\pi kx)dx \tag{1.12}$$

Now, according to the convolution theorem:

$$\mathcal{T}(A \times B) = \mathcal{T}(A) * \mathcal{T}(B) \tag{1.13}$$

where $\mathcal{T}$ indicates a Fourier transform, A and B are arbitrary functions, and the symbol '$*$' indicates convolution. Applying the convolution theorem, the spectral distribution which is recovered is then

$$I'_o(k) = I_0(k) * \mathcal{T}\left\{\Pi\left(\frac{x}{2a}\right)\right\}. \tag{1.14}$$

The Fourier transform of a boxcar function is a sinc function:

$$\mathcal{T}\left\{\Pi\left(\frac{x}{2a}\right)\right\} = \frac{\sin(2\pi ka)}{\pi k} \tag{1.15}$$

and thus

$$I'_o(k) = I_0(k) * \frac{\sin(2\pi ka)}{\pi k}. \tag{1.16}$$

The effect of convolving the actual spectral distribution with the sinc function is to lower the spectral resolution. As the maximum path difference, a, increases the sinc function becomes narrower and the maximum resolution which can be recovered increases.

The manner in which the path difference is varied is another practical consideration which can affect the recovery of the spectral distribution. The CFHT FTS varies the path difference in discrete steps rather than in a continuous fashion; such a scheme makes it possible to monitor the position of the moving mirror with a high degree of accuracy. However, the interferogram is then digitized, and an appropriate sampling interval must be selected to avoid aliasing. According to the sampling theorem, aliasing in the wave number interval between k_l and k_u can be prevented by using a step size for the path difference which is no more than:

$$\Delta x = \frac{1}{2(k_u - k_l)} \tag{1.17}$$

1.3 The Effects of Modulation

The detector and the atmosphere are two important sources of noise for interferometric observations in the infrared. Noise from the former source is present in all observations and intensity variations due to changes in atmospheric transparency occur on many nights. Fluctuations of the refractive index of the atmosphere along the light path between the source and the detector, the so-called scintillation noise, can dominate in bright objects and in the thermal regime.

While the ubiquitous photon noise is characterized by its standard deviation being proportional to the square root of the total intensity, scintillation noise has the interesting property of being *linearly* proportional to the source intensity. This is the reason it becomes increasingly important for bright stars and in wavelength regions where the sky background becomes very large. It is generally not a factor in traditional grating spectroscopy because each detection element 'sees' radiation originating from only a narrow wavelength region, and as a result the intensities at the detector are quite low and photon noise continues to dominate. However, scintillation noise is an important consideration in interferometry where the detector is always measuring radiation multiplexed from a wide range of wavelengths. In fact, scintillation can introduce a multiplex *dis*advantage when observing bright stars.

Detector and scintillation noise both have a $\frac{1}{f}$ frequency dependence. This suggests that they might both be suppressed by modulating the signal so that it is sampled at high frequencies. In infrared photometry this is usually accomplished by use of a chopping secondary mirror, which is an example of *amplitude modulation.* Although chopping can also be used for interferometric observations, the same result can be achieved more efficiently with high frequency, low amplitude modulation of the path difference, a technique referred to as *phase* or *internal modulation.*

The CFHT FTS uses internal modulation and as a consequence the nature of the recorded interferogram is changed. In the case of a monochromatic source, the measured signal now represents the *change* of the signal given by Equation 1.2 occurring over a small increment of retardation. As a result, the constant component of the interferogram, I_0, and low frequency variations in this term are not modulated and can be totally eliminated providing the frequency of the modulation is chosen to be high enough. For the CFHT FTS, modulation frequencies of 20, 150, and 300 Hz are available at the turn of a switch (see Section 3.1.3).

Generalizing to the broadband case, if the path difference is modulated with an amplitude δ about some mean path difference x, the signal recorded by a synchronous detector will be

(from Equation 1.8)

$$I_M(x) = \int_{-k}^{+k} I_0(k)\cos(2\pi k[x+\delta]) - \cos(2\pi k[x-\delta])dk. \tag{1.18}$$

Trigonometric identities can be used to reduce this to the form

$$I_M(x) = \int_{-k}^{+k} -2\sin(2\pi k\delta)I_0(k)\sin(2\pi kx)dk. \tag{1.19}$$

It is apparent from this expression that the spectral distribution can be recovered when modulation is applied, although a sine transform must be used. Moreover, the result should be divided by $-2\sin(2\pi k\delta)$. Besides suppressing noise, modulation also makes the location of ZPD easy to identify because it now occurs as a zero crossing, instead of a maximum in signal intensity, which can be more difficult to locate accurately.

The optimum amplitude for modulation occurs when $I_0(k)\sin(2\pi k\delta)$ is maximized. This occurs when

$$\sin(2\pi\bar{k}\delta_{opt}) = 1 \tag{1.20}$$

where $\bar{k}$ is the wavenumber at the middle of the spectral region being studied and δ_{opt} is the optimum amplitude of the modulation. This condition is satisfied when

$$\delta_{opt} = \frac{2n+1}{4\bar{k}} = \frac{\bar{\lambda}(2n+1)}{4} \tag{1.21}$$

where n is an integer. In other words, modulation is most efficient when its amplitude is an odd multiple of the central wavelength of the region being observed divided by 4.

Chapter 2

The CFHT FTS

2.1 General Design

The FTS was designed and constructed by J.-P. Maillard for use at the $f/36$ infrared focus of the CFHT, and is bolted to the underside of the Cassegrain Bonnette. The focal plane is located 450 mm below the adaptor. The observer must specify on the Observing Time Request form whether the guide pellicle or mirror is to be mounted in the Bonnette. The choice depends on the nature of the observing program. The pellicle beam splitter permits guiding on the source directly while the guide mirror may be needed when off axis guiding with the Cassegrain Bonnette is needed, most often because of the faintness of the program target at optical wavelengths. In practice, the pellicle can be used for guiding on objects with V magnitudes brighter than 13 or 14 if the moon is not too close to the target area. Offset guiding is also possible with the pellicle but the area of the accessible guide field is somewhat smaller than for the guide mirror (for a more detailed discription see the discussion of the $f/36$ Cassegrain Focus in the CFHT Observers Manual).

The CFHT FTS is a stepped-scan interferometer. The movable mirror is held stationary at each sampling point and then moved rapidly to the next sampling position. The interferogram signal is produced by integrating the detector output signal during the time interval that the mirror is held stationary. The general optical layout of the FTS is shown in Figure 2.1. Two different light paths are indicated in this figure; the solid lines trace the paths followed by the sources on the sky, while the dashed line shows the path of the signal provided by the reference laser. A mirror (not shown) can be injected into one of the input beams just before the entrance aperture to direct radiation from a white light source into the FTS instead of a remote source. Not illustrated in the diagram is the path followed by the signal from a second laser used for alignment of the FTS.

A more schematic layout of the FTS is shown in Figure 2.2. The basic FTS design utilizes both inputs of the interferometer. The two entrance apertures have a projected separation of 52 arcsec and are oriented along the E/W axis when the Cassegrain Bonnette has a rotation angle of 0°. An adjustable *uncooled* iris, with a maximum opening of 24 arcsec, is located at each entrance aperture. One aperture samples the object being observed, while the other samples the sky. As a result, the sky background is automatically subtracted from

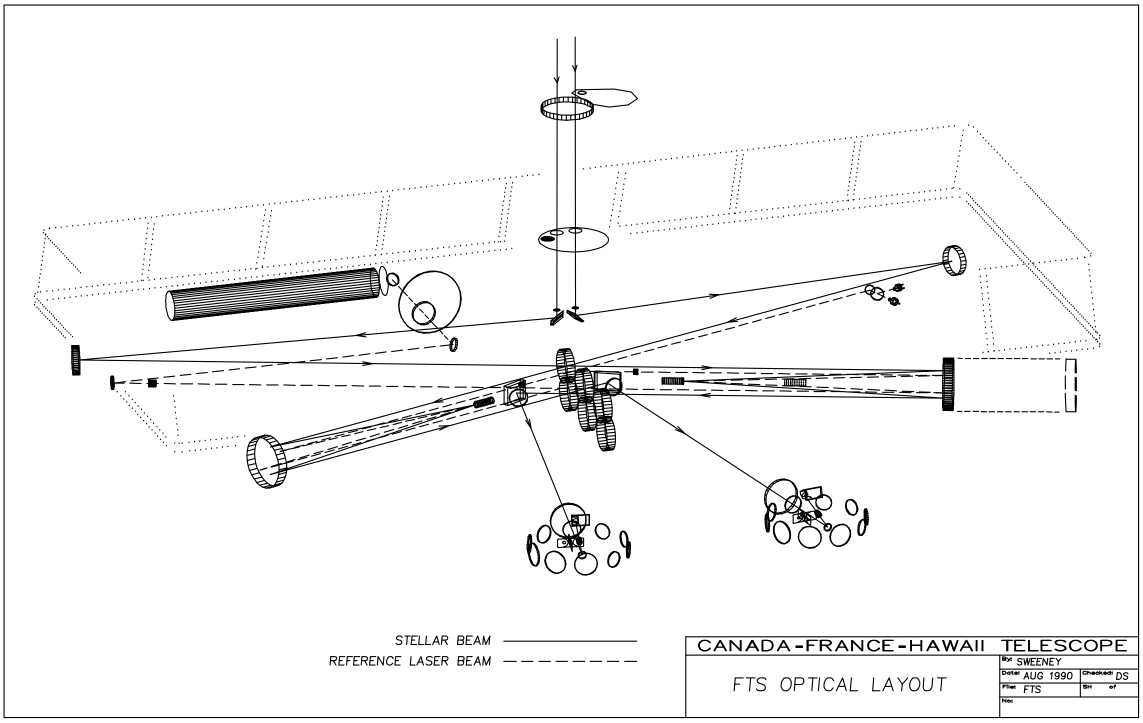

Figure 2.1: FTS Optical Layout

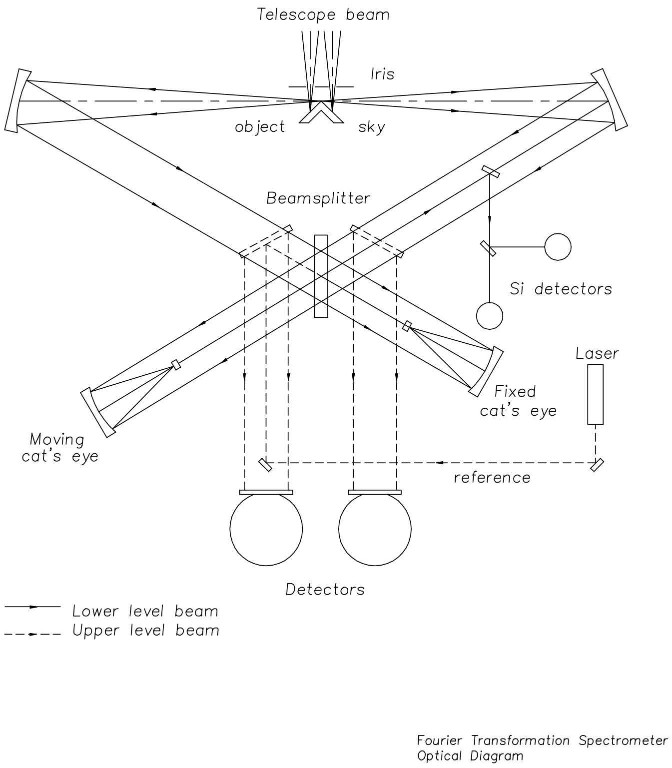

Figure 2.2: Schematic FTS Optical Layout

Beamsplitter	Material	Wavelength Range
VIS	Al coating on fused silica	0.4 - 1.1 μm
IR1	Si coating on fused silica	0.9 - 2.5 μm
IR2	Si coating on calcium fluoride	2.5 - 5.5 μm

Table 2.1: FTS Beam Splitters

the source signal since the radiation from the two inputs arrives in antiphase at the detector because of the different number of reflections and transmissions along the two paths through the interferometer (just as the two output signals from a single source are in antiphase; see Section 1.2). Beam switching can also be performed for situations requiring extremely accurate background subtraction, such as for observations in the thermal infrared where the sky background becomes very important — at wavelengths beyond $2.5\mu m$ the sky becomes increasingly bright, until longward of $3.5\mu m$ it is brighter than most astronomical objects. Beam switching is also recommended in the H and K bands for sources with K magnitudes fainter than 8, particularly if a large aperature is used.

The mirrors directly beneath the entrance apertures deflect incoming light to collimators which, like all mirrors in the interferometer, are sapphire-overcoated silver. The collimated signals, which have a beam size of $25mm$, are then directed to one of three beam splitters permanently mounted on a sliding carriage inside the spectrometer. The general characteristics of the three beam splitters are summarized in Table 2.1. The beam splitters are positioned using push buttons on the Auxiliary Control Panel (see Section 3.2) mounted on the side of the FTS.

Each arm of the interferometer contains a cat's eye mirror, a typical example of which is shown in Figure 2.3. A cat's eye system consists of a focusing primary mirror, M_1, and a secondary mirror, M_2, with centers of curvature located at C_1 and C_2 respectively. If collimated light is incident on the primary mirror these retroreflective devices return the beam in the original direction, almost independently of the angle of incidence. As a result, the arrangement is insensitive to tilt adjustments and ensures alignment of the input and output beams. It also offers two other advantages: the output beam is displaced from the input beam so that both outputs of the FTS can be utilized, and a small path difference change in the interferometer can be realized without moving the entire cat's eye assembly. In the case of the CFHT FTS the secondary mirror of each cat's eye is mounted on a piezo-ceramic stack, allowing the path difference to be modulated at very high frequencies (Section 1.3). One cat's eye assembly (the 'moving' mirror) is mounted on a screw-driven carriage with a $0.3m$ travel, which therefore permits a maximum path difference of $0.6m$. This assembly is translated along the carriage by a DC motor. The other cat's eye assembly (the 'fixed' mirror) is suspended from the optical plate and can move up to $\pm 1mm$. The motion of this mirror is controlled with a loudspeaker motor.

The fixed mirror is mounted with Bendix flexural joints, a setup which is almost entirely free of friction; however, this is not the case for the moving mirror. Adjustments to the overall path difference are made by first moving the fixed mirror assembly. A position transducer monitors this movement and sends a signal to the DC motor which adjusts the position of

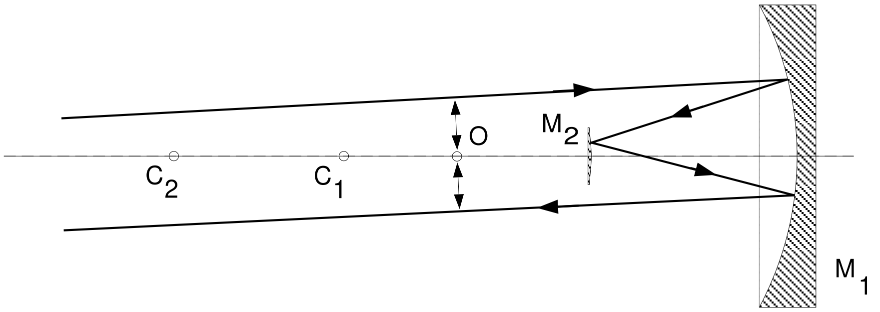

Figure 2.3: Cat's Eye Retroreflector

the moving cat's eye by a similar amount.

The relative position of the moving cat's eye assembly is controlled by using a fringe pattern produced by a single mode He-Ne laser (with a reference wavelength $\lambda_r = 6328\mathring{A}$). The basic procedure for generating the reference fringes is briefly discussed in the next section.

2.2 Generation of Error Signals

During data acquisition, the path difference is controlled very accurately using a signal from the reference laser, which is housed in a thermally stabilized environment to prevent drifting of the laser lines ($\frac{\Delta\lambda}{\lambda} \simeq 10^{-9}$). The laser beam is linearly polarized and is then directed to the beam splitter and into the arms of the interferometer. As the laser beam enters each arm of the interferometer it is passed through quarter-wave plates to induce circular polarization. The quarter-wave plates in the two arms are oriented such that the polarization vector rotates in a clockwise direction in one arm, and a counterclockwise direction in the other. As a result, when the beams are recombined, a rotating, linearly polarized signal of constant intensity is produced. The azimuth of the resulting electromagnetic vector depends on the net path difference, within one wavelength.

The angle of polarization, which contains information on the path difference, is measured using the following procedure. The rotating, linear polarized reference laser beam is directed away from the interferometer to another beam splitter, positioned before two polarizing filters and photodiodes. The polaroid filters are rotated such that the signals incident on the photodiodes have polarization angles differing by 45°, so that the signals output from the photodiodes are phase displaced by 45° to each other and each measure the strength of a different component of the incident electromagnetic vector. The signals measured by the photodiodes are

$$R_1 = I\cos^2\left\{\frac{\pi\Delta}{\lambda_r}\right\}, R_2 = I\cos^2\left\{\frac{\pi\Delta}{\lambda_r} + \frac{\pi}{4}\right\} \tag{2.1}$$

where Δ is the path difference and λ_r is the wavelength of the reference laser.

If the path difference is modulated about a mean path difference of Δ_m then

$$\Delta = \Delta_m + \epsilon\lambda_r \sin\omega t \tag{2.2}$$

where ω is 2π times the modulation frequency and ϵ is the amplitude of modulation in terms of λ_r. The signals measured by the photodiodes are then

$$R_1 = I\cos^2\left\{\frac{\pi\Delta_m}{\lambda_r} + \pi\epsilon\sin\omega t\right\} \quad (2.3)$$

$$R_2 = I\cos^2\left\{\frac{\pi\Delta_m}{\lambda_r} + \pi\epsilon\sin\omega t + \frac{\pi}{4}\right\}. \quad (2.4)$$

If the modulation is such that $\epsilon\sin\omega t \ll 1$ then simple trigonometric relations can be used to reduce these expressions further to the two quadrature signals

$$R_1 = \pi I\epsilon\sin\left\{\frac{2\pi\Delta_m}{\lambda_r}\right\}\sin\omega t \quad (2.5)$$

$$R_2 = \pi I\epsilon\cos\left\{\frac{2\pi\Delta_m}{\lambda_r}\right\}\sin\omega t. \quad (2.6)$$

If these two signals are summed after phase delaying R_2 by 90° at frequency ω, the result is then

$$S = R_1 + R_2' = \pi I\epsilon\cos\left\{2\pi\left(\frac{\omega t}{2\pi} - \frac{\Delta_m}{\lambda_r}\right)\right\} \quad (2.7)$$

This is the phase modulated reference to which the command position is compared to generate the error signal which in turn drives the servo system. However, in practice the phase of $R_1 + R_2'$ is not measured directly. The low frequency component of the error signal (< 30 Hz) is sent to the loudspeaker motor while the high frequency component (> 30 Hz) is sent to the piezo stacks.

The R_1 and R_2 signals are displayed as a Lissajou on an oscilloscope on the Master Control Panel (see Section 3.1.4). If the Lissajou figure on this oscilloscope is skewed then the net difference in polarization angles is markedly different from 45° and the polaroid filters in front of one of the photodiodes should be adjusted - consult CFHT support personnel.

2.3 Dewars and Detectors

The CFHT FTS uses two nitrogen cooled dewars mounted at each of the interferometer outputs. Each dewar contains a hybrid type Cincinnati Electronics InSb photovoltaic detector with a $10^{10}\Omega$ feedback resistor. With a band gap width at 77 K of 0.23 eV these devices are sensitive to radiation with $\lambda \leq 5.5\mu m$. A typical response curve for such a device is shown in Figure 2.4. During standard setups the nitrogen chamber is pumped and the detectors are operated at solid nitrogen temperatures (~ 56K). Three preamp gain settings are available, and the appropriate setting is selected based on the brightness of the source being observed. The lowest setting should be used for extremely bright objects, the middle setting is for objects of intermediate brightness, while the highest setting is intended for the faintest objects.

