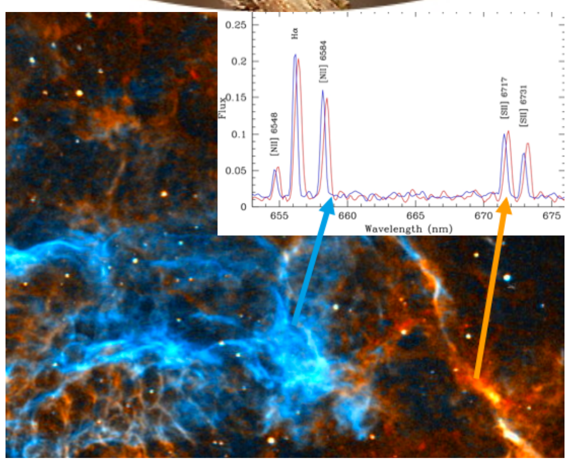
SITELLE



Science-based Requirements Document

Revised - October 31, 2011

Executive summary

This document describes the science-driven requirements for SITELLE, an Imaging Fourier transform spectrometer that will be installed at the Cassegrain focus of the Canada-France-Hawaii Telescope (CFHT). SITELLE will be able to obtain spectra in selected bands within the visible domain (350 – 970 nm) of every source of light in a wide (minimum 10' x 10') field of view, with a spectral resolution of R ~100 – 30000. The science cases for SITELLE were presented in the feasibility study submitted to the CFHT in October 2008.

1 – OPERATIONS

1.1 – Location

SITELLE will be attached to the Cassegrain focus of the Canada-France-Hawaii telescope, located at the summit of Mauna Kea on the Island of Hawaii, at an altitude of 4200 m. SITELLE shall be completely functional under normal observing conditions of temperature, temperature variations, atmospheric pressure and winds, as well as vibrations and electronic conditions of the telescope environment prevailing at the site. Details about the site and the telescope are available at the following URL (Version 1.0 – January 2003) :
http://www.cfht.hawaii.edu/Instruments/ObservatoryManual/CFHT_Observatory_Manual_TOC.html

1.2 – Timeframe

SITELLE shall be delivered to the CFHT no later than December 2012 for the commissioning phase. This means that it should be ready to be attached to the telescope, completely functional and ready to see its first light and obtain its first data cubes. A commissioning phase of two weeks at the telescope will then be planned to test its capabilities in most of its operating modes. A commissioning and science verification plan will be available as a separate document. SITELLE is a CFHT guest instrument.

Comment : A unique window of opportunity will be opened in early 2013 for SITELLE. Soon after, other instruments will be installed with a higher priority and the observing time available for SITELLE will significantly decrease. In order to maximize the scientific return of the instrument, the first scientific data cube must be obtained at the telescope as early as possible in 2013.

1.3 – Operations

Once attached to the Cassegrain focus of the telescope, SITELLE must be operated remotely, without any human intervention on the site for a minimum of 7 days.

Comment : Starting in 2001A, CFHT started to implement queue observing (QSO mode) to increase the efficiency of the telescope and reduce operational costs. All new instruments must be used as queued service instruments and remotely operated (Reference : IDS, section 1.2.4).
This will imply the use of a Cryotiger-like cooling system (or a reasonable equivalent) for the CCDs, since the CCDs must be kept cold during one full week. Enough filters must be provided within the filter wheel to last one observing run.

1.4 – Usage at the telescope

1.4.1 - The number of nights attributed to SITELLE at the CFHT depends only on the demand by users and the attribution of telescope time to the different projects, on a competitive basis, by the Time Allocation Committee .

1.4.2 – Because of SITELLE's great versatility, it can and will be used as a moderate resolution imaging spectrometer working in the red band, alllowing it as a bright time instrument. Cosmology and other broad-band, low-resolution projects will require dark time.

