SITELLE, a wide-field Imaging FTS at the CFH Telescope

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Abstract: This paper gives an overview of SITELLE, one of the three instruments planned for CFHT in the 2013-2020 era. SITELLE is a UV-VIS-NIR wide-field imaging Fourier transform spectrometer optimized for astronomical observations of extended objects.

OCIS codes: (300.6300) Fourier transforms Spectroscopy; (300.6550) visible spectroscopy; (350.1260) Astronomical optics

1. Introduction

SITELLE [1] is a new imaging Fourier transform spectrometer (IFTS) to be installed at the end of 2012 at the 3.6-meter Canada-France-Hawaii Telescope (CFHT). This instrument follows in the footsteps of another astronomical IFTS called SpIOMM which is operating at the 1.6-m telescope of the Observatoire du mont Mégantic in Québec since 2005. SpIOMM was designed based on the experience acquired with LIFTS, another IFTS originally meant to be a demonstrator in support of an instrument proposal for the James Webb Space Telescope [2].

The origin of FTS can be traced back to astronomical applications with the Connes' work in the 60's but since then they have been rather sparsely used in astronomy. In fact none of today's large optical telescopes (about 30 with a primary mirror larger than 3.5 meters) offer FTS instruments on the menu. The traditional high spectral resolution capability that made FTS famous in the 70's is nowadays carried out by echelle grating spectrographs. One good explanation for this is the astronomer's epic quest for lowest noise observations in order to remain photon noise limited even for the faintest objects in the field. Imaging detectors used in astronomy today are nearly photon counting devices with quantum efficiencies in excess of 90% and read noise of a few photons (3 photoelectrons typical). This low noise is not only useful for imagery but also for spectroscopy which is where FTS loses the battle against the grating. The main problem is the distributed noise property of the FFT which tends to corrupt the region of low intensity with the strong photon noise of emission lines or bright continuum spectral regions. However this disadvantage can be overcome to some extent when taking advantage of the large throughput available in an FTS used with an array detector. This is exactly the property that SITELLE is going to exploit as much as possible by using a 2048 x 2048 low noise CCD detector with a quantum efficiency exceeding 80% from 360 nm to 780 nm.

This combination makes SITELLE a unique instrument in the field imaging spectrometer referred to as Integral Field Unit (IFU) in astronomy. Almost every large telescope is now equipped with one of those IFUs whose concept are typically based on image slicer or fiber bundle feeding a classical dispersive spectrograph. Given that one axis of the detector must be used for spectral sampling, none of today's IFU rivals with SITELLE's large FOV and number of fields sampling points which will exceed 4 million. Typical IFU field sampling locations are limited to the number of rows (or columns) on their array detector used and as such are typically 3 orders of magnitude smaller than SITELLE. For many extended astronomical targets filling SITELLE's FOV, the coverage advantage largely overcomes the distributed noise limitation, especially for the study of emission lines in ionized gaseous regions.

2. Optical Design

Once a clear set of scientific goals has been defined, the elaboration of such an instrument starts with the identification of a low noise CCD chip and the verification that an optical system can be designed to meet the desired image quality over the large FOV and for all wavelengths simultaneously. This is a challenging task that is nevertheless more or less common to other wide-field imaging cameras in astronomy. The presence of the interferometer however adds additional constraints. First is the desire to minimize the interferometer size for cost and performance purposes. This is achieved by centering the interferometric cavity on an auxiliary image or pupil plane of reduced size. The pupil plane was preferred for various reasons and the trade on the pupil size was mainly driven by the attempt to minimize the beamsplitter diameter while maintaining an acceptable image quality on the CCD. The smaller the pupil, the larger the incidence angles are on the imaging lenses which tend to affect image quality at the edges of the field. Second is the need to maintain sufficient beam collimation in the interferometer section such that the spectral resolution is not degraded at the edges of the field due to the rapidly changing OPD at large incidence angle in the interferometer. The design task is further constrained by the desire to maintain a high transmittance at 372.7 nm, an important [OII] line that is used by astronomers for chemical composition diagnostics. Many glass substrates commonly used in optical design exhibit strong absorption below 400 nm and cannot be used.