Four aperture cold stops are available with projected sizes of 2.5, 5.0, 8.0, and 12.0 arcsec. On special request a different size aperture can be mounted on one of the two largest aperture stops. Each dewar also contains a 10 position filter wheel, of which 9 positions are available

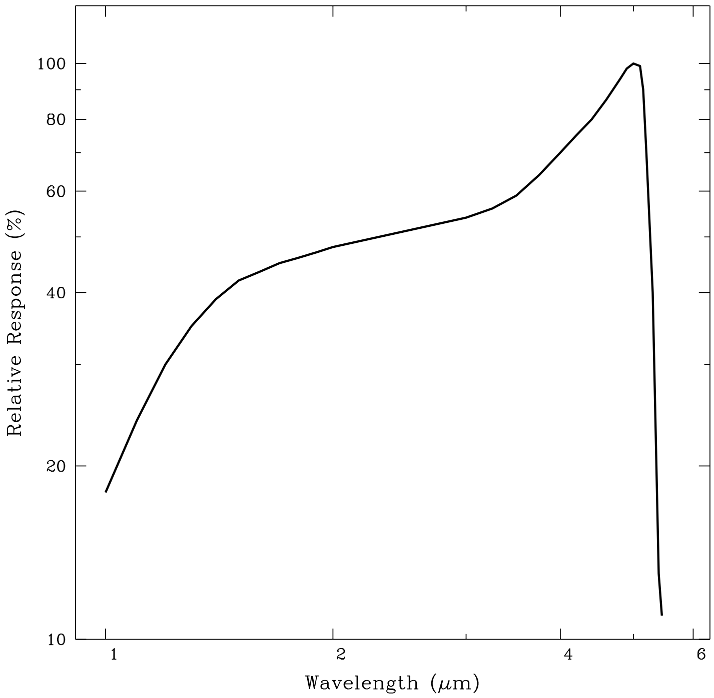

Figure 2.4: Typical InSb Detector Wavelength Response

for filters. A current list of infrared filters in stock at CFHT for use with the FTS is given in Appendix A. If custom filters are needed they should be ordered in pairs (one for each dewar) and should have a minimum diameter of 1 inch and a maximum thickness of 6 mm. Filters should also be coolable to liquid nitrogen temperatures, and have central wavelengths and bandwidths specified at this temperature.

Each dewar contains a 100Ω thermistor to monitor the temperature of the detector. The temperature can be measured using an ohmmeter from BNC connectors located on the side of each preamp electronics box. The electronic boxes are blue in color, and are mounted immediately in front of the dewars. When the nitrogen in the dewars is at atmospheric pressure, the resistance should be in the range $18.5 - 19.5\Omega$. Note that the two dewars may give slightly different (i.e. $\pm 1\Omega$) readings. When the nitrogen is pumped to low pressures, the thermistors should register values in the range $\sim 13.5 - 14.5\Omega$; values less than this indicate that the amount of pumping on the nitrogen reservoir is too great and should be reduced using the 'throttle valves' on the Cassegrain Bonnette vacuum manifold (see Section 4.2). As a reference, these valves should be opened about two or three turns from their closed positions.

Chapter 3

The FTS Control Panels

The FTS is operated from a master control panel located in the fourth floor observing area. There is also an auxiliary control environment, mounted on the north side of the FTS, which controls more fundamental aspects of the instrument, such as beam splitter and aperture selection and the operation of the reference laser. In general, the auxiliary area is used at the beginning/end of the night to setup/shutdown the instrument. The layout and various functions of the two control areas are discussed in the following sections.

3.1 The Master Control Panel

The general layout of the master control panel is shown in Figure 3.1. The control panel can be subdivided into 4 areas, each of which has a separate function. In the subsequent discussion, these areas will be referred to as (1) instrument setup, (2) data acquisition control, (3) servo control, and (4) instrument status. Detailed close-ups of each area are shown in Figures 3.2, 3.3, 3.5 and 3.6

3.1.1 Instrument Setup

The FTS optics control panel is illustrated in Figure 3.2 and its various functions are described below.

- **On/Off:** Controls power to the master control panel. However, to access all functions the optical control must also be 'enabled' (see discussion concerning the 'Enable/Disable' switch).

- **Enable/Disable:** When this toggle is enabled the instrument optics can be controlled from the master control panel. When disabled, control defaults to the auxiliary control panel (Section 3.2).

- **Open/Close:** Opens the entrance aperture of the FTS.

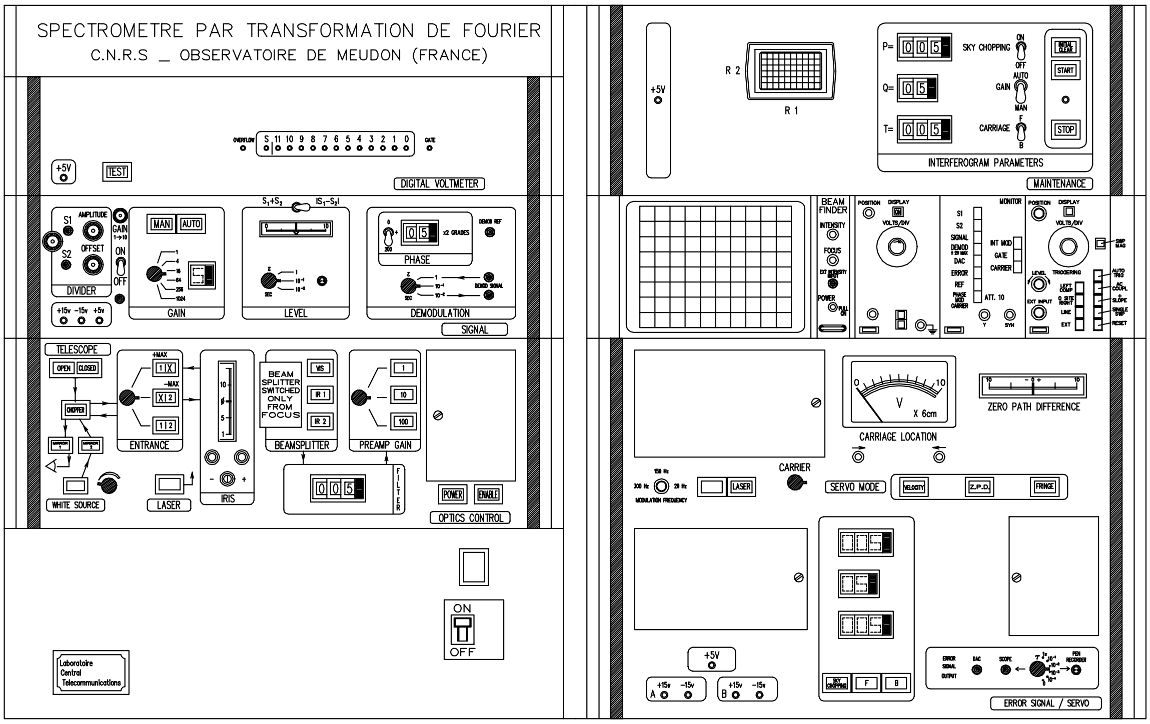

Figure 3.1: FTS Master Control Panel

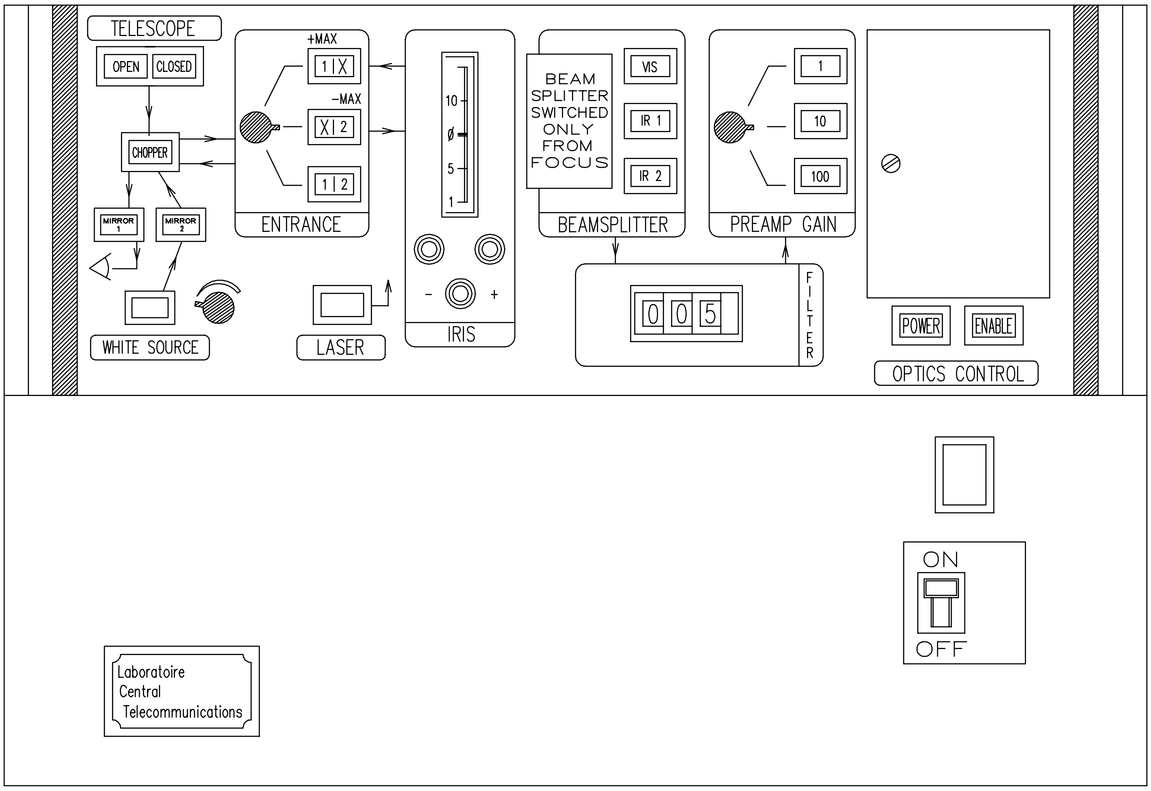

Figure 3.2: FTS Optics Control Panel

- **Mirror 1:** This switch inserts a mirror at entrance #1 of the instrument. When in place, this entrance is blocked from the sky and light is directed from inside the instrument to an eyepiece. This mode is generally used in conjunction with the auxiliary laser. In certain instances this mirror can also be used to confirm that a star is in the field of view of the instrument and assist in locating the "hot spot" (see Section 4.6). Then mirror 1 must be flipped in and the entrance switch (see below) set to position X | 2. When the telescope is pointed at a bright star ($V \simeq 5$), the star should be visible in the eyepiece. If the star is then centered in the middle of a vertical dark groove in the viewing mirror then the star is also well centered in the entrance #1 of the FTS. For observing conditions the mirror 1 switch must be off.

- **Mirror 2:** This switch inserts a mirror at entrance #2 of the instrument. When in place, this intrance is blocked from the sky and light from the white light source (see below) is directed into the interferometer. For observing conditions this switch must be off.

- **White Source:** Turns on the white light source. The strength of the source is controlled with the rheostat to the right of the switch. The white light source is used primarily for engineering applications, but can also be used to find ZPD in the absence of a bright source on the sky (see Section 4.4).

- **Entrance:** There are three settings for this switch: '1 | X', 'X | 2' and '1 | 2.' The first two settings cause entrance apertures 2 and 1, respectively, to be blocked. The final setting, which corresponds to both entrance apertures being open, is used for almost all observing applications.

- **Laser:** Turns on the auxiliary laser, which is used to align the interferometer optics. When activated, this switch inserts a mirror in the optical path which permits the auxiliary laser fringe pattern to be viewed from the eyepiece on the north side of the FTS.

- **Iris:** The two metal push buttons control the size of the irises located in each entrance to the FTS at the focal plane of the telescope. The aperture size is displayed on the meter above the push buttons. The maximum setting is 24 arcsec and this is the standard observing configuration. Smaller aperture sizes are useful for centering an object in the field prior to observation, but it is important to remember to open the aperture to its full size before observing as the diaphragm is not cooled, and hence is a large source of thermal radiation.

- **Beam splitter:** Displays the beam splitter currently in place. Note that the beam splitter can only be changed from the auxiliary control panel (see Section 3.2).

- **Filter:** Selects the filter to be used for observations. The filter number in place is displayed on the LED's to the left of the filter selection wheel. Setting '0' is a blank filter position.

- **Preamp gain:** Sets the preamp gain for the detectors. There are three different settings, and it is important to select the gain which best matches the brightness of the source. Applying too much gain will cause the signal to be saturated while too little gain will introduce 'digitization' noise. The following are rules of thumb for work in the $2\mu m$ region: Setting '1' should be used for $K \leq 2$, Setting '10' should be used for $2 \leq K \leq 8$, and setting '100' should be used for all fainter sources. The amplitude of the observed data can be checked using the 'digital voltmeter' (next section), or by displaying the 'S1' and 'S2' signals on the oscilloscope (Section 3.1.4). The gain level can be fine tuned using the dial located to the left of the 'amplitude' and 'offset' knobs of the divider section of the panel (Section 3.1.2).

3.1.2 Data Acquisition Control

The FTS signal control unit is shown in Figure 3.3.

- **Divider:** A basic assumption when recording an interferogram is that the brightness of the source does not vary. This may not be the case when sky transparency is variable due to clouds. Use of the divider provides a means of correcting for variations in source brightness by normalizing the detected signal with respect to the DC component. However, the divider is not a 'catch-all' cure for cloudy nights, and care should be exercised in its use. In particular, the data quality should be monitored carefully when the sky conditions, and hence extinction, are changing rapidly and by large amounts. Under these conditions, the data quality across the scan will not be uniform, and noise will be introduced into the data. Moreover, the divider should not be used for faint sources; because of the low signal-to-noise ratios inherent for faint objects, the divider will rectify the output according to noise level, and not signal level.

  There is a setup procedure which must be followed before the divider is used. First, activate the divider circuitry using the 'on/off' switch. Second, point the telescope at a blank region of sky near the object to be observed, and adjust the 'offset' knob until the DC signal, displayed on the voltmeter beneath the switch marked '$S_1+S_2 \mid S_1-S_2$' reads 0. Finally, center the telescope on the source, and adjust the 'amplitude' knob so that the mean signal registers ~ 5 units on the same voltmeter. A data scan can then be initiated. Monitor the signal level on the voltmeter for quality control.

- **Gain:** An interferogram contains data spanning a wide range of amplitudes; the signal is very strong at ZPD, and very weak at large path differences. To optimize the dynamic range of the recorded signal, the gain used to measure the signal coming from the detectors should vary according to path difference. The way in which this gain correction is applied is set by the software automatically. **Data are always recorded in autogain — the manual setting is for engineering purposes only**. The LED next to this switch displays the gain setting. Additional gain can be added using the knob marked 'Gain $1 \rightarrow 10$', located near the upper left hand corner of the 'gain' area.

- **Level:** The voltmeter displays the signal level. The type of signal to be displayed is selected with the switch above the meter. The switch below this meter sets the time

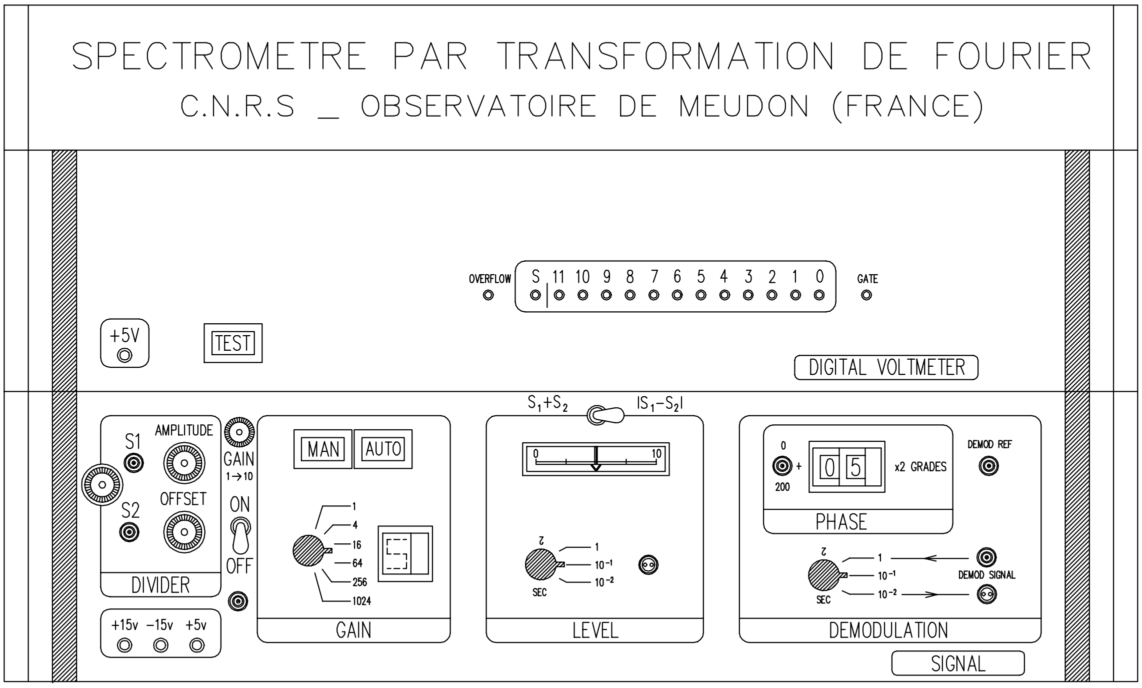

Figure 3.3: FTS Signal Control Panel

constant for an output device. The most interesting signal is $S_1 + S_2$ which indicates the total signal received by the detectors

- **Demodulation:** The phase of the demodulation signal, specified in grads, can be selected using the dials marked 'Phase'. The correct phase setting can be determined at the beginning of the night using a bright source. After positioning the carriage at optical ZPD, and before positioning the carriage ahead of ZPD in preparation for observing, display the demodulated signal on the oscilloscope (Section 3.1.4). The correct phase is that which produces a continuous signal (i.e. no breaks are apparent on the oscilloscope screen) as illustrated in Figure 3.4.

- **Digital Voltmeter:** The voltmeter displays the data in bit form as it is recorded. To prevent digitization noise, as many of the bits as possible should be used, and this is controlled via the preamp gain setting (Section 3.1.1).

3.1.3 Servo Control

Figure 3.5 shows the FTS error signal and servo control panel. The relevant settings and displays of this unit are detailed below.