2 – SCIENCE CAPABILITIES

2.1 – Field of view - Threshold : 10' x 10'
Goal : 20' x 20'

Comments :
** The only way an Imaging FTS can be competitive with the new generation of IFUs (VIRUS on the HET -15' FOV) is by having a large FOV and high efficiency. With a few exceptions, galactic nebulae around evolved stars and nearby galaxies of interest have a diameter less than 10'. This sets the threshold FOV. However, work on galactic HII regions, as well as the cosmological surveys will require a larger FOV.*
** The FOV is expected to be that of a square CCD, with a minimum unvignetted circular FOV of 6' radius and minimal optical aberrations at the corner.*
** Given the maximum CCD size we can afford in terms of readout time and $$ (2k x 2k), and in order to avoid a huge PSF undersampling, the goal is limited to 20'.*

2.2 – Pixel size – 0.3'' – 0.6''

Comments :
- Obviously, pixel size and FOV are linked, given the CCD size. The median seing (site + dome) is 0.8'' in the R band. . The optimized pixel size (2.5 pixels/ FWHM) is therefore 0.28'' to 0.32'', leading to a FOV of 10.9 arcminutes (just above the threshold set in 1.3). However, ~ 20 years experience with HST images have clearly demonstrated that PSF undersampling is not a problem for photometric measurement. Considering that the scientific niche of SITELLE is the wide field rather than high spatial resolution, pixel sizes of up to 0.55'' are acceptable.

- On the other hand, the natural median seing is at the site is 0.55'' (Salmon et al. 2009, PASP, 121, 905), and modifications to the dome could improve the total median seeing down to 0.7''. Moreover, although SITELLE will not be used with Adaptive Optics in its first few years of operation, it would be perfectly suited behind IMAKA's GLAO system. IMAKA's goal is to provide images with 0.3'' FWHM over a one degree FOV. SITELLE could then provide ground-layer corrected imaging spectroscopic capabilities over a ~10' FOV.

- On-site binning is also an option to increase the S/N ratio and lower the readout time/noise, as it is usually done with SpIOMM

For a 2048 x 2048 CCD, 15µm/pixel :
0,293''/pixel → 10' x 10'
0,438''/pixel → 15' x 15'
0,500''/pixel → 17' x 17'
0,586''/pixel → 20' x 20'

2.3 – Image quality and distortion – Panchromatic FWHM < 1'' at the edge

2.3.1 – Image quality

The panchromatic image quality in wide-band filters (200 nm) shall be no worse than 1.0'' (PSF FWHM) at the edge of the field (in the corners of the CCDs). Image quality in the central circular field (5' radius) shall be no worse than 0.8'' (PSF FWHM).

Comments :

- Most of the time, SITELLE will be used with medium-band filters. This constraint must be discussed to optimize image quality without significantly increasing the costs of the optics.

- These constraints apply to both detectors simultaneously.

2.3.2 - Optical distortions - Optical distortions shall be no more than 1% within a 6' radius FOV.

Notes :

- This constraint is added to ensure that mosaics of extended targets can be built from individual data cubes. It refers to the difference between the astronometricaly measured position of a star and its location on the image.

- Image quality is much more important than optical distortion

2.4 – Maximum Limit of Resolution - Threshold : 6,4 cm^{-1}
Goal : 0,5 cm^{-1}

Comment : It is essential to resolve the [SII] 671.7, 673.1 doublet : 0,466 nm → R = 1400 (10 cm^{-1}). It is important to resolve the [OII] 372.61, 372.88 doublet in bright nebulae : 0,09 nm → R = 4141 (6,4 cm^{-1}). A resolution of 4 cm^{-1} corresponds to R = 6700 @ 372.7 nm, and R = 3360 @ 740 nm. A higher resolution is not wished for if using a wide bandpass because it would take too long. However, if we want to use SITELLE for nebular or stellar kinematics, a resolution of R = 30 000 (0,5 cm^{-1} @ 650 nm) is required. This mode will be used in conjunction with a narrow-band filter. These values refer to the non-apodized Instrument Line Shape.