The current SITELLE optical design is based on a 3 lens collimator and a 7 lens camera objective. The total internal transmittance (excluding Fresnel reflection) exceeds 90% down to 373 nm. Such a large number of lenses was required to achieve a good image quality and is not uncommon in astronomical instrumentation. However the large number of interfaces put more emphasis on the need for good broadband antireflection coating for all lens materials. The image quality is monitored using the encircled energy metric which reaches 75% for a circle fitted within 4 adjacent pixels anywhere on the array which is consistent with the image blur caused by the atmosphere (0.7 arc sec median seeing at CFHT). The primary aberration is chromatic and as such, image quality is improved when using preselection band pass filters since the telescope has the ability to adjust focus on the fly. Figure 1 shows a view of the optical train unfolded at the interferometer mirror (each beamsplitter pass appears separately).

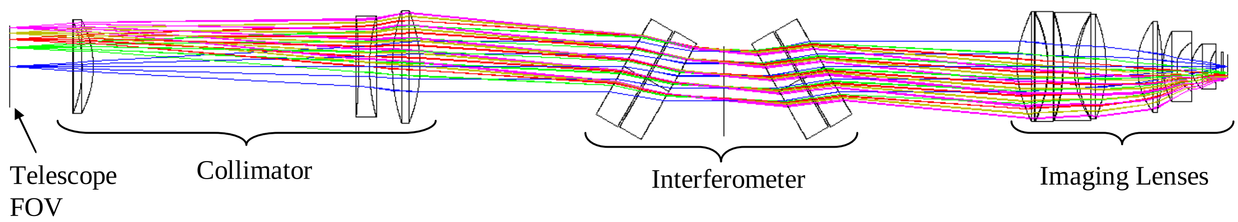

Figure 1: Unfolded Optical Train

3. Interferometer Design

A serious trade for the optimum interferometer configuration was performed. There were numerous motivations for a corner-cube-based design that would take advantage of the small pixel divergence to yield a shear and tilt insensitive system. However, the accuracy required combined with the size of the part was beyond the reach of potential suppliers for the available budget. A roof-top based design proposed by J.P. Maillard was also seriously considered as a contender. The complexity of manufacturing a large roof top with the required accuracy remained too high but the possibility to manufacture two parts with compliant relative tilt errors was investigated; the two interferometer arms would direct their output beam in the same angle if retro reflectors are clocked properly. An ingenious scan mechanism carrying both interferometer mirrors would cover for the risk of misalignment in the tilt sensitive axis of the roof top. The other possible approach was the use of a classic plane mirror interferometer used off-axis to obtain the input/output port separation. The successful heritage of this approach in two previous instruments [2,3] combined with the risk of thermally induced misalignment and the larger overall instrument size led us to favor the plane mirror design. Its main drawbacks are the spectral resolution limitation caused by the pixel integration of the bull eye fringe pattern at large incidence angle and the need for a high performance dynamic alignment metrology system. The overall instrument design follows from the selection of the interferometer configuration. The input and output (2) optic tubes and the cameras are rigidly attached to the interferometer cavity without adding any additional fold mirrors which tend to be costly in transmission in the near UV. This cavity is then attached to the telescope mounting ring using 8 carbon fiber posts. The mechanical design is completed by the addition of a filter wheel, a motorized spectral calibration module and mechanically decoupled external cabinets housing electronic components.