- **PQT:** The values for P, Q, and T, all of which are set by the software, are displayed on the appropriate LED's. P is the step size of the scan in terms of $\frac{\lambda_r}{8}$, Q is the amplitude of the internal modulation (Section 1.3), also in terms of $\frac{\lambda_r}{8}$, and T is the integration time in ms per step. Note that a display of 0 in the T LED corresponds to an actual

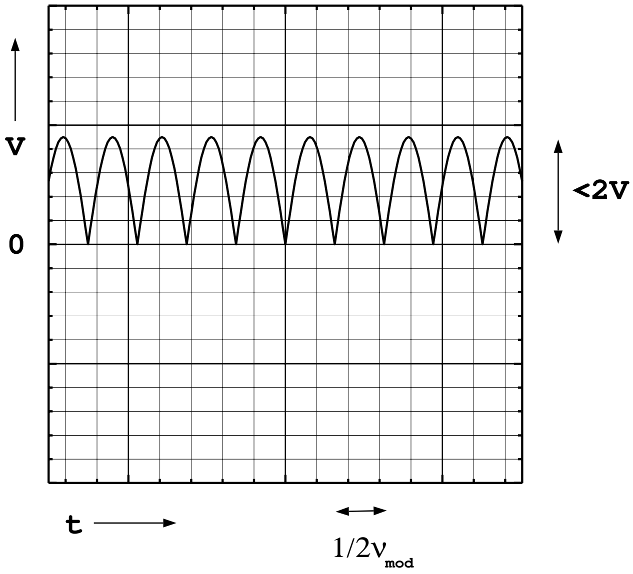

Figure 3.4: Demodulated Signal at ZPD with Proper Phase Setting

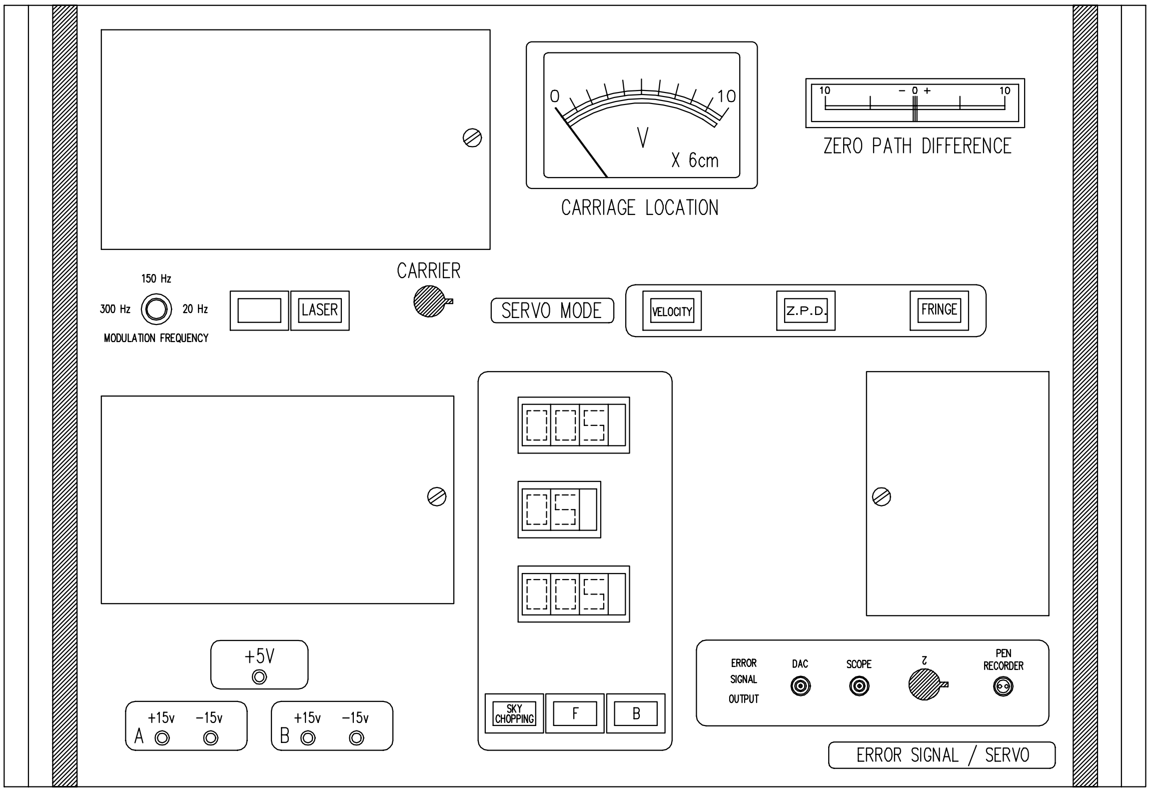

Figure 3.5: FTS Error Signal/Servo Control Panel

integration time of 10 ms per step — i.e. if the display reads 50 then the actual integration time per step is 60 ms. The 'sky chopping' light will be illuminated by the software whenever the beam switching option is requested from the 'Scans' menu (see Section 5.2.1)); the lights labelled 'F' and 'B' monitor the direction of carriage motion (forward versus backward).

- **Internal modulation frequency:** The optimum frequency for internal modulation (Section 1.3) depends on the brightness of the source being observed. For example, high frequency modulation is needed to suppress scintillation noise in very bright objects, whereas detector noise dominates for faint objects. There are three settings for the internal modulation frequency: 300 Hz (bright objects), 150 Hz (objects of intermediate brightness), and 20 Hz (very faint objects). Long integration times ($\geq 200ms$) should be used when the 20 Hz modulation frequency is selected.

- **Carrier:** Adjusts the amplitude of the demodulation carrier signal. It is important that this signal have a peak-to-peak value within ± 6 V.

- **Servo Mode:** The servo system has three different operating modes, only one of which is used for data acquisition. When the interferometer is first activated, the servo system is in velocity mode. In this configuration, the moveable carriage is free to drift, and the path difference can be set manually using the two buttons above the velocity mode switch. The position of the carriage can be monitored using the meter marked 'carriage location'.

  ZPD mode is used to position the carriage near (but not at) optical ZPD. Using error signals generated by a position potentiometer and a position transducer, the carriage is moved to the position of 'mechanical' zero path difference. It is important to note that this is not the same as 'optical' ZPD, which is found using a scanning technique, with the servo system in 'fringe' mode (see Section 4.4).

  Once the carriage has been positioned at mechanical ZPD (which occurs when the error signal displayed on the oscilloscope [Section 3.1.4] has stabilized and the ZPD button is illuminated), then the servo system can be put into 'fringe' mode, which is the mode used for data acquisition. In this mode, the interference fringes produced by the reference laser are used to monitor path difference (Section 2.2). The servo system is activated in a four step process, which can be monitored from the R1/R2 oscilloscope (Section 3.1.4); if the servo system comes out of lock, or fails to lock, an alarm will sound and the system returns to velocity mode. The alarm can be turned off by putting the servo system into ZPD mode.

3.1.4 Performance Monitoring

The FTS oscilloscope and error signal displays are illustrated in Figure 3.6. Various signals from each of these displays should be monitored carefully while observing.

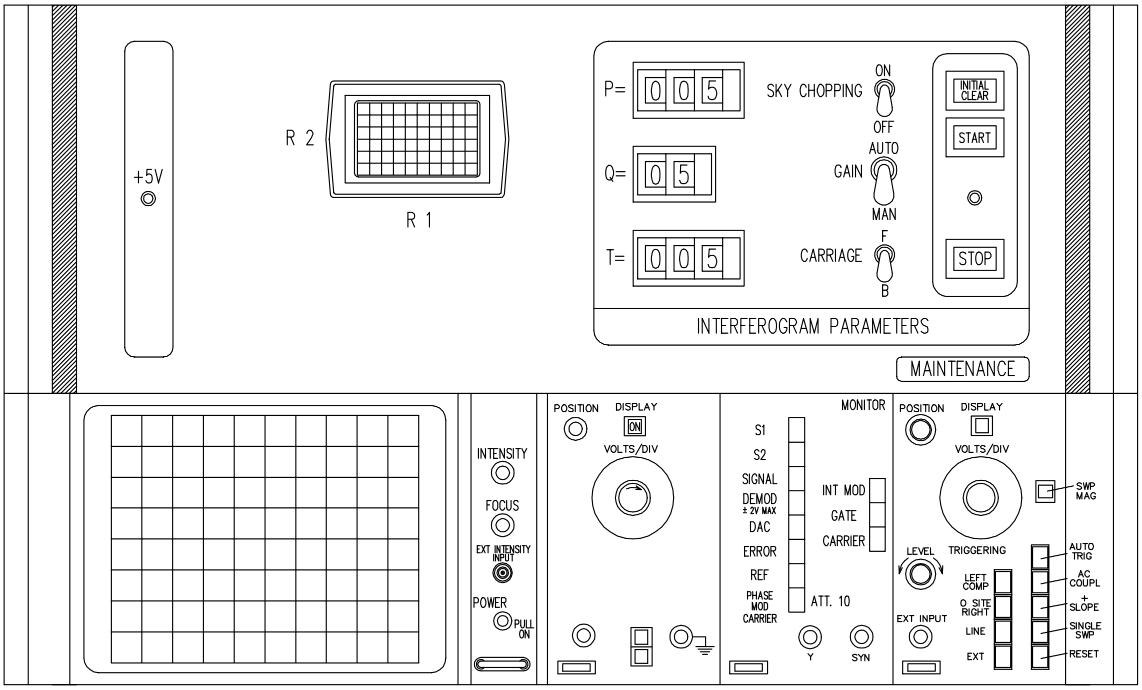

Figure 3.6: FTS Oscilloscopes and Error Signal Display

- **The Oscilloscope:** The oscilloscope allows many of the critical signals produced by the interferometer electronics and the detectors to be monitored. The key signals to be monitored at various times during data acquisition are:

  1. S1 and S2, the DC outputs from the two detectors. These signals are useful for centering the source in the aperture, and determining if the signal is saturated. Saturation corresponds to a voltage of about 10 V so from the discussion in section 1.2 these signals should **NOT** exceed 5 V when the FTS is not located at ZPD.
  2. DEMOD, the demodulated output signal (interferogram). This signal can be used to set the phase of the demodulation reference signal, and can also be used to determine if the signal is saturated (in this case the signal will appear clipped as illustrated in Figure 3.7).
  3. ERROR, the servo system error signal. It is important to monitor this signal as one enters ZPD mode and fringe mode to determine when, or if, the servo system has locked. The normal appearance of the error signal when in fringe mode, but not scanning, is shown in Figure 3.8.

- **The R1/R2 oscilloscope:** This oscilloscope monitors the R_1 and R_2 signals produced by the photodiodes in the interferometer (Section 2.2). The oscilloscope has an independent power supply, and must be turned on using the on/off switch at the back of the oscilloscope. Under normal operating conditions this oscilloscope will display a Lissajous figure. Any departure from an oval shape when entering fringe mode indicates that the servo system is not locking. At the beginning of the night, the Lissajous

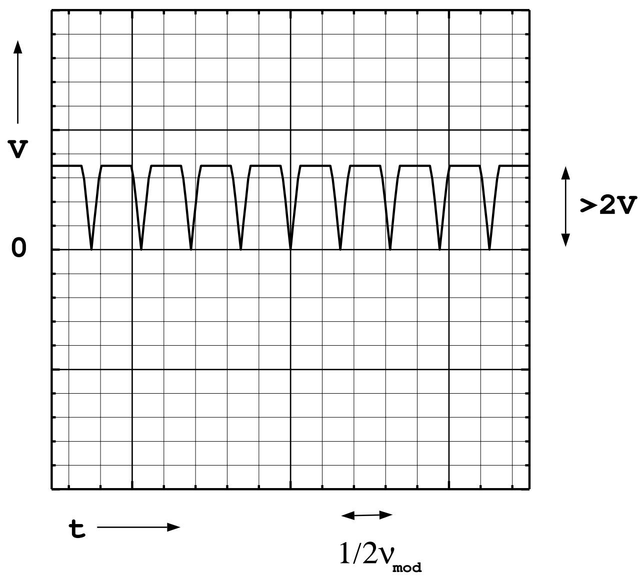

Figure 3.7: Possible Demodulated Signal at ZPD When Saturated

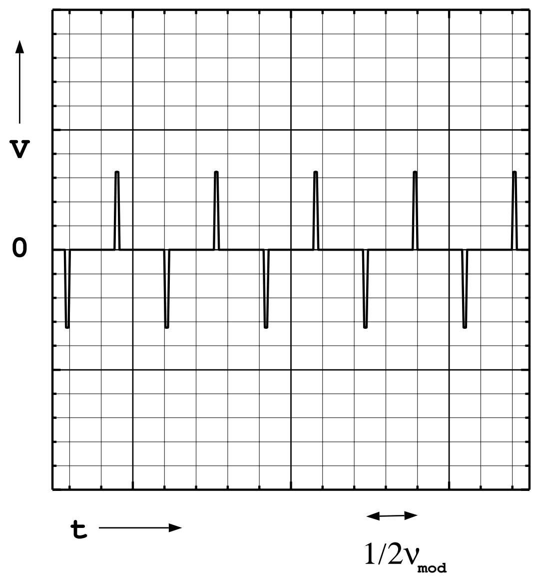

Figure 3.8: Normal Error Signal

figure will vary in size until the reference laser stabilizes ($\sim$ one half hour after the laser is turned on).

3.2 The Auxiliary Control Environment

The auxiliary control environment, shown in Figures 3.9 and 3.10, can be divided into four separate areas: (1) the master power switch, (2) the laser power switch, (3) the aperture wheel controller, and (4) the auxiliary control panel. Each of these are discussed below.

- **The master power breaker:** This switch controls all power to the FTS, and must be turned on prior to observation. This is the first switch to be turned on at the beginning of each night, and the last to be turned off at the end of each night.

- **The laser power switch:** This switch activates the reference laser. In order to monitor path difference effectively, the resonance lines in the laser signal must be extremely stable. This is done by housing the laser in a special thermal environment, and it takes about half an hour for the temperature of the laser to stabilize sufficiently before the servo system can be locked. The stability of the laser can be monitored using the R1/R2 oscilloscope (Section 3.1.4).

- **Aperture Wheel Controller:** The aperture cold stop selection is carried out with the aperture wheel controller. The aperture wheel can be rotated in only one direction ($1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1 \ldots$) and any change in the aperture must be accompanied by a carefully choreographed change in the FTS filters. As an example, assume you have been observing with filter #3 and aperture #4 but want to change to aperture #2. First, move the filter wheel to position #0 (open) and wait for the green ready light to be illuminated on the aperture wheel controller. Now move to aperture #1 by turning the aperture control knob to the appropriate position. Again wait for the green ready light to come on. When it does, reinsert filter #3. You must then step through the procedure once more: filter #0, aperture #2, filter #3, waiting for the green ready light before proceeding with each step. This procedure is also outlined on the aperture wheel control itself for handy reference at the telescope.

- **The Auxiliary Control Panel:** The auxiliary control panel is almost an exact duplicate of the 'instrument set up' portion of the master control panel. These controls should only be used after the master control panel (see Section 3.1.1) has been disabled. The one difference between the two control panels is that the beam splitters can be changed only from the auxiliary control panel with the switch marked 'beam splitter'. The beam splitters should only be changed in one direction, which is in the sense VIS $\rightarrow$ IR1 $\rightarrow$ IR2 $\rightarrow$ VIS... Moreover, the beam splitter carriage should only be advanced one setting at a time, and the assembly should be allowed to come completely to rest before proceeding to the next setting. This usually takes $\sim$ 15 seconds; there will be a moderately loud whirring noise ($\sim$ 10 seconds) caused by the motion of the beam splitter assembly, followed by a fainter whirring noise ($\sim$ 5 seconds) while the brake

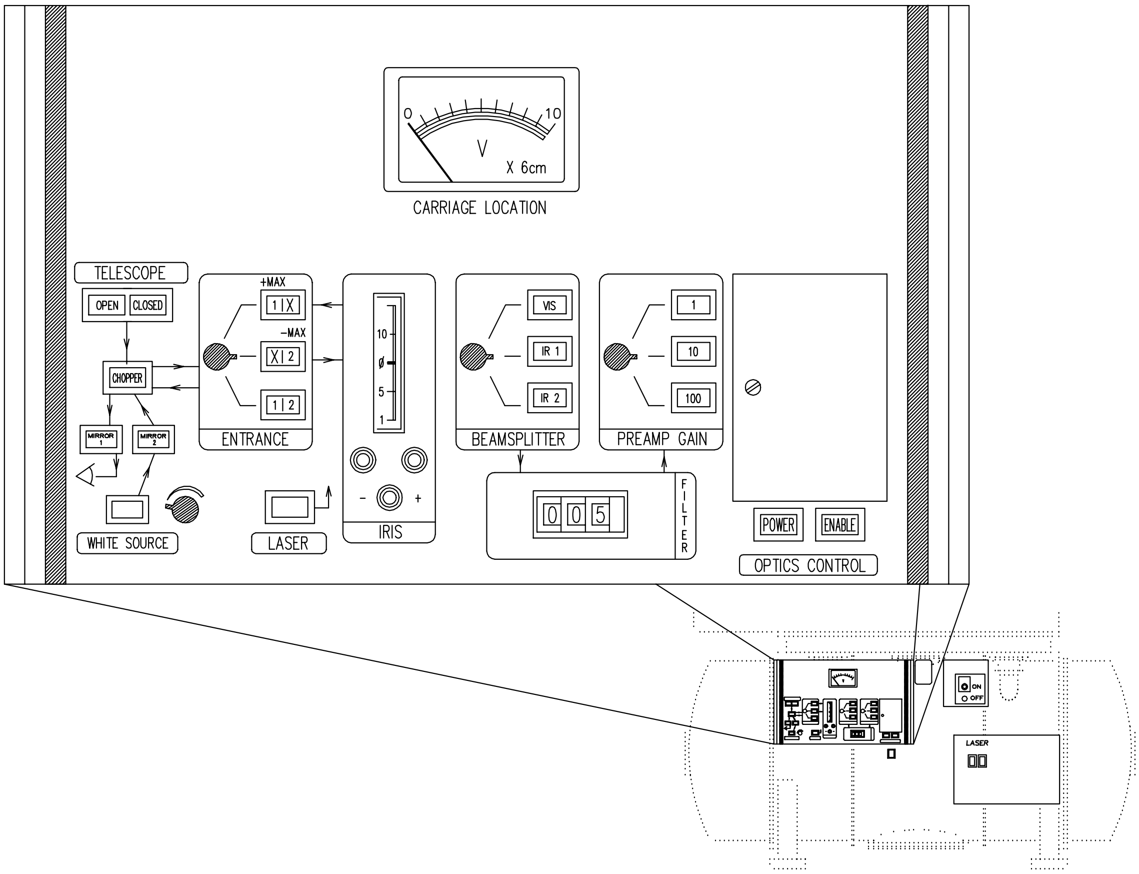

Figure 3.9: Auxiliary Control Panel

Figure 3.10: Aperture Wheel Control Panel (to come)

engages. As an example, if you are currently using the IR2 beamsplitter and want to change to IR1 you must first change to VIS, wait for the two whirring noises to end, and then change to IR1. FAILURE TO FOLLOW THIS PROCEDURE WILL CAUSE THE LIGHT PATH TO BECOME MISALIGNED.

Chapter 4

Using The FTS

4.1 Beginning of Night Start-Up

The following steps are normally performed at the beginning of a night to prepare the FTS for observing:

In the dome:

1. Turn on the master power switch (located on the north side of the interferometer.) **THIS SWITCH MUST BE ON BEFORE ALL OTHER ELECTRONICS ARE TURNED ON. MOREOVER, THE INSTRUMENT MUST BE COMPLETELY CABLED BEFORE POWER IS TURNED ON.**

2. Plug in the external oven for the reference laser. The connectors can be found on the north side of the instrument, above and to the left of the auxiliary control panel.

3. Turn on reference laser. Note that the laser does not come on immediately, but only when the oven is warm, normally 10 to 15 minutes after the oven has been plugged in. After roughly one hour the laser will stabilize sufficiently for observing.

4. Fill the dewars (see Section 4.2).

5. Turn on the dewar preamps. This is done using the 'on/off' switch located on the blue preamp boxes mounted on each dewar. **ONCE THE PREAMPS ARE TURNED ON THE USE OF WALKIE-TALKIES IN THE DOME SHOULD BE AVOIDED, AS THESE COULD CAUSE POWER SURGES WHICH MAY SERIOUSLY DAMAGE THE DETECTORS.**

6. Open the dewar dark slides. Each dewar has a dark slide, which is removed/installed using the levers on the south side of FTS, immediately above the dewar mounts. Normally the dark slides are opened at the beginning of a series of FTS runs and are left open until all runs have been completed.

At the fourth floor observing area (Section 3.1):

1. Turn on the power to the master control panel.

2. Turn on the power to the R1/R2 oscilloscope. If the laser has not yet stabilized (~ 1 hour) the lissajous figure will vary in size.

3. Check the acquisition and guide T.V.'s.

4. Open the FTS entrance shutter.

4.2 Filling the Dewars

The two dewars have hold times of roughly 24 hours, and they should be filled at the beginning of every night to ensure that the detectors are maintained at nominal operating temperature. An added complication is that the nitrogen is pumped to obtain additional cooling. The following procedure should be followed to fill the dewars.