2.5 – Wavelength regime : Threshold : 365 – 880 nm (Troughput no less than 75% of maximum)
Goal : 350 – 970 nm (Troughput no less than 75% of maximum in the threshold zone; no less than 40% outside)

Comments : Two spectral features define the minimum wavelength range of the instrument. [OII] 372.7 nm (emission line in ionised nebulae) and the calcium triplet @ 849.8, 854.2, 866.2 nm in absorption. Allowing for some *blueshift (Crab & Cas A supernova remnants) and redshift (galaxies) as well as continuum on both sides of these two lines defines the threshold. The* *extended goal allows for a wider range of redshifts in the cosmological surveys as well as the [SIII] 906.7, 953.2 nm emission lines to determine the ionization factor and the abundances in galaxies.*

*Throughput = (Modulation Efficiency) * (Optics transmission)*

Note : the quantum efficiency of the detector has been removed from the definition of throughput here.

2.6 – Observing efficiency - Threshold Dead Time: 3 seconds
Goal : 2 seconds

*We absolutely need to mimize the overhead time of each integration, since this time is multiplied by the number of recorded frames in a data cube acquisition, which is of several hundreds, making an important total dead time. This time is made of two components, CCD readout time and the moving part stabilisation time, which must be simultaneous. With current 2K*2K CCD a readout time of 1s is obtained with an acceptable level of readout noise. Thus, the position servo-system must be designed with enough dynamic power and a damping signal in order to approach this limit.*

Typical integration times for individual frames are 5 – 60 seconds.

2.7 – Output ports

SITELLE shall be a two output-ports system. This implies constraints on focus on both detectors, i.e. perfect focus on one must imply perfect focus on the other, either automatically or with an independent adjustement on one of the output ports.

Not only will the two output ports provide twice as much flux of a standard Michelson one output system, but corrections for the sky transparency variations will be much easier.

2.8 - Detectors

To cover the desired FOV within the range of pixel ifov allowed, a ~2k x 2k detector is required for each of the two output ports. Detectors should be very efficient in the blue (at least 70%QE @ 370 nm) without compromising the red.

Readout time (full-frame) must be short (less than 3 seconds).

Readout noise must be kept low (less than 5 electrons per pixel).

Dark current for a 120 seconds integration time shall be negligible compared with the readout noise. Most applications will require short integration times (typically between 10 seconds and 2 minutes per step). However, SITELLE might also be used as a "standard" camera for long exposures - target of opportunity (supernovae, gamma-ray bursts, comets, ...) for instance. Its detectors's dark current should therefore be kept at a level comparable to that of "normal" camera CCDs, i.e. less than 10é/pixel/hour.

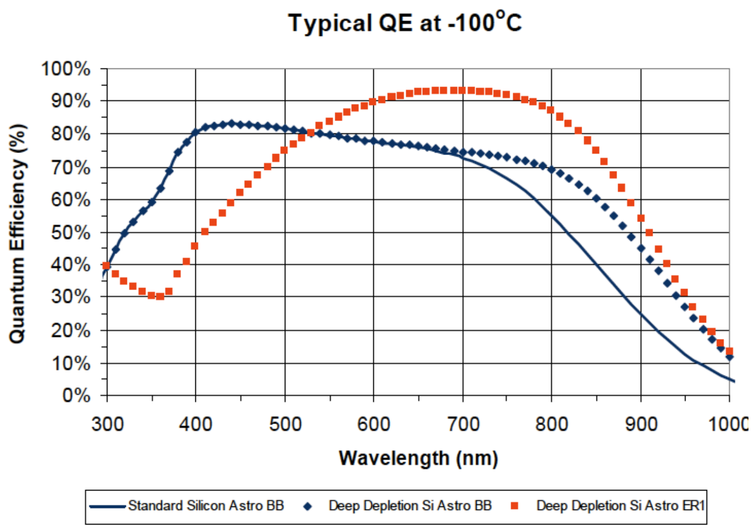
The detector should have a binning capability, chosen by the observer before each data cube. 1x1, 2x2 and 4x4 modes shall be standard and well documented. 8 x 8 and 16 x 16 modes should also be available, but at "shared risks" since they are unlikely to be frequently used.

