

An imaging spectrometer that pushes the limits for near-UV astronomy

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A new instrument for the Canada-France-Hawaii Telescope will obtain the visible spectrum of every source of light in an 11 arcminute field of view starting in 2013.

Astronomers are always looking for more efficient ways to obtain spatially-resolved spectra of extended sources. Although the vast majority of imaging spectrometers on telescopes use dispersive techniques, imaging Fourier transform spectrometers (IFTS)—modified Michelson interferometers sandwiched between a collimator and a camera—are also promising for many research programs. After having designed, built, and extensively tested a prototype IFTS, our team is now building SITELLE, a guest instrument for the Canada-France-Hawaii Telescope (CFHT), pushing the concept in terms of wavelength and field of view.¹

1 Technical challenges

Fourier transform spectroscopy (FTS) is used for a variety of infrared applications, such as characterizing the Earth's atmosphere or measuring the star formation rates of distant galaxies.² But many scientific programs, such as determining the spectral energy distributions of galaxies or the oxygen abundance in nebulae, require the IFTS concept to be pushed to shorter (~350nm) wavelengths. Unfortunately, designing an efficient short-wavelength wide-field IFTS for the harsh conditions typical of an astronomical observatory poses many technical challenges.

Apart from good image quality and overall transmission, the performance of an IFTS is characterized by its modulation efficiency (ME)—the capability of its interferometer to modulate the incoming light. This parameter is analogous to the grating efficiency in dispersive spectrographs. The ME depends on

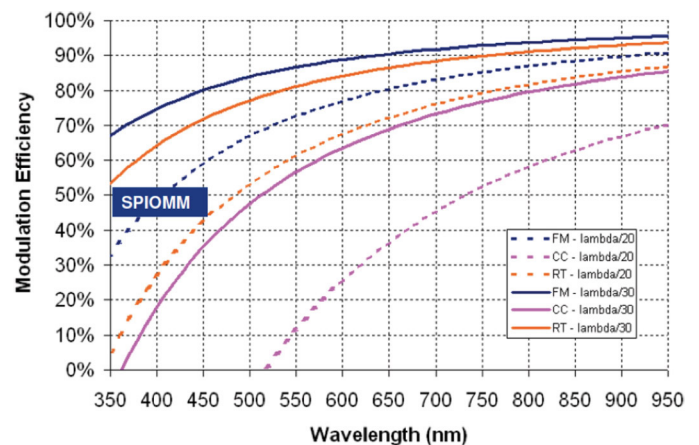


Figure 1. Simulations show the wavelength dependence of an imaging Fourier transform spectrometer's modulation efficiency is a strong function of both mirror quality (dashed vs. solid lines) and optical configuration (CC: cube corners; FM: flat mirrors; RT: roof-top mirrors). The blue dashed line has been validated with data from the SpIOMM prototype spectrometer on the Mont Mégantic Observatory 1.6m telescope.

many factors, most of which are particularly challenging at short wavelengths.³ We consider here two dominant parameters.

First, the surface quality of the mirrors and beamsplitter in the interferometer is crucial. As shown in Figure 1, the ME is lowered by a decreased surface quality. Furthermore, even if the mirror substrate is of high enough quality, any error in the coating deposit or tension caused by the mechanical parts used to maintain the mirror position can ruin the initial surface figure. These errors can dramatically reduce the ME. The number of reflections within the interferometer also plays a major role. We have therefore chosen the flat mirror configuration for SITELLE to optimize the ME in the near-UV. Tests on the mirrors and the

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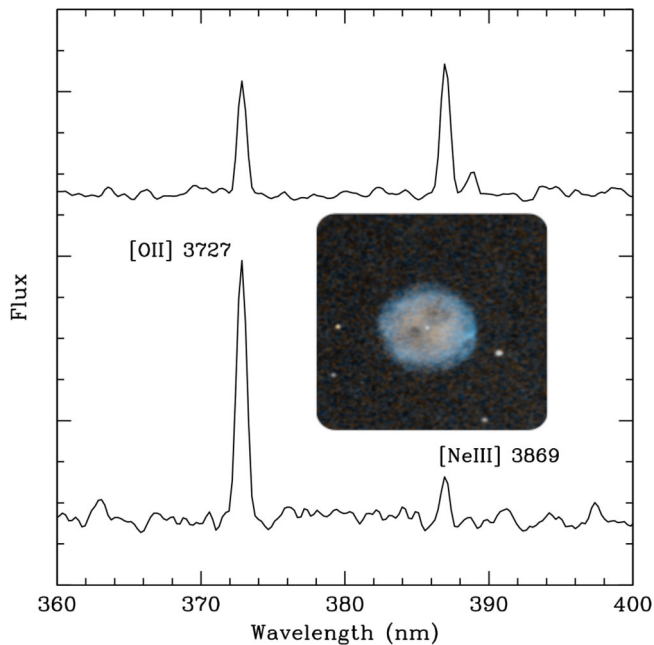


Figure 2. Spectra of a few pixels in the inner (upper panel) and outer (lower panel) regions of the planetary nebula M97, obtained with the SpIOMM prototype. The inserted image has been color-coded, with neon ([NeIII]) in pink and oxygen ([OII]) in blue.

beamsplitter, manufactured by Zygo, are encouraging. The surface quality is slightly better than the $\lambda/30$ (peak-to-valley) specification.