1. Visually inspect each dewar to make sure the outer shell is free of frost. Frosting of the dewars indicates that the internal vacuum is not good. **DO NOT FILL THE DEWARS UNDER THESE SITUATIONS - CONTACT CFHT PERSONNEL.**

2. Using an ohmmeter, measure the temperature of each dewar from the BNC connector on the side of each preamp box (Section 2.3). If the dewars are too hot then they may be difficult to fill.

3. Completely close throttle valves on Cass environment vacuum manifold by turning them in a clockwise direction.

4. Open atmospheric vent valves on the vacuum manifold. A hissing sound will occur as the pump lines are brought up to atmospheric pressure.

5. When the hissing from the pump stops, remove the coupling flange which joins the vacuum pump line to the top of each dewar. There is also an o-ring between the pumpline and dewar spout; make sure you don't lose this! The best practice is to put one of the o-rings in each pocket to keep them warm.

6. Fill each dewar using the long neck funnel and styrofoam LN_2 container. **Wear protective gloves for this procedure!**

7. Reconnect the pumpline to the top of the dewar after clearing away and frost buildup and reinstalling the o-ring between the pumpline and dewar spout. When properly installed, it should be possible to completely close the coupling clamp using the wing nut and screw.

8. Close atmosphere vent valves on vacuum manifold.

9. Slowly open throttle valves on the vacuum manifold. Each valve should be opened 2 or 3 full turns in a counter-clockwise direction.

10. Check pump lines for signs of liquid nitrogen; if this is seen, it indicates that the dewars are being pumped too hard - turn down the throttle valve $\sim \frac{1}{2}$ a turn and recheck.

11. Check dewar temperatures after $\sim$ half an hour of pumping; adjust vacuum as necessary.

4.3 Aligning the Dewars

At the start of a series of FTS observing runs it is sometimes necessary to check that the FTS dewars are properly aligned with the optical axis of the rest of the FTS and the telescope, especially if a small cold stop is to be used during observations. This procedure is normally carried out by the CFHT support staff, but is included here for completeness.

1. Stop down the iris at the entrance aperture of the FTS to a small diameter (5 arcsec).

2. Insert the large aperture cold stop (normally 12 arcsec).

3. Select a pair of filters with a bandpass in the thermal infrared, preferably at about 5 μm.

4. Connect a voltmeter to the test output of one of the preamps.

5. Since the iris at the entrance aperture of the instrument is not cooled and is smaller than the aperture cold stop it acts as a thermal source. Alignment of a dewars is carried out by adjusting the large hand screws at the bottom of the dewar to maximize the signal received by the detector, which occurs when the detector is aligned along an axis passing through the center of the entrance iris.

6. Repeat the procedure for the other dewar.

4.4 Locking the Servo System and Locating Optical ZPD

Once the laser has stabilized, the servo system can be locked. This is a two step process: using the appropriate buttons on the Error Signal/Servo Control Panel (see Section 3.1.3), first put the servo system in 'ZPD' mode, and then enter 'Fringe' mode

There are two ways to position the interferometer at optical ZPD:

Method A (using the source to be observed):

1. Open the FTS entrance aperture.

2. Select the filter you will be using with the filter selection wheel on the master control panel.

3. Position the star in the 'hot spot' (see Section 4.6).

4. Run the ZPD task from the HP9000 workstation.

5. The instrument is now ready for observing.

Method B (using internal light source):

1. Turn on the white light source, and position mirror 2.

2. Select a filter (for instance, the He I filter) using the filter selection wheel on the master control panel.

3. Run the ZPD task from the HP9000 workstation.

4. After ZPD has been found, turn off the white light source and remove the injection mirror.

The instrument is now ready for observing.

4.5 Scanning a Filter

The following procedure can be used to obtain a spectrum of a filter illuminated by white light (i.e. at nonthermal wavelengths). It is presumed that the servo system is locked.

1. Turn on the white light source and insert mirror 2.

2. Select the filter to be scanned.

3. Check the signal level on the detectors with the oscilloscope.

4. Run the ZPD task from the HP9000 workstation.

5. Fill out the SCANS menu on the HP9000 terminal. Only a small number of steps (e.g. 1024) is required.

6. Once the SCANS menu has been filled out, select Accept, and the scan will commence.

Note: not all filters can be scanned with the white light source. For broad band filters in the nonthermal infrared the detectors saturate, even with the light source set at minimum intensity, and in the thermal infrared the glass envelope of the white light source reduces the infrared radiation to impractical levels.

4.6 Locating the "Hot Spot"

The 'hot spot' is the location on the guide T.V. which corresponds to the entrance aperture of the instrument. The exact procedure for locating the 'hot spot' depends on whether the FTS is installed with the guide pellicle or guide mirror installed. An outline of the technique for each circumstance is given below. The 'hot spot' location is not fixed, and can drift slightly during the night. Consequently, it is important to check the 'hot spot' location periodically.

4.6.1 Guide Pellicle in Place

1. Slew to a relatively bright source (V $\simeq$ 5). Insert the K band filter, even if the instrument is configured for work in the thermal infrared to provide a measurable signal above the background.

2. Select a preamp setting appropriate for the source. Typically, setting '1' should be used for $K \leq 2$, Setting '10' should be used for $2 \leq K \leq 8$, and setting '100' should be used for all fainter sources.

3. Ask the telescope operator to position the Bonnette guide probe to (x,y) = (0,0).

4. Position the rectangular guide box on the acquisition T.V. screen to the current 'hot spot' location. If the 'hot spot' location is not known, a good default preliminary setting is (X,Y) = (119,43) — *note that these coordinates refer to those displayed in the lower left hand corner of the acquisition T.V. screen, and not to the position of the Bonnette guide probe.*

5. Center the source in the preliminary 'hot spot' location.

6. Display the S1 signal on the main oscilloscope.

7. Use the hand paddle to gradually move the star away from the 'hot spot' - the S1 signal displayed on the oscilloscope should decrease. If not, hunt around the 'hot spot' location until a signal is detected. If a signal is not detected see Chapter 6.

8. Move the star around until the S1 signal is maximized and then relocate the guide box to the location of the star on the acquisition T.V. (Note: if this procedure does not work you can also visual inspect the entrance field of the FTS as discussed in Section 3.1.1)

9. Using the appropriate buttons on the Main Control panel, close the iris to its smallest opening. (This step is not necessary if you are using a small cold stop.)

10. Readjust the position of the star to maximize the S1 signal, and move the guide box to the new position of the star on the acquisition T.V. It is also a good idea to fine-tune the focusing at this point as well, adjusting the focus and position of the star in an iterative manner until the maximum signal is realized. The final position of the guide

box then corresponds to the 'hot spot' location. You should record the value for future reference and also inform the telescope operator.

11. Reopen the iris to its maximum setting.

4.6.2 Guide Mirror in Place

1. Slew to a relatively bright source (V $\simeq$ 5). Insert the K band filter, even if the instrument is configured for work in the thermal infrared to provide a measurable signal above the background.

2. Select a preamp setting appropriate for the source. Typically, setting '1' should be used for $K \leq 2$, Setting '10' should be used for $2 \leq K \leq 8$, and setting '100' should be used for all fainter sources.

3. Ask the telescope operator to position the Bonnette guide probe to (x,y) = (0,0).

4. Position the rectangular guide box on the acquisition T.V. screen to the current 'hot spot' location. If the 'hot spot' location is not known, a good default preliminary setting is (X,Y) = (119,43) — *note that these coordinates refer to those displayed in the lower left hand corner of the acquisition T.V. screen, and not to the position of the Bonnette guide probe.*

5. Center the source in the preliminary 'hot spot' location.

6. Display the S1 signal on the main oscilloscope.

7. Ask the telescope operator to find a suitable guide star.

8. Use the hand paddle to gradually move the guide star - the S1 signal displayed on the oscilloscope should decrease. If not, hunt around the 'hot spot' location until a signal is detected. If a signal is not detected see Chapter 6.

9. Move the guide star around until the S1 signal is maximized and then relocate the guide box to the location of the star on the acquisition T.V. (Note: if this procedure does not work you can also visual inspect the entrance field of the FTS as discussed in Section 3.1.1)

10. Using the appropriate buttons on the Main Control panel, close the iris to its smallest opening. (This step is not necessary if you are using a small cold stop.)

11. Readjust the position of the guide star to maximize the S1 signal, and move the guide box to the new position of the star on the acquisition T.V. It is also a good idea to fine-tune the focusing at this point as well, adjusting the focus and position of the star in an iterative manner until the maximum signal is realized. Ask the telescope to reposition the Bonnette guide probe to (x,y) = (0,0) and then relocate the guide box to the new location of the source on the acquisition T.V. The final position of the

guide box then corresponds to the 'hot spot' location. You should record the value for future reference and also inform the telescope operator.

12. Reopen the iris to its maximum setting.

4.7 Observing an Object on the Sky

4.7.1 Guide Pellicle in Place

1. Select the appropriate pair of filters.

2. Select an appropriate preamp gain setting and modulation frequency based on the brightness of the source. Typically, the preamp gain setting '1' should be used for $K \leq 2$, Setting '10' should be used for $2 \leq K \leq 8$, and setting '100' should be used for all fainter sources. Use an internal modulation frequency of 300 Hz for bright objects, 150 Hz for objects of intermediate brightness, and 20 Hz for very faint objects. Long integration times ($\geq$ 200 ms) should also be used when the 20 Hz modulation frequency is selected.

3. Select an appropriate cold stop. A small aperture should be used for thermal IR observations while a large aperture should be used for bright stars and in cases of poor seeing to minimise scintilation effects.

4. Position the object on the hot spot.

5. Move target away from the hot spot until the signal level on the voltmeter drops. Turn up the 'amplitude' knob on the FTS Data Acquisition Control Panel (see Section 3.1.2) until you see a signal from the background on the voltmeter.

6. Adust the 'offset' knob until the voltmeter reads 0.

7. Reposition the object in the hot spot and maximimize the signal by adjusting the position of the object. Reposition the T.V. guide box as needed. Ask the telescope operator to turn the autoguider on.

8. Adjust the 'gain' dial until the voltmeter is reading in the 7 to 8 V range.

9. Readjust the 'amplitude' again so that the voltmeter reads 5 V. This provides a useful voltage level for monitoring the sky conditions and should be checked frequently.

10. Fill out the 'Scans' menu (see Section 5.2.1); remember to select 'move carriage' option if the carriage is still positioned at optical ZPD. An integration time should be selected which will produce an easily recognizable signal on the interferogram at ZPD; if this condition is not met it will not be possible to reduce the data.

11. Once the scan has been started, monitor the interferogram and power spectrum as they are displayed. Two questions which should be asked during data acquisition are (1) 'Is ZPD apparent on the interferogram?', and (2) 'Does the power spectrum look reasonable?'. Ripples outside of the filter boundaries may indicate that the preamp setting is set too high, so that the detectors are saturated near ZPD. It is also useful to use the 'Eng' menu (see Section 5.3.2) to examine the most recent forward and reverse scans and check for possible problems such as missed steps.

4.7.2 Guide Mirror in Place

1. Select the appropriate pair of filters.

2. Select an appropriate preamp gain setting and modulation frequency based on the brightness of the source. Typically, the preamp gain setting '1' should be used for $K \leq 2$, Setting '10' should be used for $2 \leq K \leq 8$, and setting '100' should be used for all fainter sources. Use an internal modulation frequency of 300 Hz for bright objects, 150 Hz for objects of intermediate brightness, and 20 Hz for very faint objects. Long integration times ($\geq$ 200 ms) should also be used when the 20 Hz modulation frequency is selected.

3. Select an appropriate cold stop. A small aperture should be used for thermal IR observations while a large aperture should be used for bright stars and in cases of poor seeing to minimise scintilation effects.

4. Ask the telescope operator to position the Bonnette guide probe to (x,y) = (0,0).

5. Center the source on the hot spot, after making sure that the guide box is in the proper (x,y) location you recorded while locating the hot spot.

6. Ask the telescope operator to find a suitable guide star.

7. Center the T.V. guide box on the guide star.

8. Select an appropriate preamp gain setting and modulation frequency based on the brightness of the source.

9. Move the guide star away from the guide box until the signal level on the voltmeter drops. Turn up the 'amplitude' knob on the FTS Data Acquisition Control Panel (see Section 3.1.2) until you see a signal from the background on the voltmeter.

10. Adust the 'offset' knob until the voltmeter reads 0.

11. Reposition the guide star in the guide box and maximimize the signal by adjusting the position of the object. Reposition the T.V. guide box as needed. Ask the telescope operator to turn the autoguider on.

12. Adjust the 'gain' dial until the voltmeter is reading in the 7 to 8 V range.

13. Readjust the 'amplitude' again so that the voltmeter reads 5 V. This provides a useful voltage level for monitoring the sky conditions and should be checked frequently.

14. Fill out the 'Scans' menu (see Section 5.2.1); remember to select 'move carriage' option if the carriage is still positioned at optical ZPD. An integration time should be selected which will produce an easily recognizable signal on the interferogram at ZPD; if this condition is not met it will not be possible to reduce the data.

15. Once the scan has been started, monitor the interferogram and power spectrum as they are displayed. Two questions which should be asked during data acquisition are (1) 'Is ZPD apparent on the interferogram?', and (2) 'Does the power spectrum look reasonable?'. Ripples outside of the filter boundaries may indicate that the preamp setting is set too high, so that the detectors are saturated near ZPD. It is also useful to use the see Section 5.3.2) to examine the most recent forward and reverse scans and check for possible problems such as missed steps.

4.8 If the Servo Should Unlock

1. An obnoxious sounding buzzer will go off. Don't panic - compose yourself.

2. Stop or Abort the scan in progress. If the scan is in the reverse direction and has not yet passed through ZPD then it is useless and should be aborted. However, if the scan is in the forward direction it may be worth saving, depending on the resolution which has been achieved up to the point of the servo unlock.

3. Once the scan has been terminated, push the ZPD servo button on the main control panel. The carriage will return to mechanical ZPD, and the buzzer will eventually go off.

4. Reenter fringe mode.

5. Refind optical ZPD, and resume observations.

4.9 End of Night Shutdown

The end of night procedure is basically the reverse of the start-up procedure.

At the fourth floor observing area (Section 3.1):

1. Close the entrance apertures to the FTS.

2. Place the filter wheels at position 0.

3. Unlock the servo system by entering 'velocity' mode.

4. Turn off power to acquisition and guide TV sets.

5. Turn off the R1/R2 oscilloscope.

6. Turn off power to main control panel.

On the fifth floor:

1. Turn off dewar preamps. **BECAUSE OF THE EXTREME SENSITIVITY OF THE DETECTORS AND SINCE THEY ARE PRONE TO DAMAGE BY RADIO HANDSET TRANSMISSIONS, THIS IS A VERY IMPORTANT STEP!**

2. Check the temperatures of both dewars. They normally have a holding time of approximately 24 hours. If one them indicates a value of more than 16 mV then it will be too warm by the evening and should be refilled before leaving the summit.

3. Turn off main power supply. **ALL ELECTRONICS SHOULD BE TURNED OFF PRIOR TO THIS STEP.**

Chapter 5

The FTS Pegasus Session

5.1 The Software Environment

Data acquisition is controlled via the CFHT HP9000 summit computer system, using software written by John Kerr of CFHT. Instructions are entered by filling out menus, and the overall user interface is similar to that used for other CFHT instruments, such as MOS. In this section, the functions and contents of the various menus are described.

The login id for the FTS software is 'fts'. Once this and the current password (see your support astronomer) are entered the work station will show a display, after a few seconds delay, similar to that shown in figure 5.1. The display includes the Pegasus Session Manager which consists of a series of icons at the top of the screen used to access the various menus used for data acquisition (figure 5.2); a window labelled 'FTS feedback'; a window monitoring CPU usage; a window monitoring available disk space; and a clock.

The 'FTS feedback window' monitors the progress of command sequences executed from the menus. When a scan has completed successfully, the message 'successful scan completion' will be displayed in this window. Error messages will also appear in this window and these should be noted as they appear since this information can be used by the software group to diagnose problems.

The menus in the Pegasus Session Manager (figure 5.2) used for data acquisition and other functions are accessed by moving the mouse so as to position the pointer over the desired icon, and then pressing the left-hand button on the mouse (in all subsequent discussion, this procedure is referred to as '*selecting*'). The various menus, grouped according to their function, are summarized in Table 5.1.

Function	Menu			
FTS Control	Scans	ZPD	Carriage	TPQ
Data Management	Look	Eng	Files	Modes
Utilities	Tools	Suggestions		News
Disaster Relief	Aloha			

Table 5.1: Menu Summary

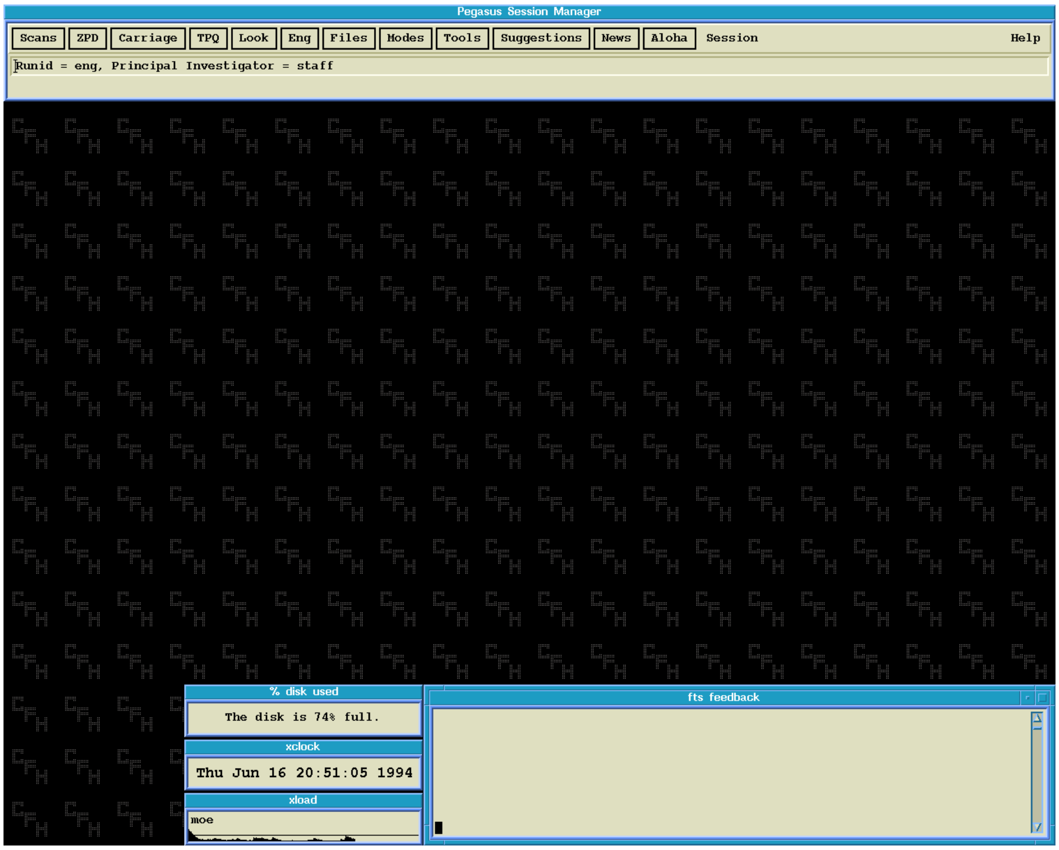

Figure 5.1: The FTS Data Acquisition Software Display

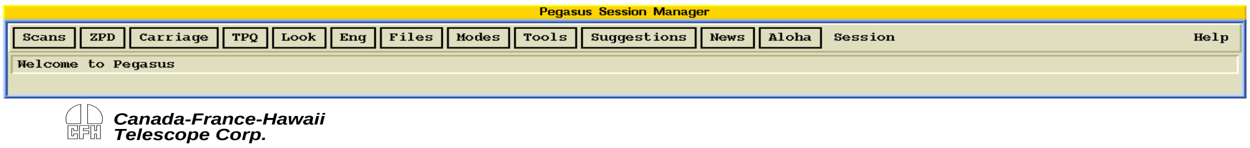

Figure 5.2: The FTS Pegasus Session Manager

The menus contain two different types of input: predefined toggle switches, which can be turned off or on by selecting the circle or box next to the desired option, and numerical or text input. Examples of the latter are values of T, P, or Q, entered in the 'Scans' menu (see Section 5.2.1). Text can be entered by selecting the leftmost region of the box provided for the input (when the pointer is positioned over the text box the box will be outlined in red), and then typing in the desired information. Existing information can be deleted by selecting the rightmost portion of text and pressing the 'Delete' key repeatedly. Alternatively, one word of text can be overwritten by 'double clicking' with the left button on the desired word and then entering the new text. You can also hold the left mouse button down, 'drag' the pointer over several words, release the button, and then erase the highlighted words by pressing 'Delete' or overwrite them by entering new text. Similarly an entire line can be overwritten by 'dragging' the pointer across the entire line or 'triple clicking' in the text box and entering new text.