Electronic cross-talk shall be less than 0.1%.

Binning should be A cryotiger-like system is preffered to cool the CCDs since it does not require LN_2. Subsections of the entire frame shall be possible, as well as on-chip binning.

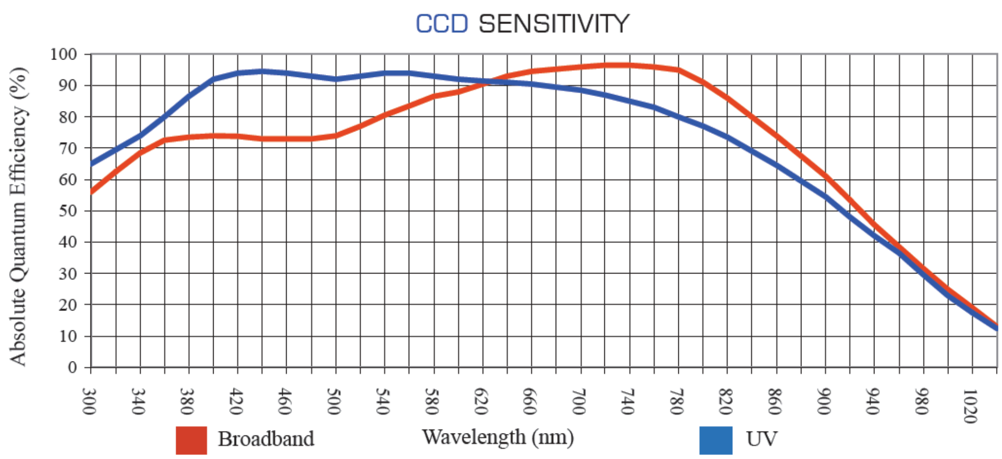
Detectors considered at the present time are :
(1) e2v CCD242-31, 2048 x 2048 15 µm pixels, with custom UV-sensitive coating
Standard CCD, 4 output ports for fast reading at low readout noise.
(2) e2v EMCCD207-40, 1632 x 1608 16 µm pixels, with custom UV-sensitive coating

Typical e2v QE curves shown below :



EM-CCD, can be used in two modes : standard and no-noise. The no-noise option is at the expense of a 2x-reduced quantum efficiency. Both options can be used during the same night for different objects.

(3) Fairchild U3041-UV , 2048 x 2048 15 µm pixels, packaged by Apogee. Cooled by a set of fans to 65 °C below ambiant temperature. Higher dark current (0.1eps), adds ~2.5 e to the readout noise for a typical 60s exposure. Very simple to use, low cost, very high QE in the blue (82% @ 372.7 nm). May require binning to reduce readout time/noise. QE curve is shown below :



2.9 – Filter wheel and filter set: Threshold : 5 filters
Goal : 10 filters

A filter wheel must be provided within the instrument. It should accomodate at least five filters simultaneously, 10 filters if possible. We do not expect to be using more than 3 – 5 filters per night, but a total of ~ 10 filters is expected to cover most science cases. A double-deck filter wheel with 5 filters each would be ideal.
If the filter wheel accommodates only 5 filters (because of space constraints for example), this adds a constraint on queue scheduling.

Filter change shall take less than 1 minute

Filter position shall be encoded absolutely

The final choice of filters will be done during phases A – B, but the following examples should cover a wide range of science cases.