The choice of a flat mirror configuration has, however, an impact on the second factor influencing the ME: the precision with which the mirrors can be aligned and the distance between them maintained. This is because flat mirrors require a very efficient alignment system, especially at short wavelengths. A deviation of only 1.5 microradian from perfect alignment can decrease the ME by up to 25% at 350nm. At the same time, the optical distance between the two mirrors must be kept constant during an exposure. A jitter with a 10nm standard deviation typically reduces the ME by a few percent.

The metrology and servo system therefore play a crucial role in SITELLE. Using a 1550nm high-stability laser, a multi-beam pattern surrounding the science beam determines both mirror position and angle to a precision better than a thousandth of a laser fringe. The metrology fringe signals are digitized and processed using an ABB proprietary method. This method, based on a quadrature fringe signal, provides continuous absolute optical path difference information throughout the interferometer scanning range at a frequency of 10kHz.

2 SpIOMM, a useful prototype

SITELLE could not have been so efficiently designed (or even have received funding) without all the experience we acquired with its prototype, SpIOMM, a similar instrument attached to the Mont Mégantic Observatory 1.6m telescope.⁴ Working in the same wavelength range with a similar field of view as SITELLE, SpIOMM has been used to study Galactic nebulae,⁵ supernova remnants,⁶ and galaxies⁷ for the past five years. Having regular access to the telescope for prototype testing has been of paramount importance to this project. The harsh environment (wind shake, telescope vibrations, and large temperature changes often reaching -30°C in winter) required many modifications to SpIOMM's design and control software. After successful lab tests and a long period of on-site adjustments, the instrument is now stable. All improvements on SpIOMM, and the lessons learned from our experience during the past few years, have been implemented in the design of SITELLE. The data reduction software, as important to the success of an astronomical instrument as a good design, has also been constantly improved and is now ready to process the first SITELLE data cubes.

Figure 2 shows a rare example of a science result from a wide-field IFTS in the near-UV. Despite much lower ME ($\sim 30\%$) than in the red (85% at 630nm), SpIOMM has been able to characterize the spatial distribution of [OII] and [NeIII] at $\sim 380\text{nm}$ in the planetary nebula M97. The current design of SITELLE calls for a $\sim 60\text{--}70\%$ ME at these wavelengths. Combined with its overall throughput, larger telescope aperture, and low-noise detectors, the new design should improve the near-UV sensitivity by a factor of ~ 20 .

SITELLE is a new wide-field Fourier transform spectrograph for the Canada-France-Hawaii Telescope. The innovative design pushes the capabilities of integral field spectroscopy to new limits of wavelength and field of view. Expanding these tools to near-UV wavelengths will allow astronomers to study a range of questions from the kinematics of star forming regions to chemical abundances in distant galaxies. If all goes according to plan, SITELLE will see its "first light" in the fall of 2013. Hopefully, a large number of astronomers will take advantage of its many possibilities. Our next challenge is to convince them of the unique advantages offered by the IFTS technology for their research and of its ease of use despite its unconventional approach.

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After receiving his PhD in astrophysics from the University of Montréal (1990), Laurent Drissen went on to a postdoctoral fellowship at the Space Telescope Science Institute in Baltimore, MD (1990–1994). Since 2001, he has been a professor at Laval University. He researches massive stars, nearby galaxies, and imaging Fourier transform spectroscopy.

After obtaining his PhD in engineering physics in 1998 from Laval University, Simon Thibault joined the National Optics Institute as a full time researcher. In 2000 he was appointed head of the optical design department. Now a professor at Laval University (Industrial Research Chair in Optical Design), he is actively involved in the design of numerous astronomical instruments.

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Mandar obtained her MSc in engineering physics (Laval University, 2011), under Thibault and Grandmont's co-supervision, on performance simulations for SITELLE. She is now a systems engineer at ABB and, along with Grandmont, supervises the design, construction and testing of SITELLE.

Grandmont won the Plaskett medal in 2007 from the Canadian Astronomical Society for the best astrophysics PhD thesis in Canada (Laval University, supervised by Drissen). He designed and built SpIOMM, SITELLE's prototype. Now a systems engineer at ABB, he has worked on many remote sensing and astronomical projects, including the James Webb Space Telescope Fine Guidance Sensor and the NASA climate change mission, CLARREO.. He is now supervising SITELLE.

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