Once a menu has been filled out, the desired operations can be executed and the values entered saved by selecting 'Accept'. If you simply want to save the specified parameters without executing the menu's routine then select 'Save values'. Selecting 'Defaults' will restore a menu's settings to the default values. If a mistake has occurred, such as selecting an incorrect menu or if it is decided that no changes are necessary, then the menu can be removed by selecting 'Cancel'.

A brief discussion of the various menus, according to the categories listed in Table 5.1, can be found in Sections 5.2, 5.3, 5.4, and 5.5.

5.2 FTS Control Menus

The menus discussed in this section are illustrated in Figures 5.2 to 5.7.

5.2.1 Scans

The Scans menu (figure 5.3) is the basic menu for all data acquisition. Many of the parameters in this menu are correlated; consequently, since changing one parameter may affect other entries, the menu is automatically updated to reflect these changes. For example, if the step size P is changed, then the 'resolution' entry will change automatically to accommodate the new value of P. Before starting a scan, check that the automatically selected parameters are the ones you actually want. Also make sure that the correct filter has been selected: the current filter wavenumber boundaries are indicated at the top of the Scans form.

The following parameters can be set or entered in the Scans menu:

- **Gain Mode:** This switch toggles between automatic and manual gain settings for the signal read from the detectors (not to be confused with preamp gain, which is set on the master control panel). 'Automatic' is the normal mode for data acquisition and, as the name implies, the gain setting is automatically adjusted to match the dynamic range of the recorded data.

- **T:** The integration time in ms at each path difference. Changing this parameter will cause the scan time and total observing time entries near the bottom of the menu to be updated.

- **P:** The step size of the scan, in terms of $\frac{\lambda_r}{8}$. An optimum value for the step size, the maximum that prevents aliasing, is given, and is automatically computed from the relation

$$\Delta x = \frac{1}{2(k_u - k_l)} \tag{5.1}$$

  where the lower and upper passband boundaries of the selected filter (in cm^{-1}), plus some extra range on each side of the filter, are given by k_l and k_u respectively. As a result, Changing P will cause the resolution entry on the menu to be updated. P values lower than the optimal value (corresponding to a broader FSR, discussed below) can be used and can be useful, as an example, for low resolution work with a narrow band filter. However, the FSR must always include the filter boundaries, so some values of P will not be accepted.

- **FSR Limits:** These entries are display only, and provide the limits of the **F**ree **S**pectral **R**ange, which is computed based on the current value of P. The spectrum will be computed between these two limits.

- **Q:** The internal modulation amplitude (Section 1.3), in terms of $\frac{\lambda_r}{8}$. An optimum value, based on the central wavelength of the filter and Equation 1.21, is displayed next to the Q entry.

- **Wave Number:** This entry is display only, and gives the wave number corresponding to the optimum modulation for Q. This wavenumber must be within the filter boundaries. The closest wavenumber to the middle of the filter bandpass is used as the criterion to select Q.

- **Steps:** The number of steps in each scan. Since the number of steps effects the total path length of the scan, changing this entry will cause the resolution, scan time, and total observing time entries to be updated.

- **Res:** The spectral resolution, in cm^{-1}. This is defined as the location of the first zero crossing in the sinc function defined by the path difference (see Section 1.2). As of this writing, this value is for display only and can not be entered interactively.

- **Scans:** The total number of scans. Typically, scans are obtained in pairs, so that the carriage is returned to its initial starting position in preparation for subsequent data acquisition. (Executing one scan will move the carriage in only one direction.)

- **Direction:** The direction of the first scan. In almost all applications this should be set to 'forward'.

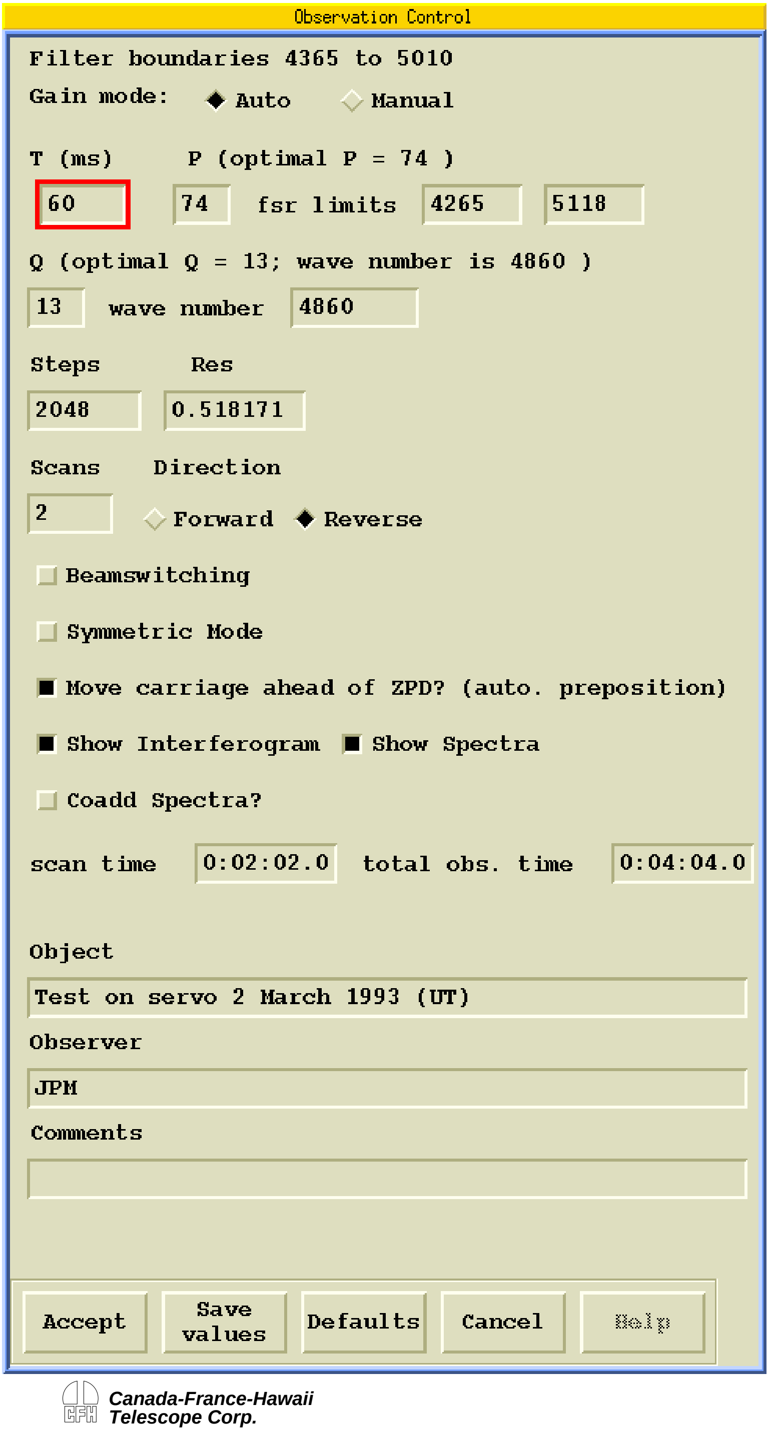

Figure 5.3: Scans Menu

- **Beam switching:** This switch activates beam switching mode, which is used whenever accurate background subtraction is required. Beam switching should be used when the sky background is very large. This flag is 'sticky' - once set it will stay on until manually reset.

- **Symmetric Mode:** For most applications, the carriage is positioned 180 steps to one side of ZPD prior to obtaining data, and this portion of the scan is discarded during the initial data processing. However, for very faint sources, where observing time is critical and high resolution data cannot be obtained, this procedure could result in significant time loss. Symmetric mode was designed to optimize observing time on faint objects. In this mode, the carriage is positioned at maximum path difference at one end of the scan. During data acquisition, the carriage travels through ZPD to maximum path difference on the other side of ZPD. In this way, data on both sides of ZPD can be used.

- **Move Carriage ahead of ZPD:** After positioning the carriage at optical ZPD using the ZPD task (see below), the carriage is normally moved 180 steps to one side of ZPD. (The exception is symmetric mode, where the carriage is placed the maximum path difference on one side of ZPD - see above.) Positioning the carriage in this manner ensures that all the high amplitude fringes on each side of ZPD are recorded during each scan. This information is required by the reduction software to locate the exact location of optical ZPD. As long as the carriage is returned to its initial starting position after each set of scans, then it should not be necessary to use this command unless the carriage has been repositioned at ZPD using the ZPD task. Consequently, the flag is not 'sticky' - the 'move carriage' flag is automatically reset by the software to its default 'off' position after each execution.

- **Show Interferogram:** If this option is selected, each block of the raw interferogram is displayed on the screen as the data is acquired. For a more detailed description see Section 5.3.1.

- **Show Spectra:** If this option is selected, a power spectrum of the interferogram is displayed as data is obtained. The spectral resolution will increase as the path difference increases to larger values. For a more detailed description see Section 5.3.1.

- **Coadd Spectra:** For high resolution work, or observations of faint objects, it may be desirable to display coadded spectra.

- **Scan Time:** This entry is for display only, and shows the observation time per scan in the format hh:mm:ss.s.

- **Total Observing Time:** This entry is for display only, and is the product of the scan time and the number of scans. Again, the format of the display is hh:mm:ss.s.

- **Object:** The name of the object being observed. This entry, as well as those for Observer and Comments described below, is 'sticky', and will not change unless entered

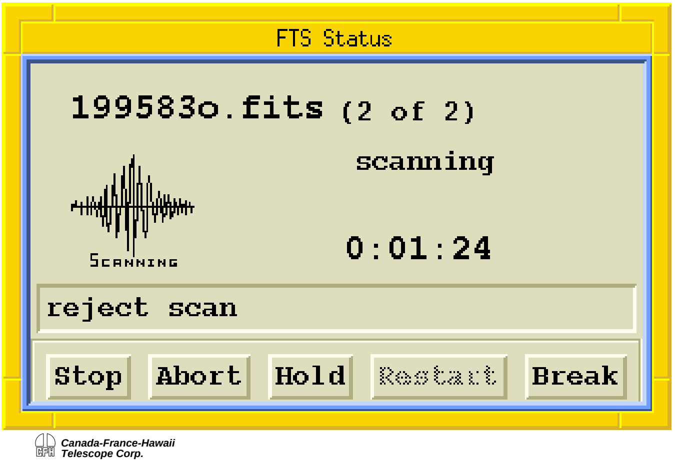

Figure 5.4: FTS Scan Status Icon

by the observer. N.B.: it is recommended that this entry **NOT** contain the special characters ", ', or # as these have the potential to cause a crash of the Pegasus session manager.

- **Observer:** The name(s) of the observer(s).
- **Comments:** Any last words for posterity before you start a scan?

An exposure will start once the scan menu is accepted. An **FTS Status** icon similar to that shown in Figure 5.4 will appear in the upper right hand corner of the workstation screen, which contains the exposure number (see Section 5.3.3), as well as the time left before the scan is completed. The five buttons at the bottom of the status icon have the following actions:

- **Stop:** selecting this button will stop a scan immediately and save the data acquired for that scan up to that point on disk. If you stop while taking a sequence of scans the remainder of the sequence is terminated.
- **Abort:** this option will terminate the current scan and not write data to disk. As a consequence, the data is lost. If you abort while taking a sequence of scans the remainder of the sequence is terminated.
- **Hold:** choose this option if you want to temporarily halt an exposure.
- **Restart:** if you are holding an exposure, select this option to resume scanning.
- **Break:** this selection will break a sequence of scans. The scan currently being taken will be completed but the rest of the sequence will be terminated.

A confirmation message will appear if any of these options is selected.

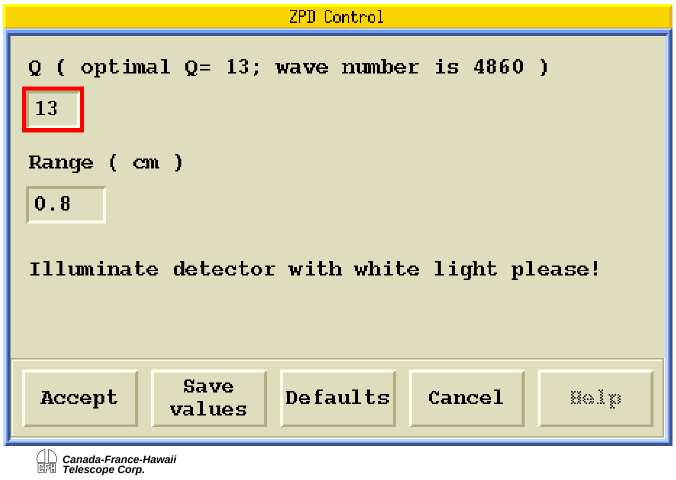

Figure 5.5: ZPD Menu

5.2.2 ZPD

Before starting a scan it is necessary to first position the carriage at optical ZPD, which is the path difference which gives the maximum fringe amplitude. The ZPD task automatically scans a portion of the carriage where this is known to occur (it is assumed that the carriage has already been set to the mechanical ZPD position, and the servo system is in fringe mode). The search for ZPD is done in two stages, the first being a crude scan with large step sizes (P $\sim$ 24), the second using P = 2.

There are two entries on the ZPD menu (Figure 5.5):

- **Q:** The amplitude of internal modulation, in terms of $\frac{\lambda_r}{8}$ of the reference laser, appropriate for the filter. The optimum value is displayed above this entry.

- **Range:** The range to be scanned, in cm^{-1}. Usually, this should be set to 0.8.

The above two values are automatically set and hence should not have to be changed or entered. Use of this command does, however, suppose that light is falling on the detectors through a selected filter. Once the ZPD menu is accepted, a series of scans will start to zero in on ZPD. During this procedure, an exposure icon will appear in the lower left hand corner of the workstation. As with regular exposures, the ZPD process can be stopped or aborted, using the procedure discussed in Section 5.2.1.

5.2.3 Carriage

In certain circumstances, an observer may want to manually move the carriage. There are two possible manual motions that can be specified in the Carriage menu (Figure 5.6):

- **Move:** When flagged, this entry causes the carriage to be moved a distance specified by the **P** and **Steps** entries. The direction of carriage motion (**Forward** or **Reverse**) must also be specified.

Figure 5.6: Carriage Menu

- **Origin:** Causes the carriage to return to the point of origin (i.e. the carriage position before the preceding scan was started). This repositioning has been found not to work very well for scans involving small path differences.

The most common use of manual carriage movement is to avoid repeatedly looking for ZPD when you are making successive pairs of scans on an object with more than one filter (provided that the change of filters does not necessitate a change of beam splitters). After the first pair of scans has been completed you can select the Carriage menu, change the entry for P to the value that was used for the previous scan, set Steps to 180, and select the Forward direction. Flagging the Move option and clicking on Accept will then move the carriage back to ZPD. A new filter can then be inserted into the beam and a new scan started from the Scans form. Another application is to setup for symmetric observing mode (see Section 5.2.1). Manual carriage control is also often useful for engineering purposes.

5.2.4 TPQ

This menu (shown in Figure 5.7) provides a quick way of setting the values of T, P, and Q found in the Scans menu, but without having to start an actual scan. The entries are filled out the same as in the Scans menu. See Section 5.2.1 for a discussion of the significance of these three important parameters.

5.2.5 The Filter Table

The filter table tells the computer which filters are installed in the FTS dewars. It is filled out during the instrument setup, and is only changed when the filter configuration is altered. There is not an icon to access the filter table; rather, it can be displayed using the following procedure. First, move the cursor into a blank part of the screen and hold down the right hand button of the mouse. A menu will appear. While continuing to hold down the right hand button of the mouse, scroll down the menu to the '**Session Setup**' entry. Release the right hand button of the mouse, and then depress it again. A second menu will appear. While continuing to hold down the right hand button of the mouse, scroll down this menu to the '**Select Detector**' entry. Release the mouse button and a filter table similar to that shown in Figure 5.8 will appear.

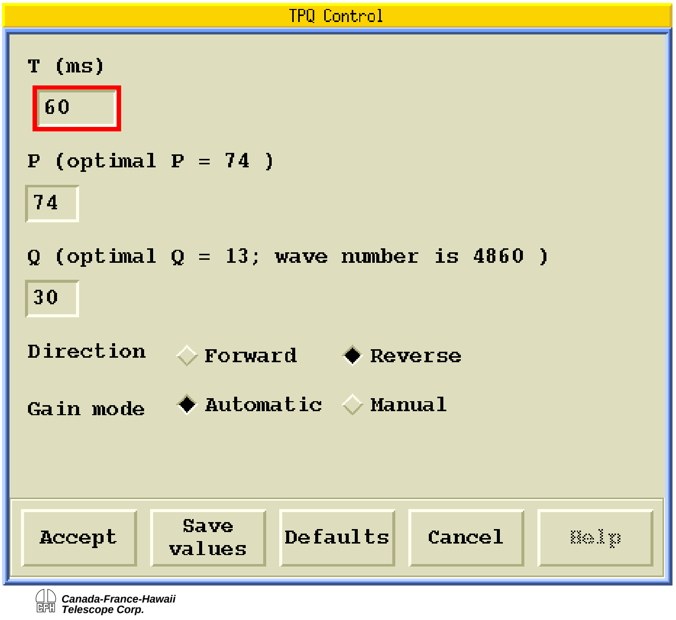

Figure 5.7: TPQ Menu

The filter table contains the following information: the positions occupied by the various filters in the filter wheel (values 1 through 9; position 0 is always open); the name of the filter; and the approximate upper and lower boundaries of the filter response, in cm^{-1}. Information for the three beam splitters is also displayed.

5.3 Data Management

The three data management menus control data display, file manipulation (e.g. writing to tape, deleting files, etc.), and whether or not TCS information is stored in the file header. Samples of the four data management menus can be found in Figures 5.9, 5.12, 5.14, and 5.15.

5.3.1 Look

The three entries in this menu are the same as in the Scans menu. If **Show Interferogram** is selected, the raw intererogram of the specified file is displayed in a window on the screen. An example is shown in Figure 5.10. If the **Show Spectra** option is selected then a power spectrum of the interferogram will be calculated and displayed as illustrated in Figure 5.11. All plotting is performed with the **Grapher Tool**, details of which can be found in the CFHT document "A User's Manual For the CCD Data Acquisition User Interface,"[1] by John Kerr and Olivier Le Fèvre. Archive numbers can be specified to plot earlier data and the two keywords 'current.fits' and 'previous.fits' provide short cuts for plotting data for the most recently completed scan and the previous scan.