Group 1 : Emission lines in Milky way nebulae & nearby galaxies
B1 : 475 – 510 nm (Hβ 486.1, [OIII] 495.9, 500.7)
B2 : 430 – 510 nm (Hγ, [OIII] 436.3 + B1)
R1 : 650 – 680 nm ([NII] 654.8, 658.4, Hα 656.3, [SII] 671.7, 673.1)
R2 : 650 – 660 nm ([NII] 654.8, 658.4, Hα 656.3 - high resolution $R=10^4$)
U1 : 360 – 510 nm ([OII] 372.7 & [OIII] 500.7 simultaneously)
V1 : 480 – 720 nm (B1 + R1)
V2 : 535 – 640 nm (Faint lines in Bright HII regions – avoids Halpha)

Variations on some of the above may be considered to take into account the redshift of some galaxies, or we might just want to extend the red end of the filters for that purpose (for example up to 690 nm for R1 for a redshift of 0.02).

Group 2 : Absorption lines – old stellar populations
I1 : 845 – 870 nm (Ca triplet 849.6, 854.2, 866.2 nm)

Group 3 : Cosmology
To be defined; will be broadband, should avoid bright night sky lines (630.0 nm). Used to detect high-redshift Lyman emitters. Simulations required? Examples :

C1 : 385 – 515 nm (Lyα @ z = 2.17 – 3.23; folding order 3, R~500, 130 steps)

C2 : 560 – 628 nm (Between 5577 and 6300 night sky lines; Lyα @ z = 3.6 – 4.18; folding order 8, R~500, 80 steps)

2.10 – Sensitivity
The sensitivities given below are for a total exposure time of 4 hours in dark time.

2.10.1 Emission line studies
SITELLE shall be able to detect (3 sigma above the noise) the faint [OIII] 436.3 nm emission line in giant HII regions of galaxies in the Virgo cluster with a typical flux of 3.0 x 10^{-16} erg/cm^2/s at R ~ 1100 (Filter B2). *Reference : Vilchez et al 2003, ApJS, 145, 225.*

2.10.2 Cosmology
SITELLE shall be able to detect Lyman-α emitters down to a 5-sigma level of 4.0 x 10^{-17} erg s^{-1} cm^{-2} (R ~ 500, filter C2)

2.11 – Type of lines
SITELLE shall be able to observe both emission and absorption lines on top of a continuum.

3 – Observing constraints and compliance with CFHT

3.1 – Compliance with CFHT
SITELLE shall be compliant with the CFHT IDS (Revision 2.5 January 29, 2009).

3.2 – Observing conditions
3.2.1 - Targets will be located all around the sky. Observations are expected to take place while the targets are between 0 and 45 degrees from the zenith. Therefore, the instrument shall meet all performance requirements with pointing angles varying between 0 and 45 degrees from the zenith during a data cube acquisition.
3.2.2 - The instrument shall be able to acquire datacubes extending from 30 minutes to 5 hours.
3.2.3 - Combination of data cubes : It must be possible to combine two incomplete data cubes obtained during two different nights to improve the S/N ratio and/or to improve the spectral resolution, provided that both cubes include frames obtained at the Zero Path Difference.
3.2.4 - The instrument shall be able to survive pointing angles between 0 and 90 degrees from the zenith.

3.2- Flexure
Individual frames are aligned to within a fraction of a pixel before creating the data cubes. A significant misalignement between the first and the last frame of a cube could cause systematic

errors in the spectra of individual sources. The higher the spectral resolution, the thinner the fringes of the interference pattern on the detector.

Maximum image motion from the zenith to 45 degrees should be less than 2 pixels.

3.3 - Atmospheric dispertion corrector – Not necessary
Between 350 and 850 nm, at a zenith angle of 45 degrees, the panchromatic image is extended ~ 0.6 arcsec by atmospheric refraction. Panchromatic images at the edge of the field being ~ 1 arcsec, it does not seem necessary to implement an ADC. For most science cases, filters are narrower, so the problem is even less important.
See TMT's SBRD, Appendix 8. Reference : Filippenko 1982, PASP, 94, 715 (but note that at CFHT, the zenith is at 0.6 airmass).