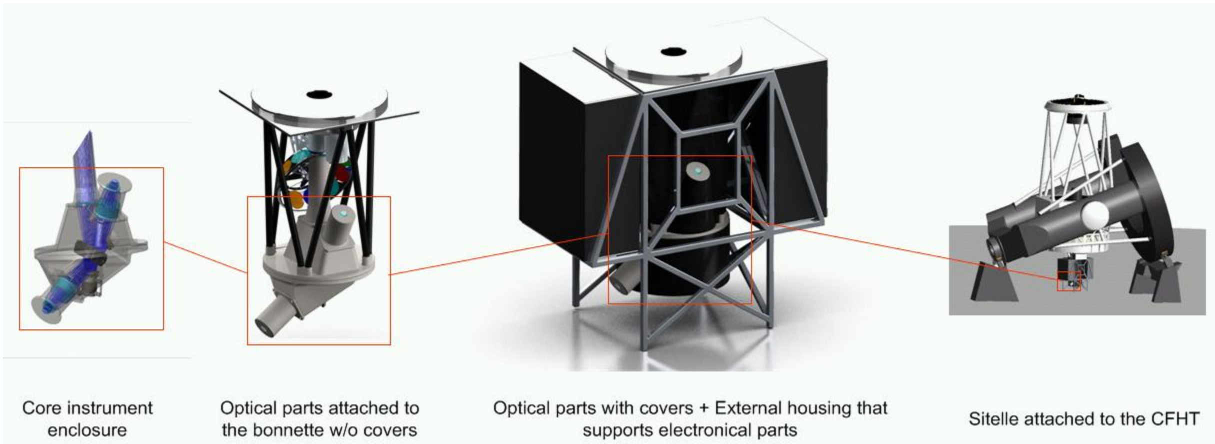

Figure 2: SITELLE Mechanical Design

The OPD scan mechanism is based on a flex blade arrangement positioned radially behind the mirror at 120 degree intervals and is actuated by piezo actuators. This configuration provides frictionless movement to achieve fine correction/positioning as well as exhibiting high rigidity minimizing alignment drift observed during telescope motion (gravity vector orientation changes). A high stiffness reduces the need for correction range on the alignment actuators and allows optimizing the dynamic range for fine control. The metrology is based on a multi-beam absolute phase measurement system using a 1550 nm high stability pigtail laser. The OPD and alignment is read at a few kHz rate to avoid possible ambiguities occurring when very rapid OPD change are seen (ex. vibration shocks caused by camera shutters, for instance).

Table 1 shows a summary of SITELLE's main features. The FOV parameter and imaging quality are defined assuming that the instrument is mounted behind the telescope. The efficiency includes the detector quantum efficiency, the transmittance of all optics (substrate internal transmittance, AR coatings, interferometer mirror and splitter coating efficiency) and the modulation efficiency based on a cumulative budget of all contributors which yields 70% at 400 nm and 90% at 800 nm (mainly driven by optics wavefront errors under operating conditions). The efficiency is the total obtained when combining photons captured by both detectors. Such a value is considered very high compared to other astronomical IFU reaching typically less than 20%.

Table 1: SITELLE Target Specification

General		
Mass	200	kg
Volume (without external housing)	1.5 × 1 × 1	m
Operating temperature	-5, +10	ºC
Imaging		
CCD size	2048 x 2048	pixels
Pixel pitch	15	µm
FOV	12 × 12	arc min
PFOV	0.35	arc sec
Interferometer pupil diameter	90	mm
Image quality (75% encircled energy)		
Side of array	0.6 ϕ	arc sec
Corner of array	0.8 ϕ	arc sec
Spectral		
Waveband (50% of peak response)	360 - 920	nm
Maximum resolution	1	cm^{-1}
Incidence angle on interferometer	15	degree
Efficiency (transmittance × ME × QE)	~ 60%	Peak

3. Conclusion

Upon completion, SITELLE should be the imaging FTS with the largest number of pixels discussed in the literature. It will also be the only IFTS to operate on a large-size ground-based telescope. The selected design should allow achieving the science goals with a relatively small budgetary envelope in comparison with other high throughput IFUs currently in development. The CFHT will provide high visibility to this technology within the users community and should allow to refine by experimentation the boundaries of observation programs benefiting the most from its unique features. The targeted instrument parameters should allow for interesting new discoveries.

4. References

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