[1] http://www.cfht.hawaii.edu/html/daprog/pegman/pegman.html

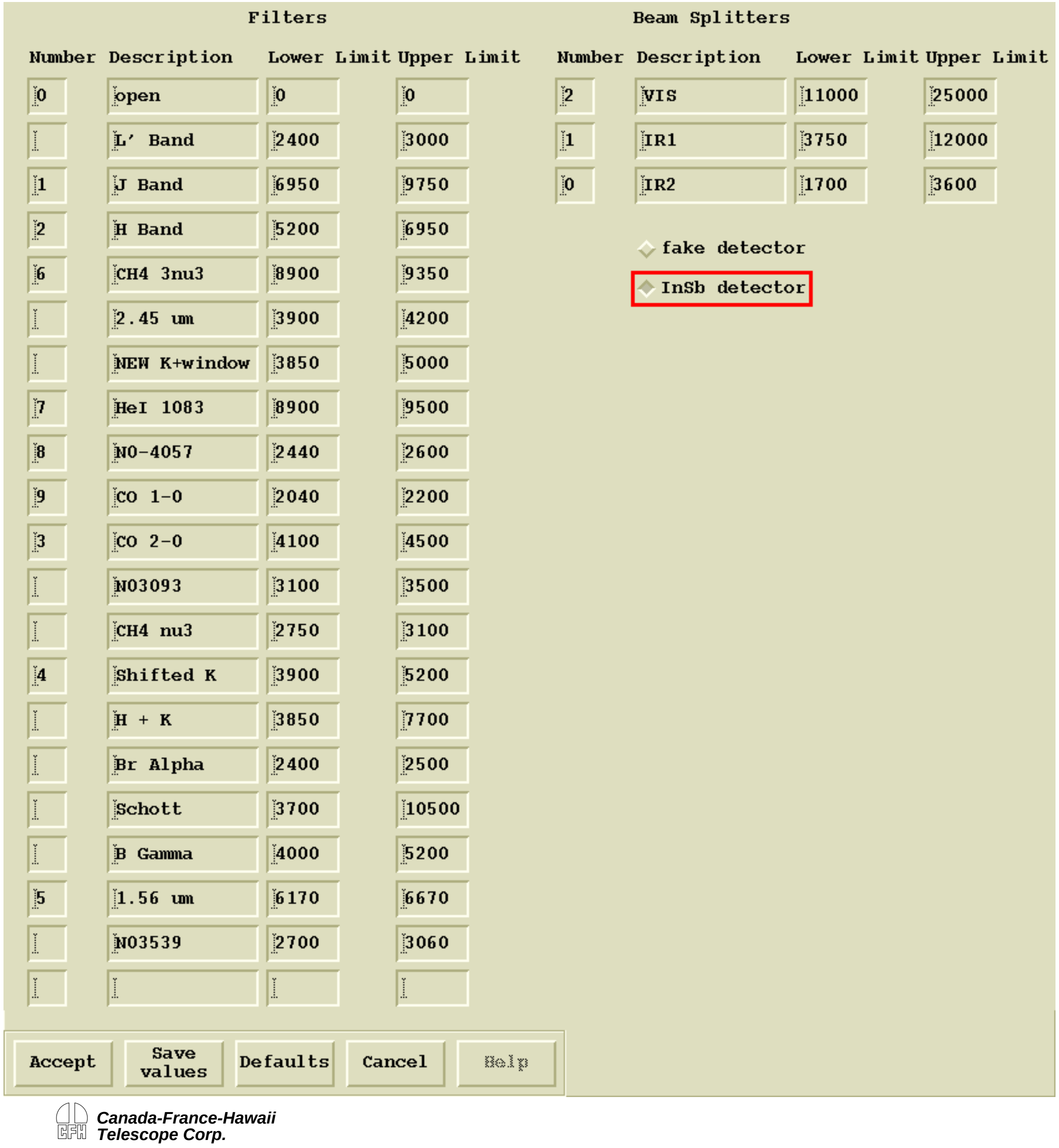

Figure 5.8: Filter/Beam Splitter/Detector Table

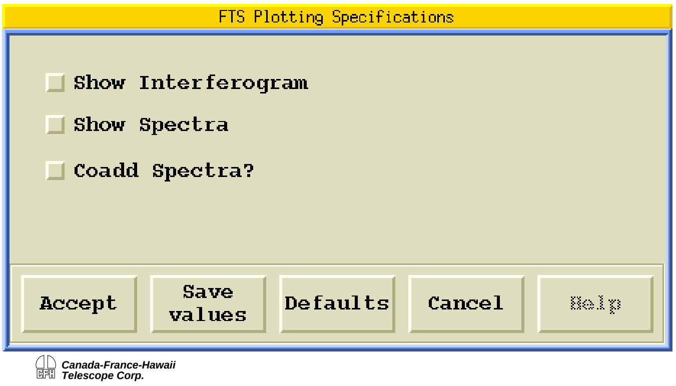

Figure 5.9: Look Menu

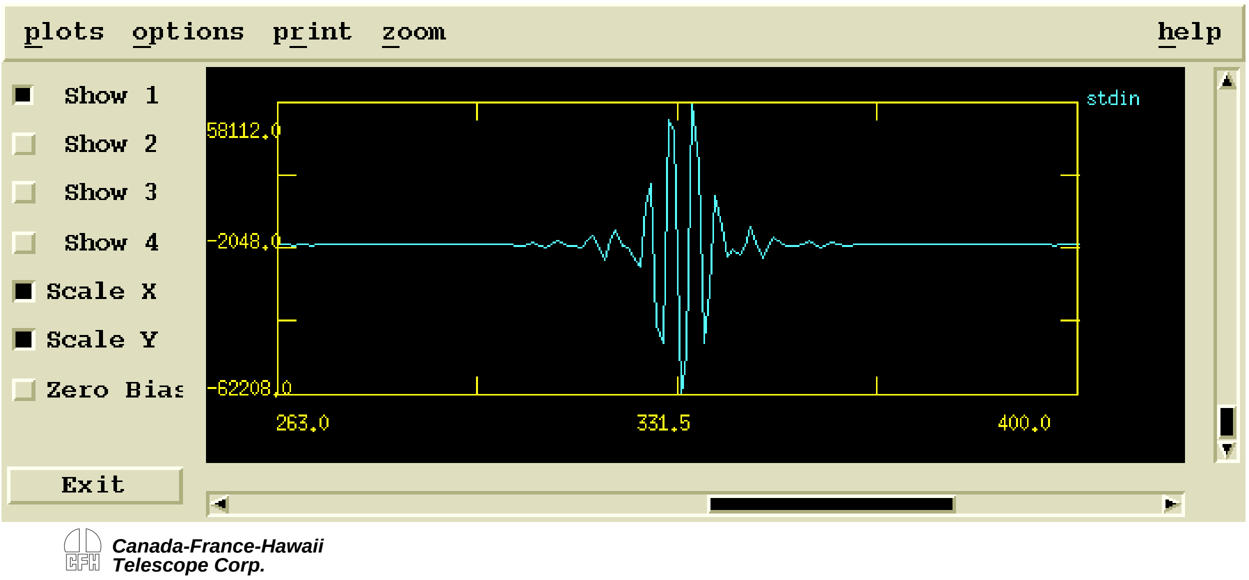

Figure 5.10: Grapher Plot of Interferogram

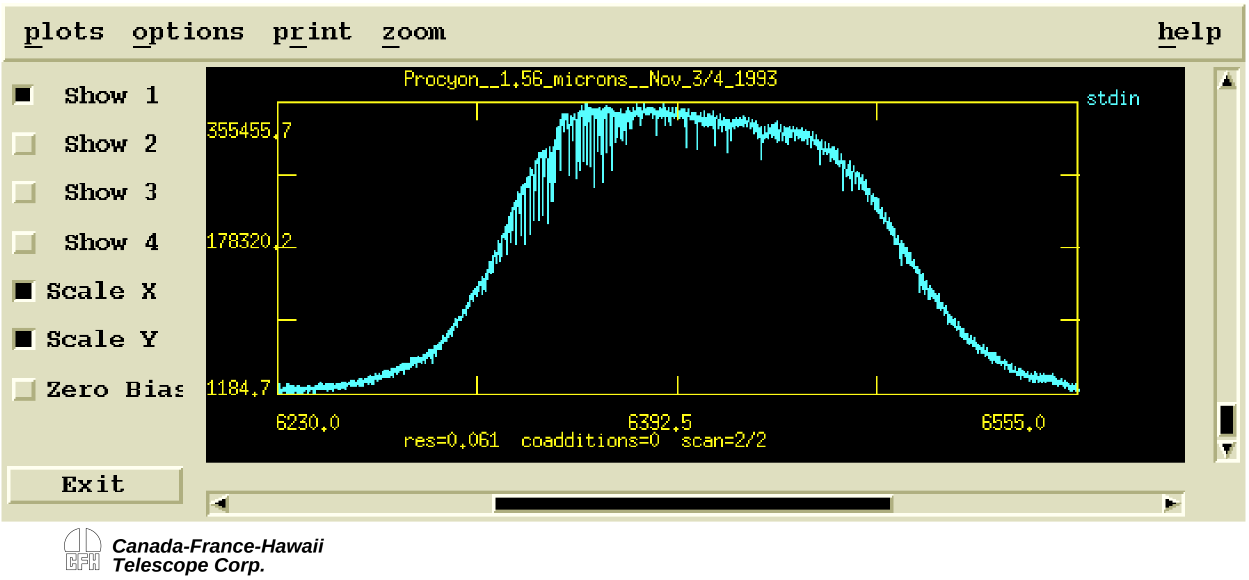

Figure 5.11: Grapher Plot of Spectrum

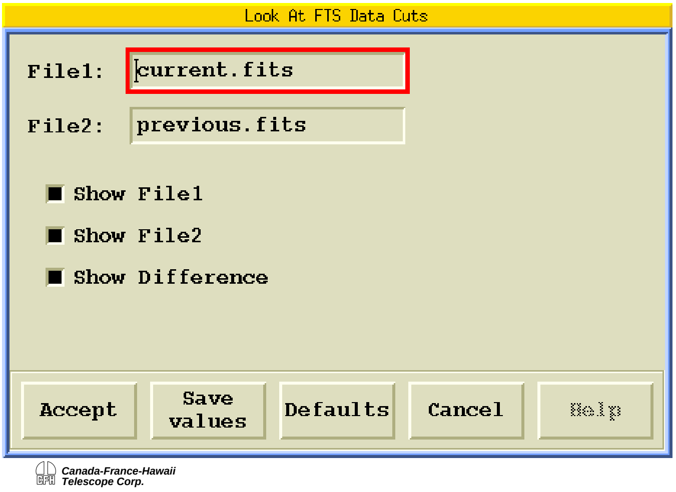

Figure 5.12: Eng Menu

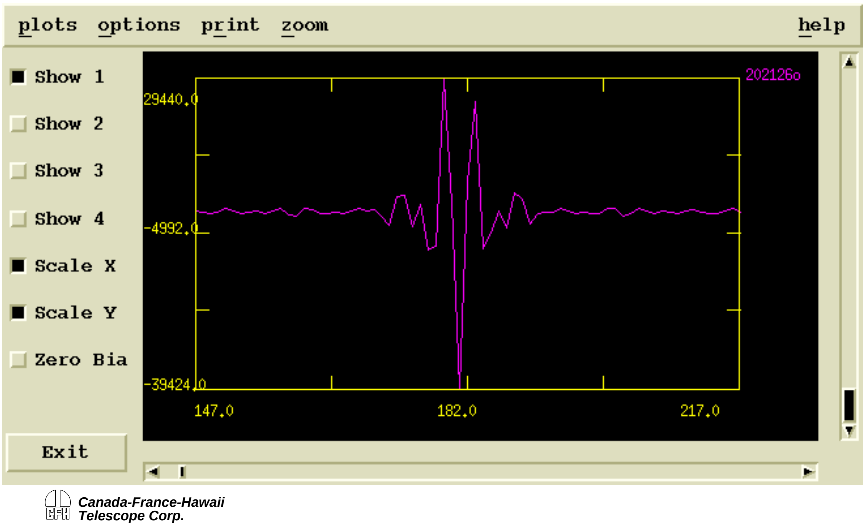

Figure 5.13: Sample Interferogram Plot Using Eng Menu

5.3.2 Eng

This menu, shown in Figure 5.12, is used primarily for engineering and setup purposes. The names of two interferograms to be plotted with grapher can be specified in the boxes for **File1** and **File2**. The difference between the two can also be illustrated by selecting the **Show Difference** option from the menu. The Eng menu enables the user to confirm that after a pair of scans the carriage has returned to its starting position, since any missing points in one of the scans will produce an obvious shift in the forward and reverse interferograms near ZPD. It also provides a convenient way to inspect the complete content of the interferogram just recorded, and to compare observations from one scan to the next if the intensity has not changed. A sample plot of a portion of an interferogram near ZPD is illustrated in Figure 5.13.

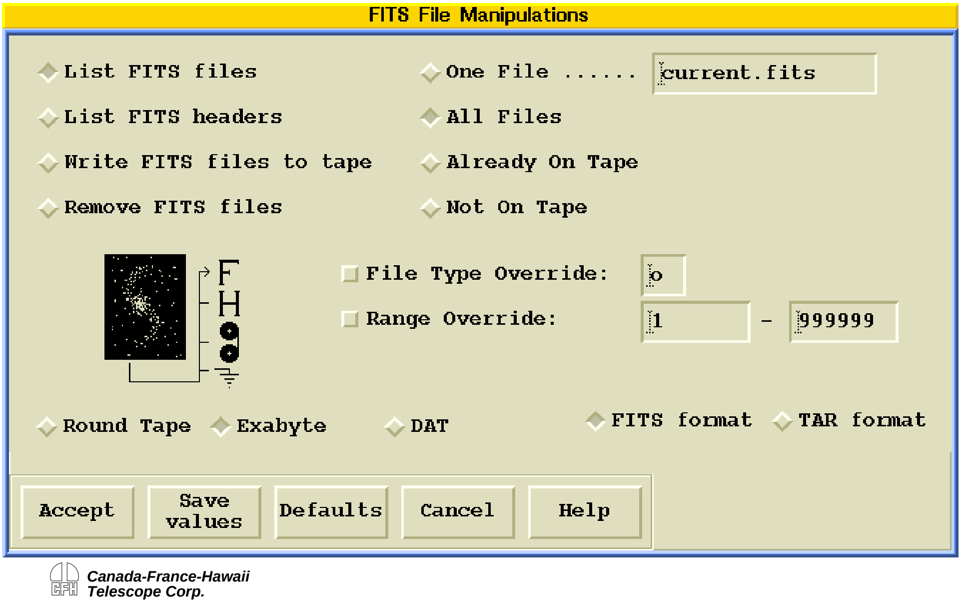

Figure 5.14: Files Menu

5.3.3 Files

The data are recorded in 'fits' format, and each file is assigned a name consisting of a 5 digit number (the 'odometer' reading), followed by the letter 'o' and the extension '.fits'. The exposure name is displayed on the FTS Status icon which appears whenever a scan is in progress (figure 5.4). The name of each exposure should be recorded on an FTS Log sheet (see Appendix D) for future reference.

The 'Files' menu controls all file operations and, for the purposes of discussion, can be divided into two parts: 'What to do', and 'what files to do it to'.

There are four operations which can be performed on the files. They are:

- **List FITS Files:** Lists the names of all specified files.

- **List FITS Headers:** Displays the complete FITS header for all of the specified files.

- **Write FITS Files to Tape:** Saves the specified files to tape. When this option is selected you must also select the kind of tape you are using (CFHT currently supports Exabyte and DAT tape formats) as well as the tape file format you desire. Writing a tape in TAR format is much more efficient and much faster than writing the files as individual FITS format files.

- **Remove FITS Files:** Deletes the specified files from disk. It is important to note that the files are not physically deleted from the summit disk until *after* a copy has been sent to Waimea for archiving on the optical disk system. However, once 'removed' the files can no longer be accessed by the observer.

The second part of the menu specifies which files are to be displayed, saved, etc. There are four entries:

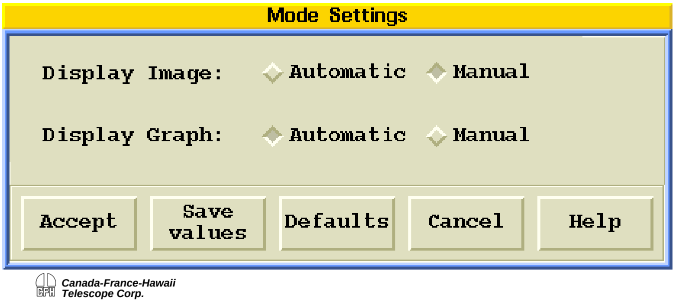

Figure 5.15: Modes Menu

- **One File:** In this case the name of the file can be entered in the window next to this entry. By entering 'current.fits' (the default) the most recent fits file is acted upon.
- **All Files:** In this case all files on the disk are acted upon (within the file type and range overrides discussed below).
- **Already on Tape:** In this case all files which have already been written to tape are acted upon, within the specified overrides (see below).
- **Not on Tape:** In this case all files not written to tape are acted upon, within the specified overrides (see below).

One can select specific subgroups of files, based on there file type (in almost all FTS applications this is 'o', for object) or their odometer reading, which is the numerical part of the file name. These can be entered in the **File Type Override**, and **Range Override** entries.

A word of caution: Before writing a large number of files to tape or, even worse, deleting them from your disk space, it is a good idea to first list them with the List FITS files option to confirm that the correct files have been identified.

5.3.4 Modes

This menu (Figure 5.15) specifies whether or not the data will be displayed automatically.

The two entries on this menu are:

- **Display Image:** This selection is not applicable to conventional FTS observations.
- **Display Graph:** If **automatic** is selected then the interferogram and/or spectrum will be output on the screen automatically during each scan. If **manual** is selected then the user must ask for each plot to be displayed.

5.4 Utilities

Three other utilities are available from the Pegasus Session Manager.

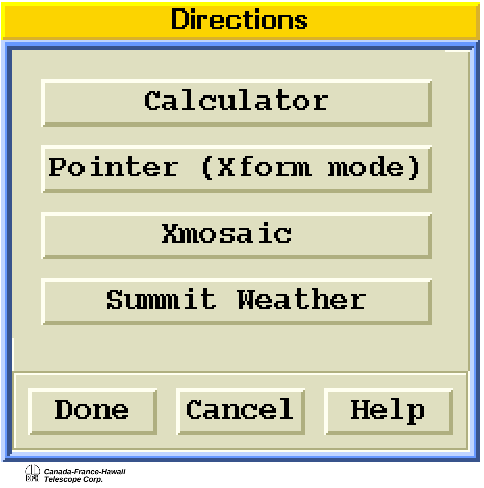

Figure 5.16: Tools Menu

5.4.1 Tools

Selecting the **Tools** icon opens up the menu shown in figure 5.16. Four choices are currently available:

- **Calculator:** If this button is selected a calculator tool appears on the screen. You can use the mouse to 'press' keys on the calculator or use the numeric keypad on the HP9000 terminal to perform calculations.

- **Pointer (Xform mode):** While not particularly useful for FTS observations this selection can be used to position a labelled pointer on the workstation screen.

- **Xmosaic** This item begins an X windows version of Mosaic, a powerful tool for accessing a wide range of data on the Internet. From the CFHT Home Page itself you can access users manuals, weather maps, observing schedules, etc.

- **Summit Weather** Selecting this button opens up a window with a display of current weather conditions at the summit of Mauna Kea.

5.4.2 Suggestions

The **Suggestion** button should be used whenever you want to report a potential, but non-critical software problem. When activated, a form similar to that shown in figure 5.17 is opened. Simply enter the requested information at the top of the form, enter a description of the problem in the area at the bottom of the form, and select **Submit Report** to send the report. The information is automatically forwarded to the members of the CFHT software group as well as many of the support astronomers and engineers. Suggestions for improvements to the data acquisition software are also greatly appreciated.