3.4 – Stray light
Baffles shall be included in the optical path to minimize stray light.

3.5 – Maintenance
Easy access to critical parts should be available.

Critical parts include :
- piezos
- Inchworm or equivalent
- List to be discussed with ABB?

A maintenance plan should be provided with the instrument. This will include recommendations for preventive and condition based maintenance items. All components that need to be addressed for maintenance requirements need to be accessible, in particular wear parts that will likely need replacing. Another example, the filter wheel should be very easy to access and filter exchange must be simple and not require significant disassembly of the instrument.

3.6 - Manuals
Users manual, maintenance manual shall be provided. Paper documents shall be provided at the time of delivery, and electronic versions should be maintained and updated on a regular basis. Define who should be responsible.

4 – CALIBRATIONS AND OBSERVATIONS
A calibration module and routine shall be implemented. Standard imagery calibrations (Bias frames, flatfields, dark current) must be complemented by photometric and wavelength calibrations. All should be done remotely.

A typical night/mission shall include :
4.1 - Bias and dark frames for both detectors (obtained during the day/twighlight); 10 bias frames + 10 dark frames for each integration time. *[20 minutes]*

4.2 - Flatfields with each filter used for science(obtained during the day/twighlight); *[90 minutes] : 3 filters maximum per night, 5 flats per filter – Internal flats or twighlight? TBD*
4.3 - Optimization of the modulation efficiency during twighlight. Ideally, shall not need to be done during the night. If need be, this step shall not require more than 20 minutes.*[20 minutes]*
4.4 - Spectral calibration – A high resolution data cube of a laser source (unfiltered He-Ne 632 nm for SpIOMM – using an integration sphere) shall be obtained at least once a week (verify this) during the day. *[3 hours]*
4.5 - Focus using a star field during twighlight. Process should be automatic : vary the telescope focus and take a series of exposures. Software must provide the ideal focus. Focus must be OK for both detectors. Usually, focus is adjusted once or twice during the night. *[20 minutes]*
4.6 – Location of target : obtain an image of the target, adjust position if needed. *[5 minutes]*
4.7 – Selection of observing mode : spectral resolution, filter & spectral folding order, exposure time per step. *[1 minute]*
4.8 – Data cubes on target. *[60 – 300 minutes]*
4.9 – Photometric calibration : exact routine needs to be defined – photometric standard field (cluster) or emission nebulae? *[30 minutes?]*

5 – SOFTWARE

5.1 – User interface:

The user interface shall be simple and provide all required functions to obtain science data cubes and calibration (on two different windows?). For coding the interface, a web based technology is preffered, allowing the control from almost anywhere, if properly authentified. One nice piece of technology is the jQuery (http://jquery.com).

Comments from CFHT (Sarah, 9 september 2010) :
Our newer instruments do not have a GUI type interface (in the observing context) but instead the instruments are controlled from our observing environment from which text based commands to the instrument can be sent (i.e. in the "director" window). During normal observing, the queue software sends the commands to director so that all the observer really needs is some way to visualize the data to validate what is coming in; detailed control of the instrument is generally not in their hands.

A library of command line functions (e.g. compiled executables) to execute various commands is one possibility; and it should be well documented. Another possibility which is more elegant and efficient, is to provide a driver that higher level software (developed by, or in partnership with CFHT) uses to access the controls. This higher level software layer is implemented as an "agent" in director and can accept commands from the director session (CFHT will definitely have to implement that).

Having a GUI is extremely useful as an engineering troubleshooting tool to allow quick access to the basic functionality of the instrument (detect limit-switch states, control actuators manually, take test images, etc). However, having the control system tied to the GUI is not desirable.