IF YOU BELIEVE A SOFTWARE (OR HARDWARE) PROBLEM IS RESULTING IN LOSS OF DATA OR INEFFICIENT USE OF THE TELESCOPE

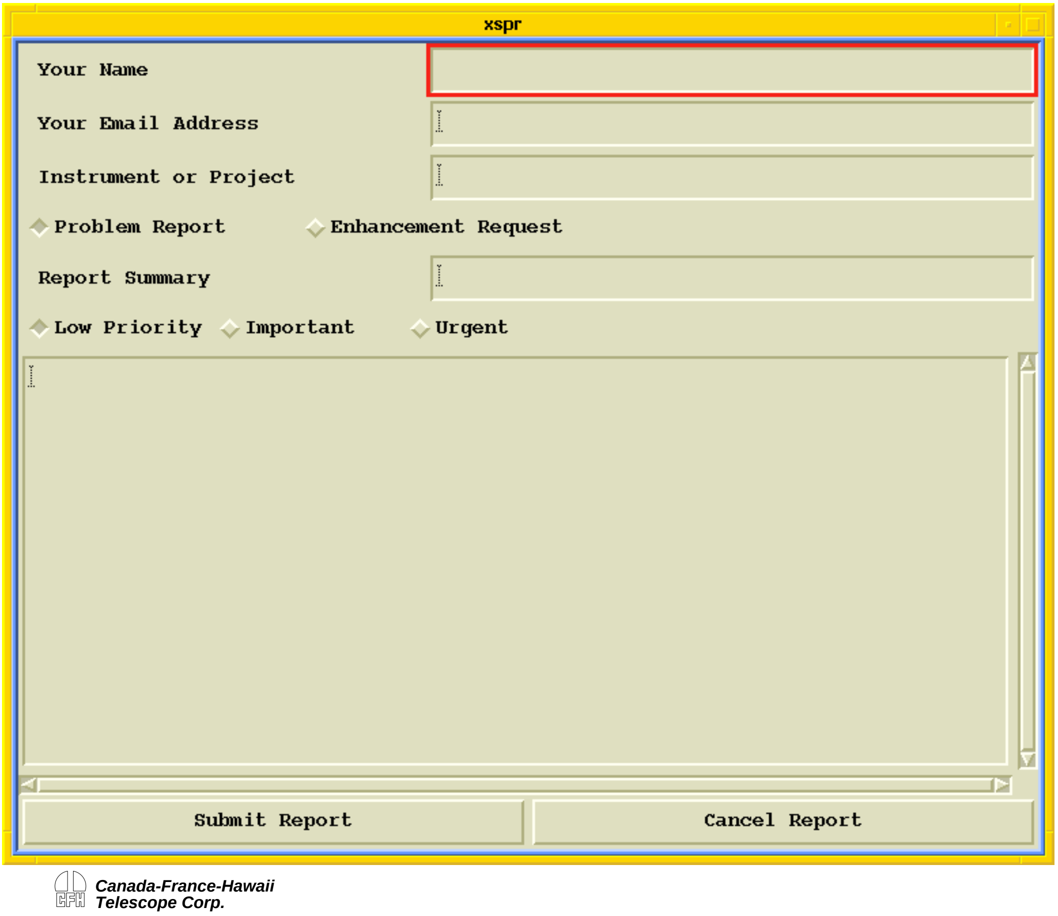

Figure 5.17: Suggestions Menu

ASK THE TELESCOPE OPERATOR TO CALL YOUR SUPPORT ASTRONOMER. THE SUGGESTION BUTTON WILL NOT RESULT IN A REAL-TIME FIX OF THE PROBLEM!

5.4.3 News

The **News** icon gives a summary of recent data acquisition software upgrades and improvements at CFHT.

5.5 Disaster Relief

There is only one menu in this section, **ALOHA**, and a sample is shown in Figure 5.18. This menu is used if a fatal hang-up occurs in the software and it is necessary to exit the program. Once this is executed, the computer returns to the login environment, from which a new FTS session can be started.

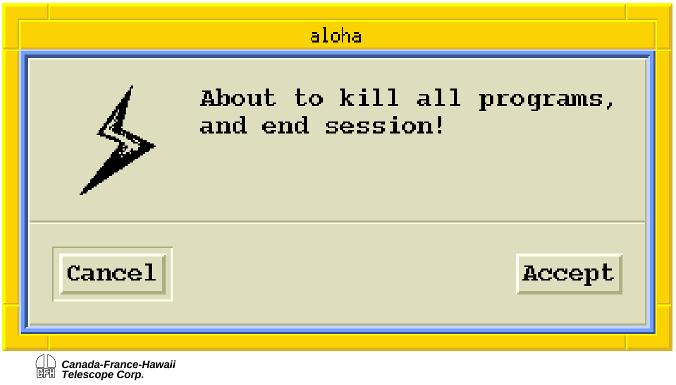

Figure 5.18: Aloha Menu

Chapter 6

FTS Troubleshooting

Because of the complexity inherent to data acquisition with an interferometer, it is easy (and common) to make mistakes. What follows are lists of possible causes for obvious problems.

6.1 No Signal, or Very Weak Signal

- Object is too faint.
- Atmospheric conditions: thick overcast or poor seeing - for the latter problem, use a larger entrance aperture.
- Object not on 'hot spot' - recenter object.
- Bonnette guide probe not at position (x,y) = (0,0) - have telescope operator return guide probe to correct position.
- Entrance shutter to interferometer closed - open shutter.
- Dewar dark slides closed - open dark slides.
- Incorrect preamp gain setting - try more sensitive preamp setting.
- Preamp switches on sides of dewars turned off - turn on preamps.
- Dewars are not at nominal operating temperature - check temperatures and vacuum manifold readings.
- If, after investigating all the possibilities listed above, there is still no measurable signal, the sensitivity of the detectors should be tested using the white light source internal to the interferometer. To do this, turn on the white light source and position mirror 2. Next, select the He I filter; the IR1 beam splitter should also be in place. Set the preamp gain to '1', and display the 'S1' signal on the oscilloscope. Turn the rheostat on the control panel which varies the power to the white light source. The strength of the S1 signal should vary. If not, try the 'S2' signal. If no change is apparent contact CFHT personnel.

6.2 Unusual Interferogram and/or Power Spectrum

- Servo system not locked in 'fringe' mode - lock servo.
- The carriage was not advanced ahead of optical ZPD before the scan started - relocate optical ZPD and remember to flag the 'move carriage' option in the SCANS menu.
- The preamp setting is too high, and the detectors are saturated (common problem when looking at the moon or very bright late-type stars). Select a less sensitive gain setting.
- Carriage may not be moving in the correct direction - check lights labelled 'F' and 'B' at the bottom of the right hand side of the main control panel.
- For faint sources, the divider may be on - turn divider off.

Appendix A

FTS Filters

λ_c (μm)	$\Delta\lambda$ (μm)	Peak Trans. %	Thickness (mm)	Comments
1.060	0.040	76	5.3	
1.081	0.036	75	5.9	
1.100	0.030	71	5.9	
1.100			5.9	no curve
1.260	0.320	79	1.95	J
1.561	0.041	90	1.95	
1.680	0.280	93	1.7	H
1.985	1.170	93	2.1	H + K
2.120			1.0	K' - no curve
2.151	0.196	88	1.2	
2.205	0.390	82		K
2.296	0.568	79	1.6	shifted K
2.339	0.553	91	0.6	K
2.349	0.097	84		
2.460			1.04	no curve, narrow band
3.0925	0.106	87		
3.129	0.065	70	1.1	
3.458	0.195	82	1.1	CH_4 - NH_3
3.534	0.272	84	0.95	
3.675	1.165	82		broken
3.677	0.161	83	1.0	
3.788	0.753	78		L'
3.825	0.191	91	0.55	one broken
3.827	0.119	71	1.05	
4.055	0.054	68	1.7	
4.057	0.164	80		
4.770			1.09	no curve, narrow band
4.820	0.184	87		
5.260	0.332	80	0.55	

Table A.1: CFHT FTS Filter List

Appendix B

FTS Filter Transmission Curves

The following figures give examples of actual spectra obtained with selected filters with the CFHT Fourier Transform Spectrometer. These should give the potential user some feeling for the bandpass of a particular filter as well as indicate telluric features that may influence a possible scientific program.

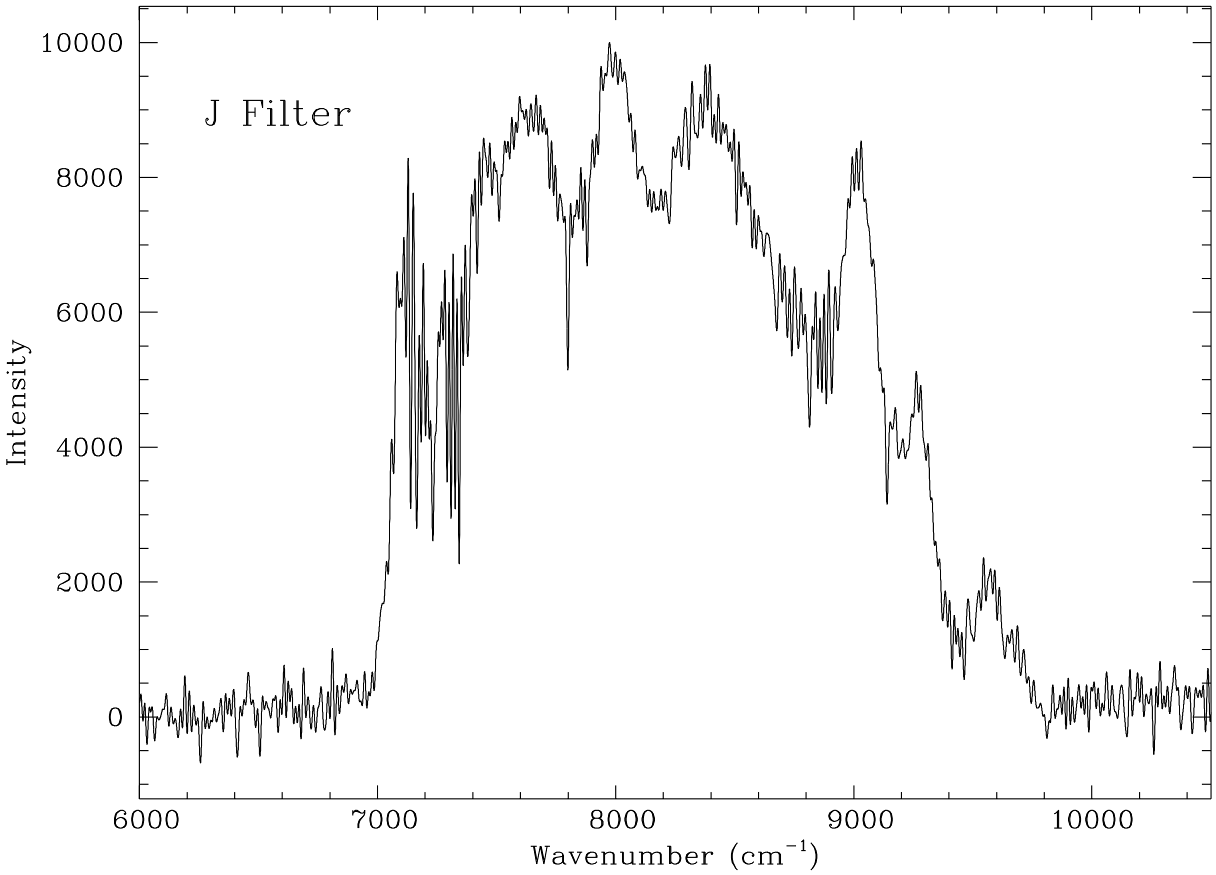

Figure B.1: J Filter Transmission Curve

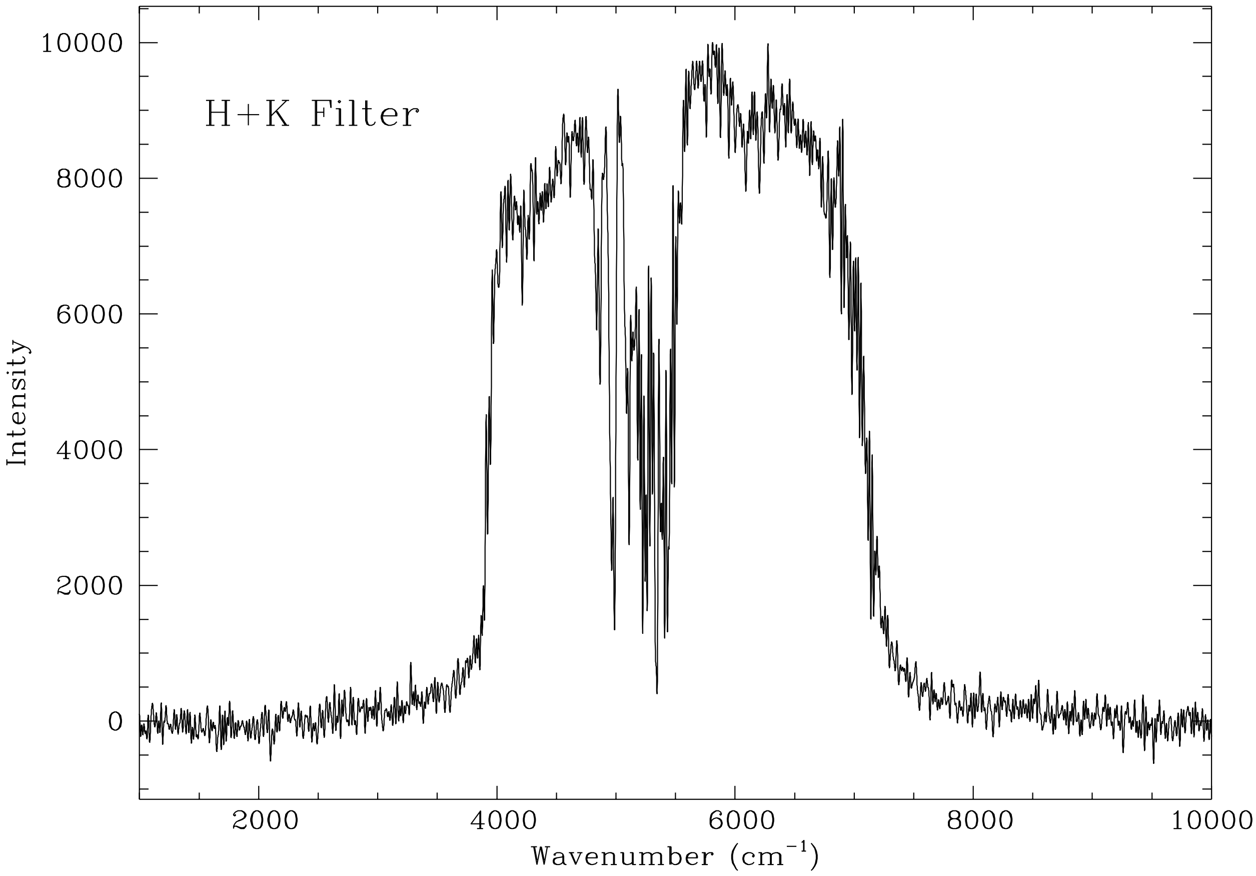

Figure B.2: H+K Filter Transmission Curve

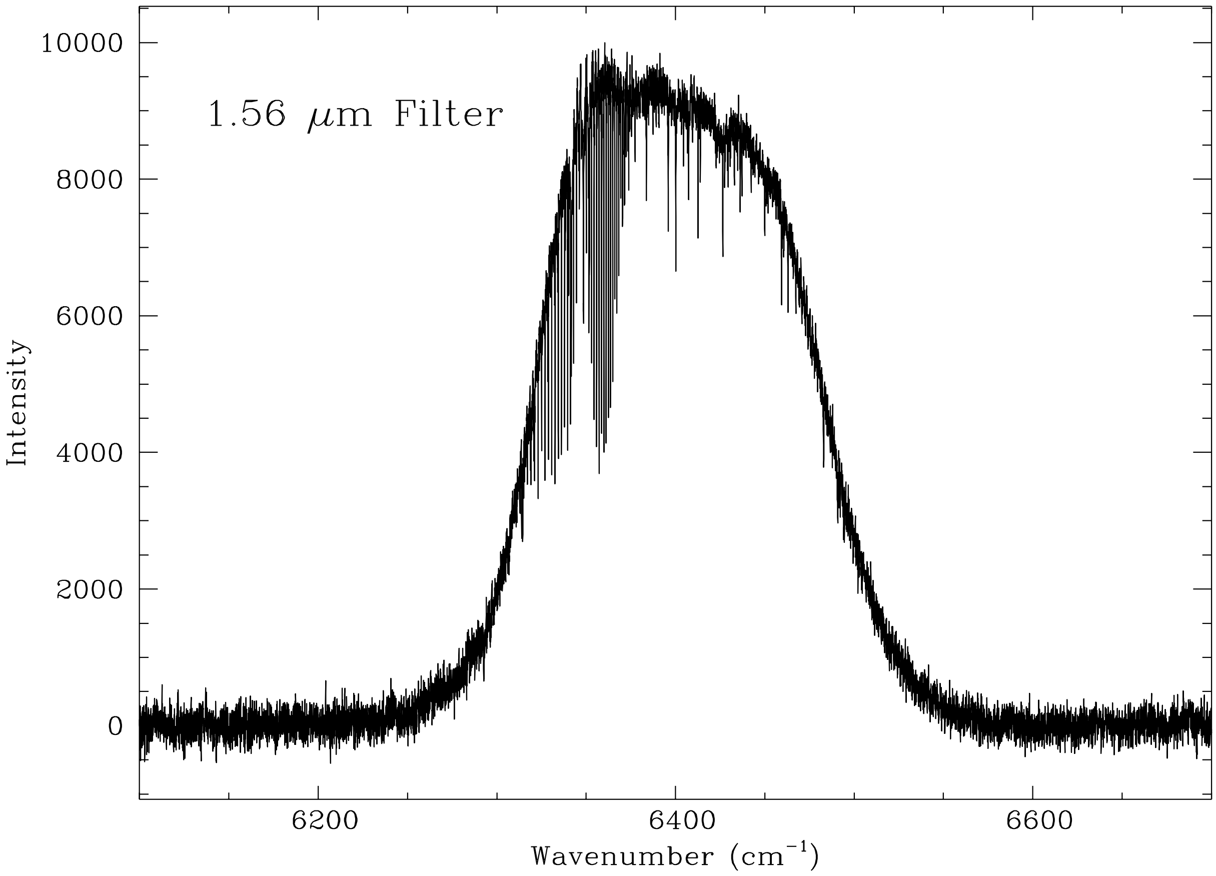

Figure B.3: $1.56 \mu m$ Filter Transmission Curve

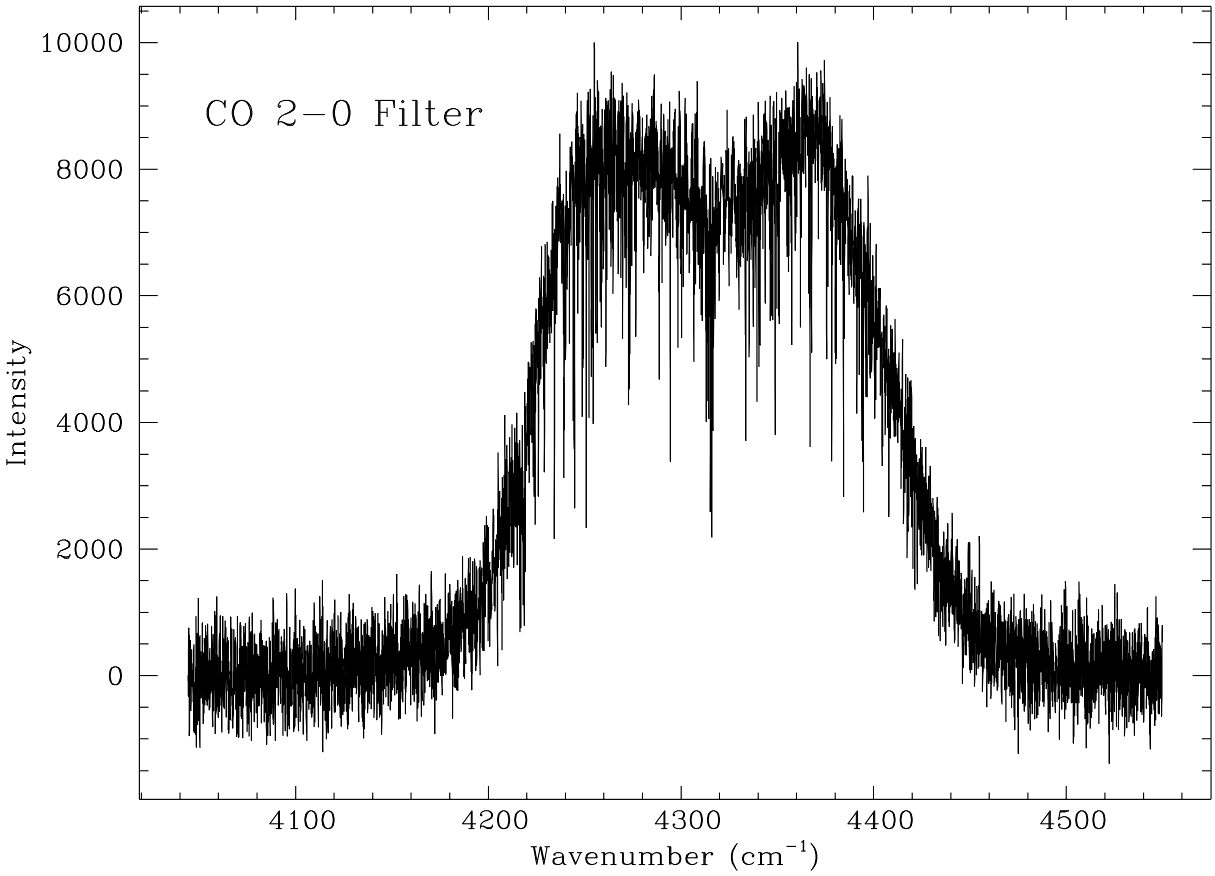

Figure B.4: CO 2-0 Filter Transmission Curve

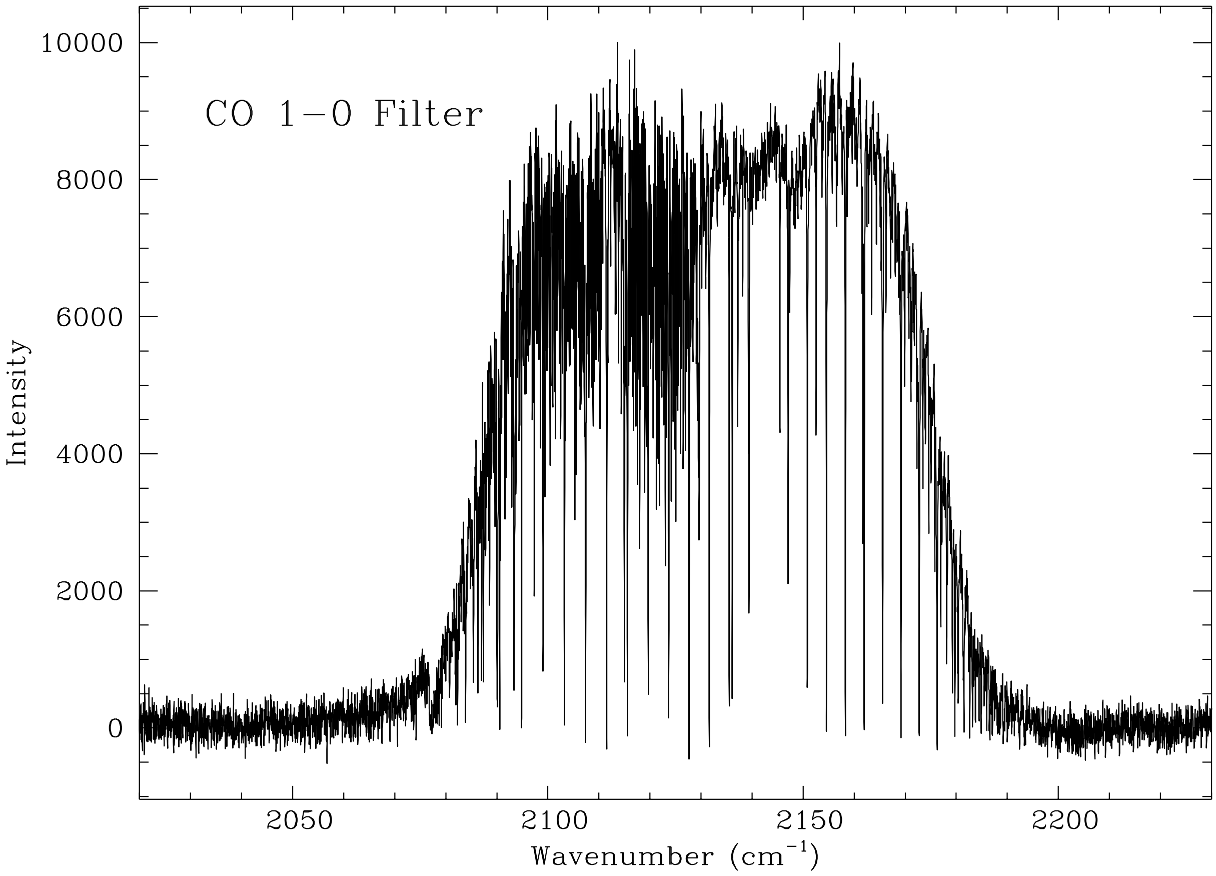

Figure B.5: CO 1-0 Filter Transmission Curve

Appendix C

FTS S/N Curves: InSb Detectors

The following figures give achievable S/N ratios (where N is 2× r.m.s. noise) in one hour integrations when observing with an intermediate modulation frequency of 143 Hz. The S/N for different resolutions is proportional to $\Delta\nu$.

Note that under detector noise limited conditions (appropriate where the slope of the lines in the figures is 1) the S/N is improved by a factor of approximately two when a modulation frequency of 20 Hz is used.

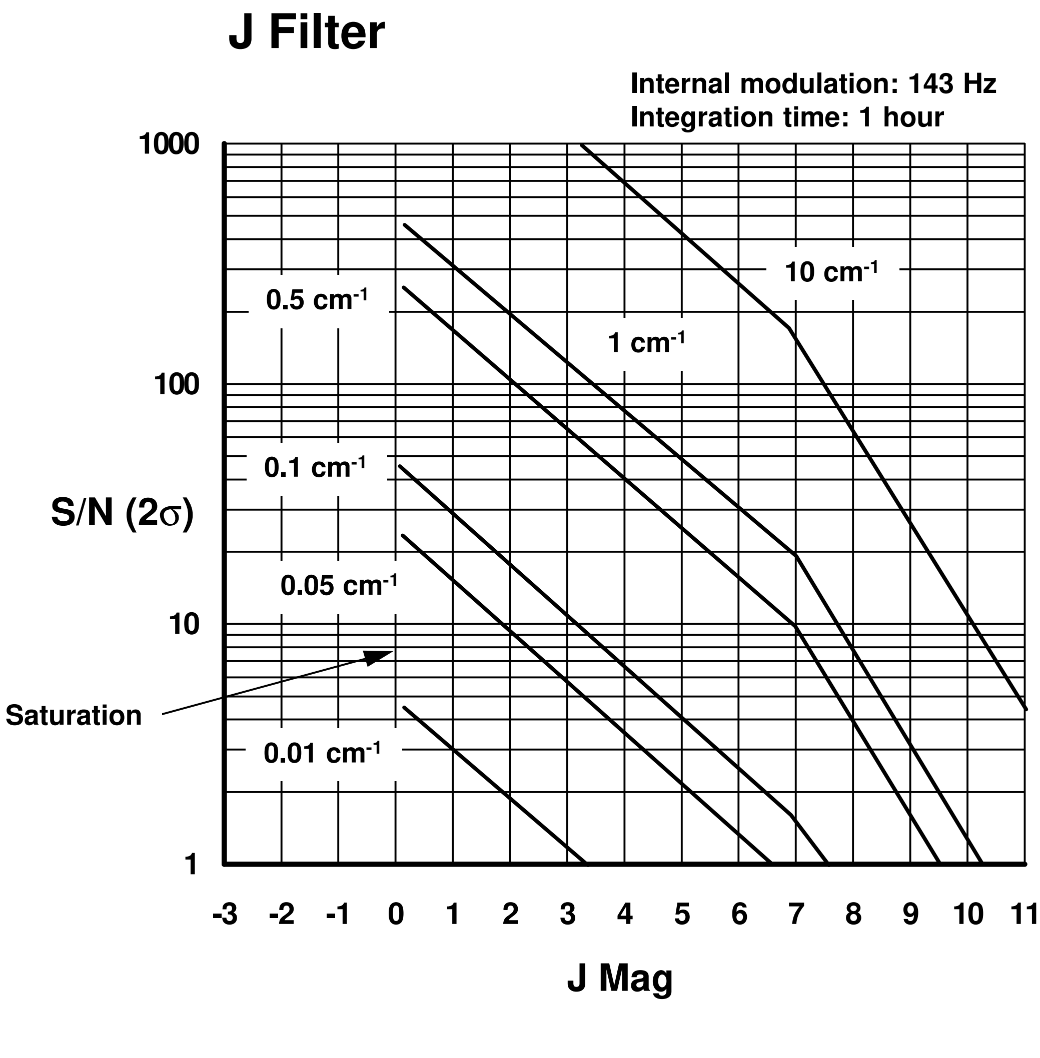

Figure C.1: J Filter S/N Curve

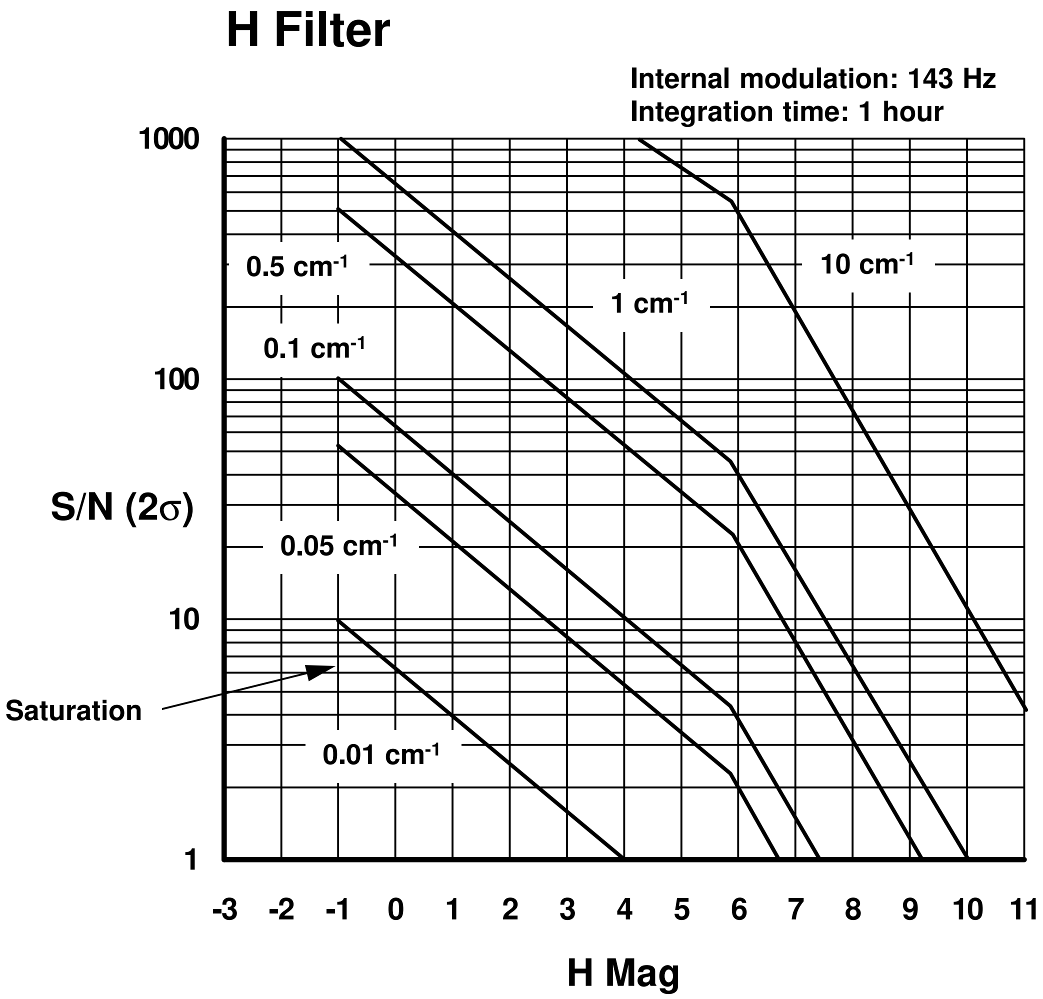

Figure C.2: H Filter S/N Curve

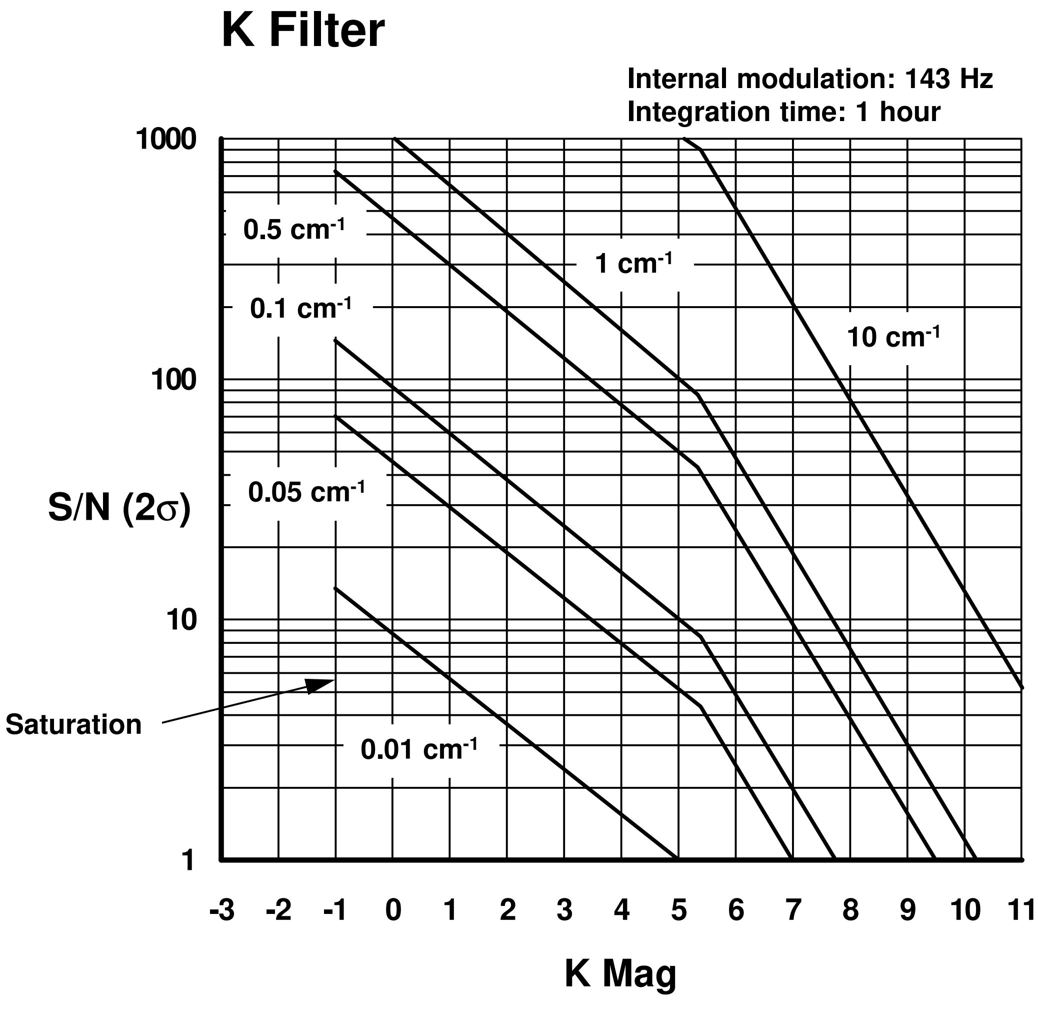

Figure C.3: K Filter S/N Curve

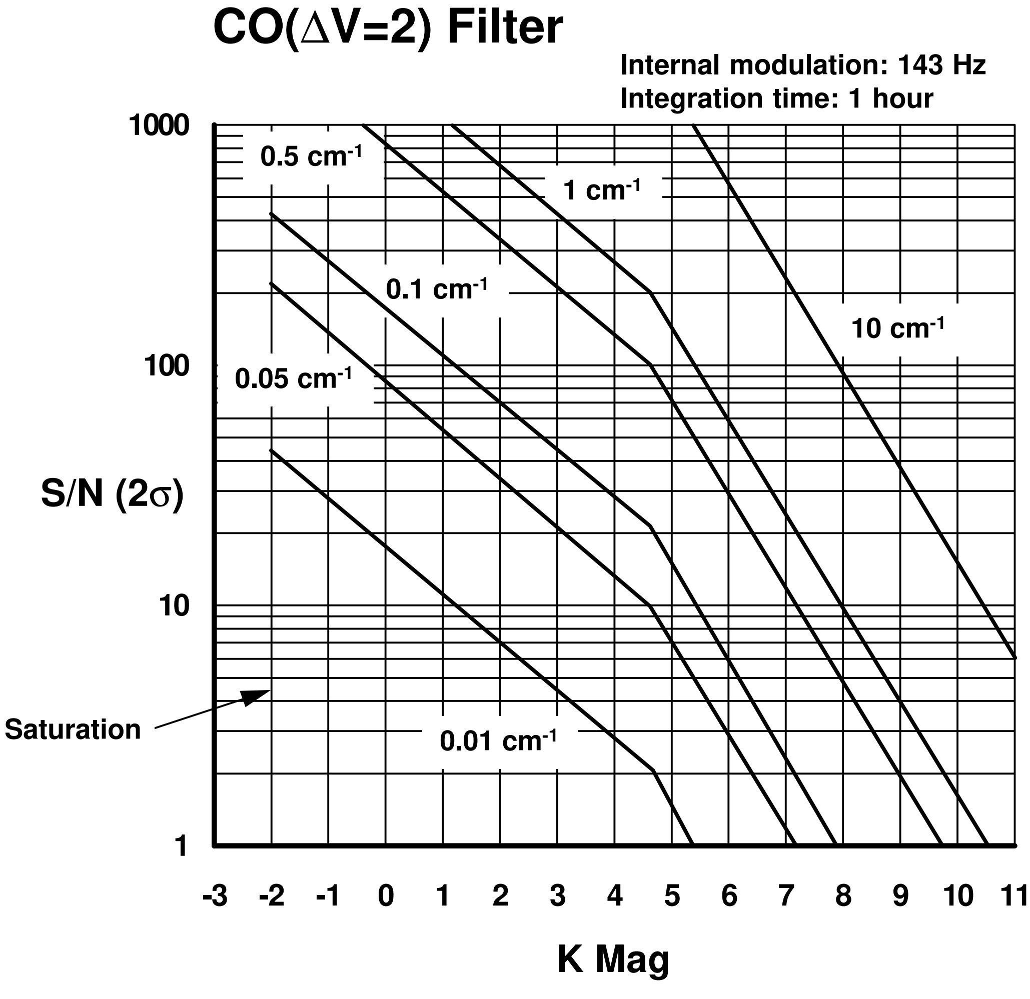

Figure C.4: CO 2-0 Filter S/N Curve

Appendix D

FTS Observing Log

FTS – OBSERVING LOG

Page __ of __

Observers: ______________ **FOCUS:** ______________ **Detector:** ______________

Date: ______________ **Archive OD #** ______________ **Beamsplitter** ______________

Program: ______________ **Remarks:** ______________

Exposure #	Object	R.A.	EPOCH	UT start	HA start	Tel. Focus	P	NSTEPS	SCAN DIRECTION	Guider @ XY	FILTER	Bm Sw ?	N O T E S
		Dec.		AIRMASS	HA end	Bonn. Z	Q	T		TV XY	BANDPASS		

Figure D.1: FTS Observing Log