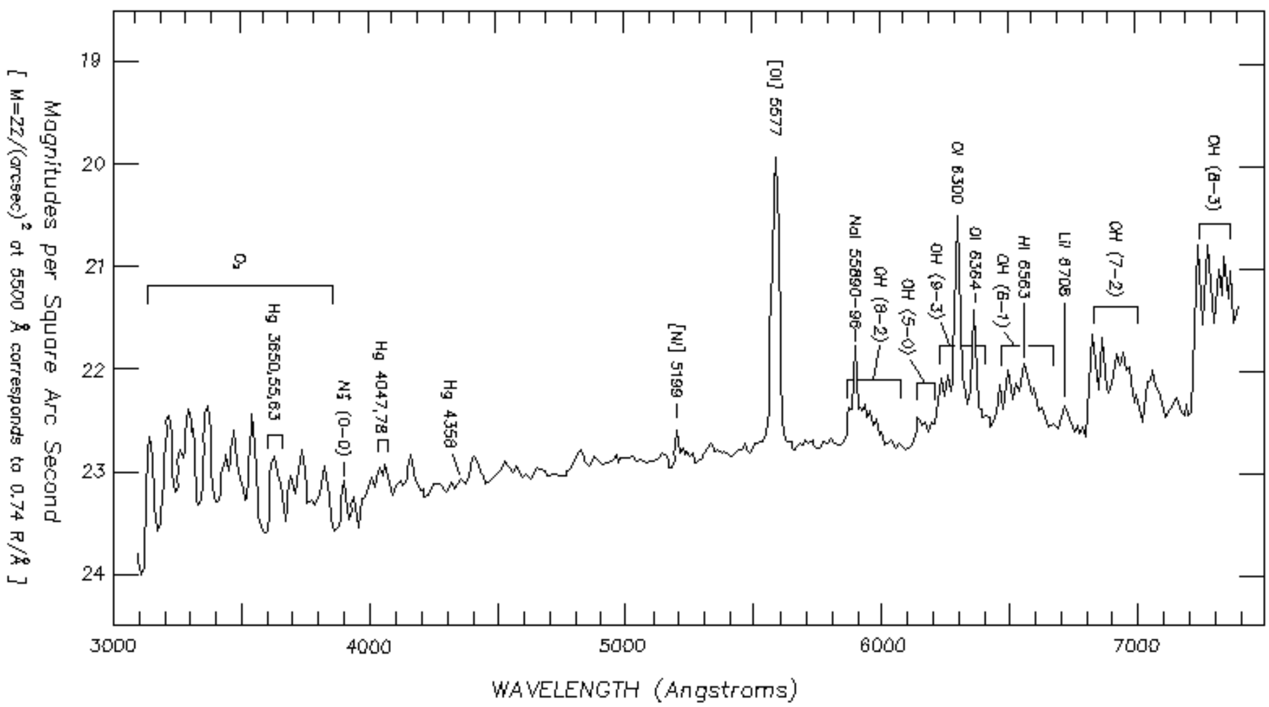
5.2 – Data reduction software :
Software for a complete data reduction shall be provided. Users will obtain the completely reduced data cube as well as the raw data.
Open source for all software.

5.3 – Data Simulator :
A simple data simulator shall be provided to the users to prepare their observing proposals and observations. Exposure time calculators and data simulators are now provided for most instruments on large telescopes.

5.4 – Engineering software :
Diagnostic Tools – to be discussed with CFHT.

APPENDIX 1 - References

*** Site characteristics**:
http://www.cfht.hawaii.edu/Instruments/ObservatoryManual/CFHT_ObservatoryManual_%28Sec_2%29.html



*** Seeing :**
Salmon et al. 2009, PASP, 121, 905
http://www.journals.uchicago.edu/doi/full/10.1086/605313

*** SITELLE Feasibility study :**
Drissen, L., et al. 2008